



# **Autonomous Robot for Pavement Cleansing**

A Personal Project  
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# AALBORG UNIVERSITY

## STUDENT REPORT

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# Preface

This report searches to develop a Roomba-like autonomous robot capable of exterminating weeds in pavement for private users.

Aalborg University, 19-12-2023

# 1 | Introduction

Every homeowner with some variation of pavement has a common thorn in their eye; weeds, moss, and grass. It is a prevailing problem experienced by homeowners, city councils, public buildings, etc. Currently, the only "easy" solutions are harmful to the pavement, water reservoirs and/or release a wide range of greenhouse gasses. Apart from their environmental impact, most of these methods are fairly time-consuming and labor-demanding.

A better solution is needed, without a doubt. However, these must first be examined and analyzed in depth to understand how to improve upon existing solutions. The individual environmental impact of each solution must be examined before a new approach can be proven a better solution. Therefore this project's initial problem statement can be expressed as:

*"What is the currently most efficient method for removing unwanted plants and plantlike material from pavement, and what are its environmental impacts?"*

## 2 | Problem Analysis

### 2.1 Existing Solutions

Before a new solution can be developed, current methods must be investigated, to understand their benefits and shortcomings. Each method will also be evaluated regarding its environmental impact and average time used to clean one square meter of 14x21cm "herregårdssten". The environmental impact will be a subjective scale of "small/medium/large" based on public guidelines set by Miljøstyrelsen and public consensus from institutions such as Bolius, Taenk, and Idenyt. Aforementioned guidelines and consensus can be accessed at: [1, 2, 3, 4, 5, 6, 7, 8, 9]. The average time used to clean one square meter of pavement will be based upon numbers from appendix A.1 on page 23 containing personal data collection from using different methods in my own driveway. Furthermore, a secondary number based upon Miljøstyrelsens numbers from their paper "Ukrudsbekæmpelse på Belægninger" will be available in cursive for some methods, [1].

#### 2.1.1 Manual Pavement Cleaning

Manual pavement cleaning refers to dragging a stick such as seen in figure 2.1 through every groove between the individual paving tiles. This is an incredibly time-consuming task, as it requires the user to cleanse every mm of groove by hand. However, it is rather effective for cleaning pavement and is one of the most popular modes of cleaning pavement for private users.



Figure 2.1: Manual brush for cleaning pavement, [10].

Pros	Cons
Effective	Hard labour
Thorough	Not efficient
	Time consuming
Environmental Impact	Average Minutes Used to Clean $1m^2$
Small	1.554

Table 2.1: Pros and cons of manually cleaning the pavement.

#### 2.1.2 Pressure Washer with Patio Cleaner

Using a pressure washer with a patio cleaner is one of the most effective methods of removing anything unwanted between tiles in the pavement. Unfortunately, it is almost

impossible not to remove the wanted parts as well, as the washer jets are strong enough to remove the sand between the tiles while removing weeds and algae. A positive byproduct of using a pressurewasher correctly on pavement is, that the pavement is cleaned and most of the time given a "new" look. This only occurs if and when the pressure washer is used correctly, as incorrect use can damage the pavement to such an extent, that it has to be replaced.

After treating pavement with a pressure washer, it will need to be re-sanded, and in some cases will benefit from having preservatives added, to discourage algae growth in the future. This part of the process is rather expensive, as new sand has to be bought, and the preservative coating has to be distributed correctly. Another downside to using preservatives is, that some products still contain substances, that are damaging to the environment

Pros	Cons
Effective	Need to refill with sand afterwards
Thorough	Expensive (new sand)
Quick execution	Dirty
Very easy	Loud
	Damages the pavement
Environmental Impact	Average Minutes Used to Clean $1m^2$
Small - Medium <sup>1</sup>	5.197, 0.2, <i>without refilling sand</i>

**Table 2.2:** Pros and cons of pressure washing the pavement.

### 2.1.3 Rotating Steel Brush

Like with manual pavement cleaning, using steel brushes is quite effective at removing unwanted plants. There even exist motorized versions, minimizing the amount of manual labor necessary, and further improving the effectiveness. However, steel brushes are prone to damaging the surface of the pavement, especially if used incorrectly or if it is overused. Apart from the risk of damaging the pavement, steel brushes still require a lot of manual labor to be an effective method for removing unwanted plants in the pavement. Furthermore, cheap steel brushes could lose bristles while being used, leaving steel wires in the vicinity of the cleaned area, which will eventually create rust stains if they are not removed. At a larger scale products such as the Kwern Greenbuster exist, but are generally aimed at professional use rather than the average homeowner.

Pros	Cons
Thorough	Hard labour
Easy to execute	Not efficient
	Time consuming
	Damages the pavement
	Possible rust patches from damaged wires
Environmental Impact	Average Minutes Used to Clean $1m^2$
Medium	1.479, 0.12

**Table 2.3:** Pros and cons of cleaning the pavement with a rotating steel brush.



### 2.1.4 Chemicals

Chemicals are sadly one of the easiest and most widely used methods for handling unwanted plants in pavement. The chemical glyphosate found in many weed-removing solutions is illegal for private people to use. Apart from commonly approved chemicals, it is fairly common that homeowners use a mix of water and salt, vinegar, or other chemicals found in the cleaning cabinet. These homebrewed elixirs and remedies are in most cases more damaging to the environment than people think. Salt and vinegar is so harmful, that they're illegal to use for weed extermination in Denmark.

Even though most of the chemical solutions do a good job at killing the plants, they have to be applied several times over such long periods of time, that they are practically inefficient compared to manual removal. Furthermore, solutions such as salt is damaging to the water reserves and could possibly ruin the pavement as well, leading to premature replacement of the pavement.

Pros	Cons
Effective	Not efficient
	Damage to natural water reserves
	Damages the pavement
Environmental Impact	Average Minutes Used to Clean $1m^2$
Large	0.496 * number of passes for the plant to perish

**Table 2.4:** Pros and cons of using chemicals to clean the pavement.

### 2.1.5 Sweeping

The easiest way of keeping pavement free from weeds is to not let the weeds settle and sprout. By this, it is meant as sweeping the pavement at least once a week, if not more often, to disrupt any seeds settling into the crevices, and if any succeed, stressing them by continuous sweeping. However, this method is most effective at the early stages of any weed's life cycle.

Pros	Cons
Thorough	Hard labour
Easy	Not efficient
	Time consuming
	Mostly efficient against new weeds
Environmental Impact	Average Minutes Used to Clean $1m^2$
Small	0.346

**Table 2.5:** Pros and cons of sweeping the pavement.

### 2.1.6 Weed Burning

Burning weeds is the prevalent method used in private homes, professional cleaning services, and public institutions. The reasons being ease of use, low labor commitments, and instant results (if used wrong). When it comes to burning off weeds, most solutions

have a large area of effect, which may not be optimal. In some cases, the effective area is quite a lot larger than the greenery being burned off.

Pros	Cons
Barely any labour	Fire
Very efficient if used correctly	Not efficient if used wrong
Easy	Time consuming
	Needs several passes to kill the plant
Environmental Impact	Average Minutes Used to Clean $1m^2$
Large	1.376, $0.12 * \text{number of passes for the plant to perish}$

**Table 2.6:** Pros and cons of burning off weeds.

## 2.2 Use Cases

## 2.3 Problem Statement

## 3 | Demand Specification

### 3.1 High Level Specification

This section describes a high-level overview of the functionality desired for the pavement cleansing robot. It is written as seen by a private person wanting to ease cleaning their pavement. Detailed specification can be found in section 3.2 starting page 7.

**As a house owner looking to ease removing weeds from my pavement, I want:**

- *An autonomous robot capable of removing dandelions, moss, grass, and other common weeds found in the pavement.*
- *An autonomous robot capable of climbing my driveway (37%/20° rise).*
- *An autonomous robot that returns "home" before the battery dies.*
- *A fully autonomous robot, meaning that I will only need to do one setup procedure, and then it will work forever.*
- *An autonomous robot only removing weeds within my land.*
- *An autonomous robot that can distinguish between pavement styles, and act accordingly.*
- *An autonomous robot that systematically cleans my driveway and other pavement, and therefore does not just bump around like a Roomba.*
- *An autonomous robot capable of passing an IP56 test.*
- *An autonomous robot that can detect when a puddle is nearby, and go around it.*
- *An autonomous robot that detects cars, outdoor furniture, and the like, so that it will only operate beneath objects where it is safe.*
- *An autonomous robot that adjusts its pattern, based both on the weather and on previous passes. I.e. if there were a lot of weeds on the previous pass around the driveway, it would schedule a new pass earlier.*
- *An autonomous robot capable of mapping what parts of the driveway that has been cleaned.*
- *An autonomous robot avoiding obstacles without bumping into them.*
- *An autonomous robot making as little noise as possible.*
- *An autonomous robot as small in size as possible, ideally no larger than a Roomba (approximately 45cm), [11].*
- *An autonomous robot that does not get stuck at random places around my land; if it does get stuck, I want it to attempt to get unstuck.*
- *An autonomous robot capable of cleaning a minimum of 500m<sup>2</sup>.*

## 3.2 Functional Specification

This section describes the functional criteria of the product. The criteria are seen from an end-user perspective and made as user stories, where accept criteria (AC1 & AC2 e.g.) must be fulfilled. A test of the functional specification is made in section 7.

### 3.2.1 Weed Removal

*As a house owner, I want an autonomous robot capable of removing dandelions, moss, groundsel, grass, and other common weeds found in the pavement.*

**Accept Criteria:**

**AC1:**

The robot should be capable of burning off several types of weeds, including but not limited to: dandelion, grass, groundsel, moss, thistle, cleavers, and horsetail.

**AC2:**

The robot should be capable of only burning the necessary intensity to stress the plants, without setting them aflame.

**AC3:**

All plants should perish within a season of continuous burning.

**AC4:**

The robot should be able to distinguish between weeds and non-organic items, such as a gardenhose.

### 3.2.2 Go Anywhere

*As a house owner, I want an autonomous robot capable of climbing my driveway (20% rise).*

**Accept Criteria:**

**AC1:**

The robot should be able to climb a 20% rise.

**AC2:**

The robot should be capable of traversing poorly laid pavement (up to 30mm height difference between tiles).

**AC3:**

The robot should be capable of traversing small obstacles, such as a garden hose.

### 3.2.3 Robot Go Home

*As a house owner, I want an autonomous robot that returns "home" before the battery dies.*

**Accept Criteria:**

**AC1:**

At all times enough battery power is left to drive "home" to a charging point + 10% extra distance, meaning that a 20-meter travel home, requires power for at least 22 meters.

**AC2:**

The robot should be capable of mapping a route "home" with obstacles such as corners, cars, and lawnchairs added, to accommodate non-direct routes.

### 3.2.4 Easy Setup

*As a house owner, I want a fully autonomous robot, meaning that I will only need to do one setup procedure, and then it will work forever.*

**Accept Criteria:**

**AC1:**

The robot has to be capable of adjusting its trajectory and routing to changing environments, as long as the outer bounds do not change.

**AC2:**

The robot "home" has to be connectable to a standard wall socket.

**AC3:**

The robot has to auto-charge between passes.

**AC4:**

The robot should be updateable and automatically update at convenient times.

**AC5:**

The robot should be easy to connect to secondary devices, such as phones, routers, etc..

### 3.2.5 Stay On My Turf

*As a house owner, I want an autonomous robot only removing weeds within my land.*

**Accept Criteria:**

**AC1:**

The robot should not wander off from assigned bounds.

**AC2:**

The robot has to stay within its registered land.

**AC3:**

If placed off of its registered land, it should first ping its "home" to plan a possible route home, or simply send a message to the owner before turning off.

### 3.2.6 Pattern Recognition

*As a house owner, I want an autonomous robot that can distinguish between pavement styles, and act accordingly.*

**Accept Criteria:**

**AC1:**

The robot should be capable of recognizing the following (danish) pavement styles: herregårdssten (14x21cm), modul fliser (30x30cm, 30x60cm, 60x60cm, 40x40cm, 50x50cm, 25x50cm, 25x25cm, 20x20cm, 20x40cm, 15x30cm, 15x15cm), soldaterfliser (60x90cm, 90x90cm, 60x120cm, 90x120, 30x90cm, 45x90cm), sekskantede fliser (32x32cm), chaussesten (9x9cm) and SF-sten (10.5x19cm).

**AC2:**

The robot has to adjust its route based on which pavement style it is currently cleaning.

### 3.2.7 Systematical Procedure

*As a house owner, I want an autonomous robot that systematically cleans my driveway and other pavement, and therefore does not just bump around like a Roomba.*

**Accept Criteria:**

**AC1:**

The robot has to map out all paved areas.

**AC2:**

A systematic approach following lines in the pavement has to be used.

**AC3:**

If several types of pavement are present, different areas must be mapped to distinguish and optimize routes for each area.

**3.2.8 Weather Endurant**

*As a house owner, I want an autonomous robot capable of passing an IP56 test.*

**Accept Criteria:****AC1:**

The shell of the robot has to pass an IP56 test.

**AC2:**

The charging/home point has to pass an IP56 test.

**AC3:**

The robot should notify the owner if temperatures become low enough to damage the battery or other electronics.

**AC4:**

The robot should be able to drive "home" in severe rainfall i.e. more than 30mm over an hour.

**AC3:**

The robot should be capable of operation in sub-zero temperatures<sup>1</sup>.

**3.2.9 Water Avoidance**

*As a house owner, I want an autonomous robot that can detect when a puddle is nearby, and go around it.*

**Accept Criteria:****AC1:**

The robot must recognize puddles, pits, and other flooded areas.

**AC2:**

The robot must reroute to navigate around water.

**AC3:**

If a reroute is unavailable, the robot must turn around and follow its previous route back to "home".

**3.2.10 Spatial Awareness**

*As a house owner, I want an autonomous robot that detects cars, outdoor furniture, and the like, so that it will only operate beneath objects where it is safe.*

**Accept Criteria:****AC1:**

The robot must be capable of determining whether or not, it can fit within a space.

**AC2:**

The robot must keep a minimum clearance of 10cm to anything above, so as to not wedge itself beneath anything.

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<sup>1</sup>In this instance, longevity of the battery is de-prioritized.

### 3.2.11 Self-adjusting Scheduling

*As a house owner, I want an autonomous robot adjusts its pattern, based both on the weather and on previous passes. I.e. if there were a lot of weeds on the previous pass around the driveway, it would schedule a new pass earlier.*

**Accept Criteria:**

**AC1:**

The robot must map out every time a plant is hit, and keep that map in memory for the next 5 cycles.

**AC2:**

The robot must schedule passes based upon the amount of remaining greenery in an area.

**AC3:**

The robot must be capable of accessing weather information, so as to not plan its next pass when rain is predicted.

**AC4:**

The robot must be capable of intensifying passes if the greenery percentage does not go down in an area.

**AC5:**

The robot must be capable of adjusting its pattern to only focus on areas previously containing weeds. I.e. scheduling every second or third pass to only go for coordinates with "known" weeds, rather than traversing the full area.

### 3.2.12 Memory Capabilities

*As a house owner, I want an autonomous robot capable of remembering what parts of the driveway have been cleaned.*

**Accept Criteria:**

**AC1:**

The robot must map out which areas have been cleaned at which point, to rotate between areas.

**AC2:**

The robot must be capable of increasing its speed when no greenery is present.

### 3.2.13 Obstacle Avoidance

*As a house owner, I want an autonomous robot avoiding obstacles without bumping into them.*

**Accept Criteria:**

**AC1:**

The robot must not hit anything to change its course.

**AC2:**

The robot must not be closer than 5cm to anything in any direction, other than the pavement below it.

**AC3:**

The robot must not drive off of a ledge and tumble down.

**AC4:**

If the robot cannot turn around its own axis, it must reverse out from its current spot.

**AC5:**

If presented in a corner with no way out, the robot must turn off and notify the owner.

### 3.2.14 Low Noise

*An autonomous robot making as little noise as possible.*

**Accept Criteria:**

**AC1:**

The robot must not make any more noise than comparable lawn mowing robots, i.e. 58dB for a Texas TMX1000, [12].

**AC2:**

Under extraordinary circumstances, such as traversing small obstacles, volume may be increased to 65dB.

**AC3:**

Cooling of the robot must not surpass 55dB.

### 3.2.15 Small Size

*An autonomous robot as small in size as possible, ideally no larger than a Roomba (approximately 45cm), [11].*

**Accept Criteria:**

**AC1:**

The length and width of the robot must be smaller than 45cm.

**AC2:**

The height of the robot must be lower than 12cm.

### 3.2.16 Selfrecovery

*An autonomous robot that does not get stuck at random places around my land; if it does get stuck, I want it to attempt to get unstuck.*

**Accept Criteria:**

**AC1:**

If the cameras do not change pictures for 25 cycles, the robot should recognize it is stuck.

**AC2:**

If stuck and no obstacles are nearby, the robot should try to first reverse, then turn clockwise, then counterclockwise - all operations must be made at half speed to minimize the risk of loosing grip due to speed.

**AC3:**

If the robot cannot get unstuck on its own, it should notify the owner and turn off.

### 3.2.17 Area

*An autonomous robot capable of cleaning a minimum of 500m<sup>2</sup>.*

**Accept Criteria:**

**AC1:**

By cleaning 500m<sup>2</sup>, it is meant as mapping out 500m<sup>2</sup> and cleaning continuously, rather than in one pass.

**AC2:**

The robot should be capable of prioritizing some areas over others, so a customer can prioritize the terrace higher than the driveway i.e..



### **3.3 Electrical Specification**

## 3.4 Demarcation

As this project only stretches for a single semester and is being done by a single student, some demarcation has to be done. The project will instead of focusing on developing a full system meeting all demand specifications from the start, be divided into iterations. Therefore each iteration will have its own distinct goal(s) and specifications that it should meet. The first iteration will be the minimum viable product (MVP), and further iterations will contain increasingly advanced features.

### 3.4.1 1st Iteration - Minimum Viable Product

The minimum viable product is a version, which only really an autonomous robot driving around pavement. The 1st iteration will therefore be based on a tracked vehicle available from AAU, and will mostly regard the steering and operation of an autonomous robot, rather than actual weed-removing capabilities.

Functional specifications to meet:

- 3.2.2 - Go Anywhere
- 3.2.3 - Robot Go Home
- 3.2.9 - Water Avoidance
- 3.2.10 - Spatial Awareness
- 3.2.12 - Memory Capabilities
- 3.2.13 - Obstacle Avoidance

### 3.4.2 2nd Iteration

The 2nd iteration will be the first to include actual weed-removing capabilities. At this iteration, a laser<sup>2</sup> and its power source will be added. Furthermore, image processing and recognition will be integrated, as well as aiming the laser correctly. On a software-level, systematical procedures for optimising routes and pattern recognition for more advanced kinds of pavement will be added.

Functional specifications to meet:

- 3.2.1 - Weed Removal
- 3.2.6 - Pattern Recognition
- 3.2.7 - Systematical Procedure

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<sup>2</sup>To stay within budget, the first laser will most likely be a laser-pointer, rather than an actual laser capable of burning weeds.

### 3.4.3 3rd Iteration

At its 3rd iteration, the autonomous robot will be configurable to stay within a designated area, ensuring the robot does not wander off into the wild. Furthermore, the setup/installation procedure should be made easier for the common man/woman to do. A self-adjusting schedule will also be integrated so that the robot optimizes its routing and number of passes to correspond with greenery growth, weather, and personalized preferences.

Functional specifications to meet:

- 3.2.4 - Easy Setup
- 3.2.5 - Stay On My Turf
- 3.2.11 - Self-adjusting Scheduling
- 3.2.16 - Selfrecovery
- 3.2.17 - Area

### 3.4.4 4th Iteration

The 4th iteration will be the first to require a new vehicle, as this iteration will focus on making the robot more comfortable to be around, while also making it weather endurant and capable of being outside for extended periods of time.

Functional specifications to meet:

- 3.2.8 - Weather Endurant
- 3.2.14 - Low Noise
- 3.2.15 - Small Size

### 3.4.5 5th Iteration

When a 5th iteration is developed, it will focus more on easing use for the consumer by implementing an app, where the user can set up prioritizing for different areas, divide their land into zones, and generally customize the operation of the robot. This iteration will have no functional specifications, as these are not designed within the scope of this project.

## 4 | Technical Analysis

## 5 | System Design

## 6 | Integration

## 7 | Acceptance test

## 8 | Discussion



## 9 | Conclusion

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# Glossary

**MVP** Minimum Viable Product. 13

# A | Appendix

## A.1 Average Cleaning Time Driveway

The testing/timing has been done by cleaning the driveway every 3 weeks across the 2024 season with one of the mentioned methods and timing how long each method took. The driveway has had similar growth between each clean, however, do keep in mind that the driveway is being used and identical weed growth cannot be guaranteed, making these numbers a mere guideline rather than strict facts."Aftertreatment" refers to treatment such as refilling pavement with sand, sweeping dead shrubs away, etc.

Method	Area in $m^2$	Time Used	Aftertreatment	Time Per $m^2$
Manual Cleaning	106.8	166		1.554
Pressure Washing	106.8	204	351	5.197
Rotating Steel Brush	106.8	128	30	1.479
Chemicals	106.8	53		0.496
Sweeping	106.8	37		0.346
Weed Burning	106.8	117	30	1.376

**Table A.1:** Average cleaning time per square meter of herregårdssten in my own (Christians) driveway. All times are in minutes.