Title page

1. Title

Wind and Waterspray

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Table of Contents

Summary

Description of the Modeling Process

Definition phase: context → problem definition and purpose

6. Context

At a large open square in the middle of the city centre, a large ornamental fountain is located. It is surrounded by terraces of cafes and restaurants where locals, businessmen and tourists enjoy a nice cold drink on a warm summer evening. The fountain is one of the big eye catchers in the city, so at night it is beautifully illuminated. Because it is one of the city's big landmarks, it is a true attraction for the many small and medium sized caterers situated at the square and the main and most important reason to visit the terraces. However, at some days, the fountain can also be a bit of a pain for the caterers and visitors. When it is windy, the wind blows a spray jet of water drops from the fountain upon them, resulting in a lower attendance.

7. Problem Definition and Purpose

The fountain located on the open square tracks a lot of attention of tourists. There are also pedestrians passing by fountain. There are also people that want to relax on the terraces. All these people have one common problem: on windy days, all these different people in different situations get wet because of the fountain. This is because the water that comes out of the fountain is not good adapted to this type of weather situations. We want to keep all these people happy by solving this problem. We want to prevent people getting wet because of the fountain. Therefore we want to solve this matter because otherwise the amount of people on the terraces will decline. The water must stay in the fountain in any situation otherwise people won't like it and the restaurants and cafe's have less visitors. The amount of people and tourist will drop because of the water problem.

The purpose of the model is to optimize the height of the fountain, depended on the wind speed and direction, measured by the anemometer, so that the water falls in the cabin and the passengers and people on terraces don't get wet.

8. Sub-questions

1. Are there other factors that influence the fountain?
2. Can the height of the water spray be explained by the horizontal displacement of the water?
3. Does the amount of water affect the attraction?
4. How does the wind influence the attraction of the fountain?
5. What is the connection between the horizontal displacement of the water and the wind?
6. What is the relation between the location of the fountain and the location of the cafes and restaurants?
7. What is the relation between the water and the tourists/pedestrians?
8. Is it relevant to consider the air resistance?
9. Is it better to use a 3D or a 2D model for this problem?
10. Is it relevant to consider temperature changes?
    a. If we do, does it really make a big difference?
11. Is it relevant to consider climate changes?

Conceptualization: initial problem → conceptual model

9. Concepts, properties, values and relations

Assumptions

In the model we assume the movement of one water drop, to make the model more clear. However, the movement of the water spray describes a parabola under windy circumstances, so it will not matter if we use one water drop of the whole water spray. It will all result in the same way.

We decided to leave out the air resistance on the water of the fountain. In this way we can make a clear model without difficult calculations about the little air resistance. The air resistance on one water drop is negligible.

We leave out the friction of the water when it leaves the basin, this is negligible and worthless for the optimization of our model.

We assume that the model is in 3D. Because we have to deal with 3 kinds of data that form 3 dimensions. We have the height of the fountain, the wind in any direction with a certain value for the speed. To make everything clear at the end, we will make a complete 3 dimensional model and 2 dimensional models (from each perspective; Above view and side views)

We assume that the gravitation force is 9.8N and the gravitation acceleration is 9.8m/s2

We assume that the efficiency of the fountain is 100%. This means that all the water that goes up in the air will fall back in the basin of the fountain.

It is fact that the water sprays vertically upward with an angle 90° to the horizon.

The distance between the terraces and the fountain does not matter because of the 100% efficiency. You won't become wet next to the fountain.
We assume that there will not be any evaporation during warm days. Rain will not affect the total amount of water in the fountain.

We assume that the temperature will not affect the volume of the water in the basin. In this way the area of a single water drop will not change because of the temperature.

Concepts, properties and values

In top left of the table the entity of the concept is described. Underneath are the properties of the entity. In the middle table the dimension is shown and on the right table the unit is shown.

By water is meant a water drop.
Density is the density of water.
By mass is meant the mass of a water drop.
By volume is meant the volume of a water drop.
By Area is meant the area of a water drop.
Height means how high the water drop has come.
Horizontal displacement is the displacement of the water drop in horizontal direction.
Gravitation g is the gravitation force on earth.

By jet is meant the pump that will move the water vertically upward.
The diameter of the jet is a constant. This the diameter of the water drop.
The force of the jet is the amount of force needed to shoot up the water.
The flow rate is the amount of water (volume) per second that is shot up in the fountain

The wind direction and speed is measured by the anemometer

The basin is the place under the fountain where the water has to fall in.
The radius of the basin determines how big the basin is.

The distance of the terraces means how far the terraces are from the fountain

kg = kilogram
m = meter
g = 9,81 m/s^2
° = degrees
s = seconds
N = Newton

Water	**Dimension**	**Unit**
Mass	[M]	kg
Density	$[M/L^3]$	kg/m^3
Volume	$[L^3]$	m^3
Area	$[L^2]$	m^2
Height	[L]	m
Horizontal displacement	[L]	m

Gravitation: g	[L/T^2]	m/s^2

Jet	**Dimension**	**Unit**
diameter	[L]	m
Force	Force	N
Flow rate	$[L^3/T]$	m^3/s

Wind	**Dimension**	**Unit**
Direction	Degrees	°
Speed	[L/T]	m/s

Basin	**Dimension**	**Unit**
Radius	[L]	m

Terraces	**Dimension**	**Unit**
Distance	[L]	m

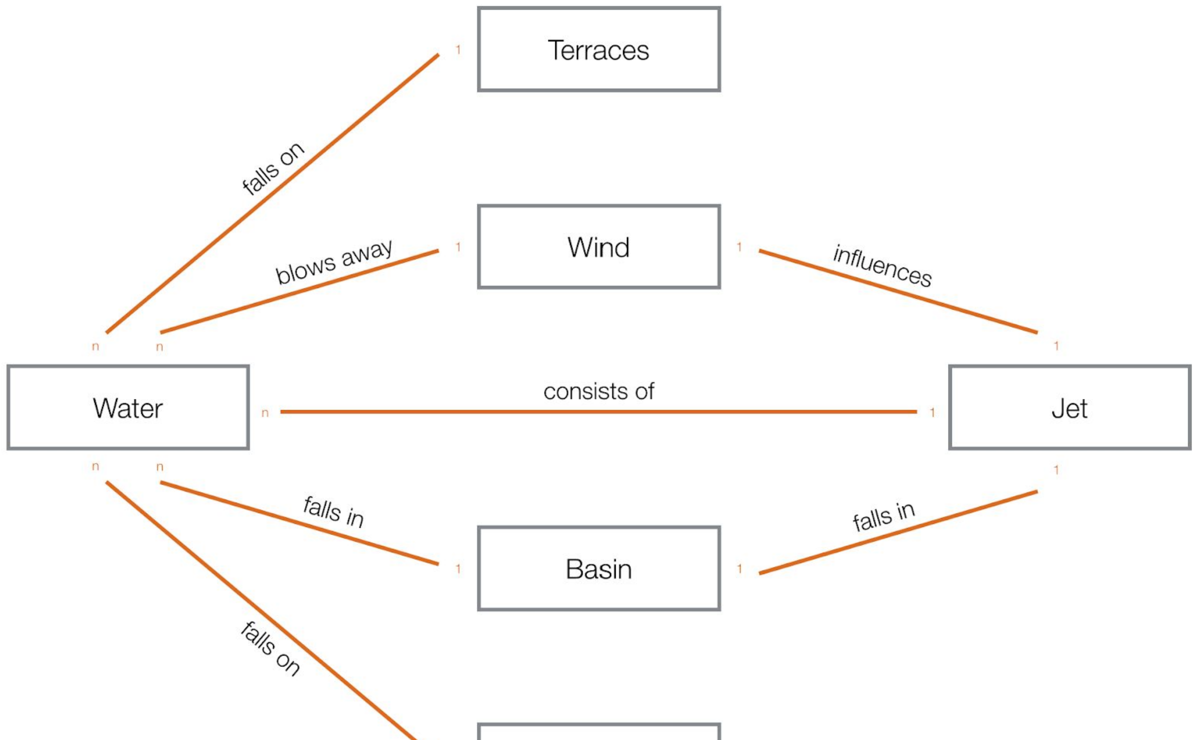

figure 1: Diagram of the relations between entities

This diagram show the relation between the entities of our conceptual model. wind, water, jet and the basin are the main entities. These are all in relation with each other.

Formalization phase: conceptual model→ formal model

10. Quantities and their Relationships

Quantities

Water

- Mass: kg (we assume that this quantity is a constant)
- Density: kg/m^3 (we assume that this quantity is a constant)
- Volume: m^3 (we assume that this quantity is a constant)
- Area: m^2 (we assume that this quantity is a constant)
- Height: m (This quantity is a variable, it is asked)
- gravitation: g (this quantity is a constant)
- horizontal displacement: m (This quantity is a variable, it depends on the amount of wind)

Wind

- Direction: ° (we assume that this quantity is a variable which comes out of the anemometer)
- Speed: m/s (we assume that this quantity is a variable which comes out of the anemometer)

Jet

- Jet diameter: m (This quantity is a constant)
- Force: N (This quantity is a variable, it is for us to decide)
- Flow rate: m^3/s (This quantity is a variable, it depends on the force)

Basin

- Radius: m (This quantity is a constant)

Terraces

- Distance: m (This quantity is a variable, it is for us to decide)

Relations

In the table you see the relations between the different properties. The first two columns show what is in relation with each other. In the left column the relation is explained.

The height is the height of the water spray that comes out of the fountain.
The horizontal displacement is the displacement of the water in horizontal direction.

This is..	**In Relation with this**	**Explanation**
Height	Jet Force	How greater the force of the jet, the higher the water will come.
Height	Wind speed	The greater the wind speed the lower the water spray is. (the

		system will lower the height of the water under windy circumstances)
Height	Flow rate	The higher the flow rate (maintaining the same radius of the jet), the higher the water will come.
Horizontal displacement	Wind direction	Due to the wind direction, the water spray will go in a certain direction. (It will not return to the same spot in the basin without the wind
Horizontal displacement	Wind speed	Due to the wind speed on the water spray, the water spray will lose its straight path in the vertical direction. Its path describes a parabola.
Horizontal displacement	The maximum height of the water	The greater the height of the water spray, the greater the influence of the wind. (The horizontal displacement will be greater)
Density	Volume of the water + Mass of the water	This ratio will determine the density
Flow rate	Jet force	The higher the jet force, the higher the flow rate
Horizontal displacement	Height of water spray	the greater the height, the greater chances water will spill out of the fountain in horizontal direction
Horizontal displacement	Distance to terraces	The greater the horizontal displacement, the less the distance to the terraces.

11. Approximations and Assumptions

We decided that the radius of the basin is 3 meter. We made this decision to that it is clear for us how far the water can have a horizontal displacement, so that the water stays in the basin and the persons next to the fountain won't get wet.

The water height of the fountain varies from 0 to 10 meters as an element of R. We decided to have a limited height, so that there is a maximum. We need this in our model otherwise the fountain can become too high and that might be an unrealistic high value.

The density of water is 998,00 kg/m³, this is a constant.

We assume that the model is in 3D. Because we have to deal with 3 kinds of data that form 3 dimensions. We have the height of the fountain, the wind in any direction with a certain value for the speed. To make everything clear at the end, we will make a complete 3 dimensional model and 2 dimensional models (from each perspective; Above view and side views)

We assume that the water goes up in the fountain with an angle of 90° to the horizontal.

In the model we assume the movement of one water drop, to make the model more clear

Our model is based on the movement of one water drop. We decided to leave out the air resistance on the water of the fountain. Because the air resistance on one water drop is negligible.

We leave out the friction of the water when it leaves the basin, this is negligible and worthless for the optimization of our model.

We assume that the gravitation force is 9.8N and the gravitation acceleration is $9.8m/s^2$

We assume that the efficiency of the is 100%. This means that all the water that goes up in the fountain falls back in the basin.

The distance between the terraces and the fountain does not matter because of the 100% efficiency. You won't become wet next to the fountain.

We assume that there will not be any evaporation during warm days. Rain will not affect the total amount of water in the fountain.

We assume that the temperature will not affect the volume nor the area (water drop) of the water.

12. Derivations

For the derivations we have different things we need to consider. Some of these can be neglected as we have assumed these are irrelevant, such as the height of the water jet *(b)*. Some of these values are constants, such as the gravitational constant *(g)*.

h	Maximum height of water
d	Horizontal displacement of the water
r	Radius of the water basin
V_w	Velocity of the wind
b	Height of the water jet
g	Negative acceleration of gravity
s	Time for the particle to reach the ground from the maximum height (*h*).
V_0	Initial velocity of the water leaving the jet

The main thing we need to calculate is the amount of time *(s)* it takes the water particle to reach the maximum height *(h)*. Something we already know is that the amount of time that the particle is moving upwards is exactly the same as the amount of time that the particle spends moving downwards, as we decided to not include the effect of air-resistance in this version of our model.

Taking all of this into consideration, we can conclude that. $s = \sqrt{\frac{2h}{g}} s = \sqrt{\frac{2h}{g}}$.
Next up, we want to calculate the effect that the wind has on this drop of water. This can be measured in the horizontal displacement of the water *(d)* . The effector in this case is the velocity of the wind *(V_w)* . As we have stated in the assumptions, *(d)* is always less or equal than the radius of the basin *(r)* , so $d \leq r\, d \leq r$, as the water particles would land outside of the fountain if *(d)* would be bigger than *(r)* .

The amount of displacement *(d)* can be calculated by multiplying the time that the particle is in the air *(s)* with the velocity of the wind *(V_w)* , so $d = Vw * s\, d = Vw * s$

13. Special Cases

Wind:

- If the wind has no speed (0 m/s), the result is that the wind will not have any influence on the water spray. So there will not be any difference in horizontal displacement of the spray. ⇔ the horizontal displacement in any direction is 0 m. Besides that, if the wind speed in 0m/s, the wind direction will not exist.
  Force of the jet:

- If the force of the jet is 0N, the jet will not pump any water vertically upwards. This results in the fact that there will not be any tourists attracted to the fountain ⇔ there will no water flow

- If the radius of the jet is decreased (maintaining the same force) ⇔ the speed of the water is increased. We get this result of $A_1 v_1 = A_2 v_2$. A is the area of the disc formed by πr^2.

14. Estimates

Gravity constant: 9,8, based on the average gravity constant in Europa. The volume of a water drop must be estimated. Therefore, we make use of some external sources to make an educated guess. We found that one drop of water (also known as gtt (abbreviation that comes from gutta, the Latin word for drop)) has a volume of 0,050 mL according to the metric system (abbreviated SI-system). In other words: 1,00 mL contains 20,00 drops.

Execution phase: formal model → result

15. Rephrase the problem statement in formal terms

Our goal is to maximize the height of the water spray of the fountain (h), without losing any water (all the water should drop back in the basin). This optimization of the height depends on the wind speed ($v_{wind)}$ and wind direction. We assume that we need the following formulas or parts of these formulas to come to a final model.

With this formula we can calculate the height that the water of the fountain reaches. It is crucial to have this formula because it will help us to optimise our model.

$$y = y_0 + v_0.t + \frac{1}{2}.a.t \ \frac{1}{2}.a.t_2$$

With this formula we can calculate the x-displacement. We need this formula because we want to prevent people getting wet of the water. So it is also important to use this formula to optimize our model.

$$x = x_0 + v_0.t + \frac{1}{2}.a.t \ \frac{1}{2}.a.t_2$$

This formula describes the velocity, from this formula we can also calculate the x-displacement.

$$v = \frac{\Delta x}{\Delta t} \frac{\Delta x}{\Delta t}$$

This formula describes the relative velocity by influence of air/wind , so this will describe the movement of the water in the air.

$$v_{P/A} = v_{P/B+} v_{B/A}$$

With this formula we can calculate the force needed to give a mass a certain acceleration in our case water.

$$F= m.a$$

This formula describes the energy needed by the pump of the fountain. If we want to know the energy consumption of our pump/jet.

$$E= P.t$$

This formula describes the power that is needed by the pump of the fountain.

$$P= \frac{W}{\Delta t}\frac{W}{\Delta t}$$

These formulas describes the work that is done by the pump of the fountain.

$$W= m.g.y$$

$$W= \frac{1}{2}\frac{1}{2} . m_a.v_a - \frac{1}{2}\frac{1}{2} . m_b . v_b$$

We use this formula to calculate the density , mass or volume of substances.

$$\rho = \frac{m}{V}\frac{m}{V}$$

These formulas describe the outline and the surface area of a circle. As we have to deal with a round basin of the fountain, these formulas are really usefull.

$$O= 2.\pi.r$$

$$A= \pi.r^2$$

This formula describes the velocity changes of a fluid through pipes with a different width and so also a different surface area.

$$A_1.v_1 = A_2.v_2$$

This formula is a description of the wind/air resistance we need this formula to calculate the force that the wind has on the water.

$$F= \frac{1}{2}\frac{1}{2}. \rho. v^2 . A . C_w$$