École Polytechnique Fédérale de Lausanne

Product design & System Engineering

Thor Trash Bin

Final Report

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Introduction

After two weeks of deliberations and votes, the finale topic was here : design a smart trash bin suitable for EPFL environment. A decision that was interesting, and extremely complicated at the same time.

An easy solution would have been to create a simple compactor, or a can crusher, but our goal was to create something innovative, something that had never been made before. And there, suddenly, in the middle of the Polydôme during a warm Friday of September, the idea of *The Hammer Of Recycling* (T.H.O.R.) came to birth. A revolutionary, 100% green, PET bottle compactor which only needed the force of the user to work. No need to flush out the remaining liquid or to even take off the cork. A simple swing on the lever, and the magic happens. A completely flat PET bottle falls in a trash bag, while the liquid is stored in another container.

However we were not completely satisfied... We wanted something more... something even better. So, at this key moment we decided to improve our trash bin for the cleaning staff. We wanted a connected trash with an online website uploading in real-time the level of each bins, an easy to use and to clean system and finally, a safe product that everybody could use.

During our journey, we encountered a multitude of challenges ; between the deadlines, the failed ideas and the cold winter entering our workshop, and so on. We did not have an easy task. But after almost four months of intense and hard work, we managed to create the first trash of its kind, the T.H.O.R. Thrash Bin. We will now introduce you our different ideas that we had, all of the choices we took and also some issues that we were confronted during this project.

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1 Product concept

1.1 General description

The Thor Trash bin is a Pet bottle crushing bin. It accepts all kind of pet bottles, whether they are closed or open, full with liquid or empty, small or large (up to 1.5 liters). The trash bin is autonomous in the sense that there is no power supply needed. This is achieved by creating a crushing mechanism which relies on the user to power it. Two levers, one on each side, can be pulled after the bottle has been placed inside the opening on the top of the trash. This movement pushes the pet bottle against saw blades which will pierce the bottle so it can be crushed and at the same time, the liquid flows out. The liquid and the crushed bottles are separated and guided in two different containers. The trash bin measures the fill state of the crushed bottles bag, sends the vital information of the trash bin to a server through Wifi and displays it on the front facing e-ink display. The low-power electrical components are fed with a lithium battery which is being recharged throughout the day with a solar panel placed on top. To make the trash bin appealing we used the Thor theme throughout the product, most noticeable on the exterior design with the Thor hammer designed handles.

1.2 Brief market analysis

As mentioned in the introduction section we have not found any compacting trash bins especially made for pet bottles. There are numerous smart bins, some of which even compact, but they are made for general waste. The best known brand being the big belly solar compactor trash bin. The big belly bins are also powered by a solar panel, but they compress the trash with help of a electric motor, making the trash bin bulky and very expensive compared to our solution.
Our first market is the EPFL campus, and since we have already won the student price, which shows that students like our trash bin, we think it will be easy to convince EPFL that our trash bin is the future of pet bottle recycling.

1.3 Unique selling points of your product

Our products most unique selling point is our self-created crushing mechanism. It is the part which went through the most redesigning iterations and even needed 2 prototypes before being what we expected it to be. It works with the users force, crushes bottles whether they are closed or open, full with liquid or empty, small or large (up to 1.5 liters). With one swing of the lever our mechanism closes the opening and crushes the bottle against the saw blades where it is emptied. When the lever is swung back up to its initial position, the now crushed bottle is thrown into the container, the top opening is re-opened for the next bottle and the ultrasonic measurement is triggered.
Thanks to the fully mechanical mechanism our system is robust to perturbations and easy to maintain. We have even included a quick access method to replace the piercing blades and clean the interior.

2 Technical solution

2.1 Specifications

Initially, we had fixed severals requirements that our TTB had to achieve. They were split in six categories : *General, Performance, Safety, Maintainability, Interface and Design.* Our goal was to define and choose some objectives, which will drive us throughout the project. We wrote a first draft for MS1. We knew that we would probably not succeed to implement all our requirements. Therefore, we sorted our specifications by importance and we used two different words : *shall* ≡ *must to have* and *should* ≡ *nice to have.*

As expected, all along the project we were confronted to some issues. Our engineer's job was to fix them, as well as we could, by changing some parts of the design. However, we had different constraints (deadline, prototype budget, and so on), thus we had to make some choices. As result, we had to drop some initial requirement.

We add below our prior requirements' list with a column, which details if the point was implemented in our final product or not. We used the following notation : *Yes = implemented ; No = point dropped ; T.I. = To be improved, but implemented ; * = The point was a « nice to have »one ;*

A. General requirements

A-1	The Thor Trash Bin (TTB) shall store empty pet bottles.	Yes
A-2	The TTB shall accept standard Pet bottles up to 1.5 Liter.	Yes
A-3	The TTB shall fill the bottles in the plastic bags given by EPFL.	Yes
A-4	The TTB shall compact the stored pet bottles.	Yes
A-5	The TTB shall empty full pet bottles.	T.I.
A-6	The TTB shall prevent overfilling.	Yes
A-7	The TTB shall separate the liquid content from the pet bottles and the pet bottle itself in 2 different compartments.	Yes
A-8	* The TTB should close the opening, when a problem with the compacting occurs.	No
A-9	* The TTB should close the pet bottle bag when changed by the cleaning staff.	No

B. Performance requirements

B-1	The TTB shall accept a pet bottle every 10 seconds.	Yes
B-2	Using the TTB to throw away a pet bottle shall not take more than 2 seconds.	No
B-3	The full pet bottle plastic bag shall not weigh more than 10 kg.	Yes
B-4	The emptied bottles shall contain less than 0.5cl of liquid.	T.I.

C. Safety requirements

C-1	The TTB shall comply with the safety regulations of the EPFL.	Yes
C-2	The compacting mechanism of the TTB shall be hidden to avoid injury of the TTB user.	Yes

D. Maintainability requirements

D-1	The cleaning staff shall see from the outside whether the TTB is full.	Yes
D-2	The emptying of the TTB by the cleaning staff shall not take more than 30 seconds.	Yes
D-3	The TTB shall be autonomous, emptying of the full pet bottle bag and liquid container by the cleaning staff excepted.	Yes
D-4	The emptied liquid shall not flow out of the TTB.	Yes
D-5	*The PET bag should not contain any liquids.	T.I.

E. Interface requirements

E-1	Instructions required to operate the TTB shall be placed on the TTB.	Yes

F. Design requirements

F-1	The TTB shall prevent students from placing pet bottles on top of the TTB.	No
F-2	The TTB design shall simplify the cleaning team's work.	Yes
F-3	The TTB housing shall be strong enough for EPFL's student environment.	Yes

To summarize, there are only two *shall* points, which have not been implemented : *B-2 and F-1.* For the first one, we thought that users would accept to spend more time (about 10 s) by using a more « fun to use »mechanism. We have therefore chosen to drop the requirement. The second one was dropped, because of some ergonomic considerations. Our TTB final design is quite high and our idea to achieve this requirement was to design TTB's top with a slope. So, we implemented a flat top, which had a more simple access to throw PET Bottles. There are also the two first *should* points, which were dropped.

However, there are three points related to the liquid's parts of our mechanism, which have been implemented, but they still need improvement.

2.2 Design phase : solutions explored

According with previous considerations, we started the design phase. We first brainstormed on how to implement our main features. Therefore, we decided to split work in two parts : *Mechanical and Electronics.*

Mechanically, our design must : compress and empty PET bottles by hand ; have an input for PET bottles up to 1.5 liters that is self-closed during the compacting phase ; have two compartments (one for the PET bottles' trash bag and a other one for liquid) ; have an easy access for the mechanism maintenance and to change worn-out parts ; have general ergonomic considerations (users and cleaners friendly) ; look good in EPFL's environment.

Electronically, our design must : measure the waste level ; send various informations to a extern server ; display informations on a screen ; find some ways to refill the battery without the cleaners' intervention.

2.2.1 Mechanical Design

For the beginning, we decided to focus on how to compress and to empty PET bottles. For crushing, we simply chose to compress bottles between two plates, one fixed and the other one has the possibility to move. For emptying bottles, we explored two different ideas : *Piercing bottle or cutting bottle.* For the first one, we thought that it would be easily implemented by using an array of spikes. Unfortunately, we tried to implement a small prototype and we identified one weakness : the time for emptying pierced PET bottle was too long to succeed our requirements. Therefore, we explored our second idea.

For cutting and compressing bottles, we had to imagine the quite unusual mechanism, which is shown on fig.1.

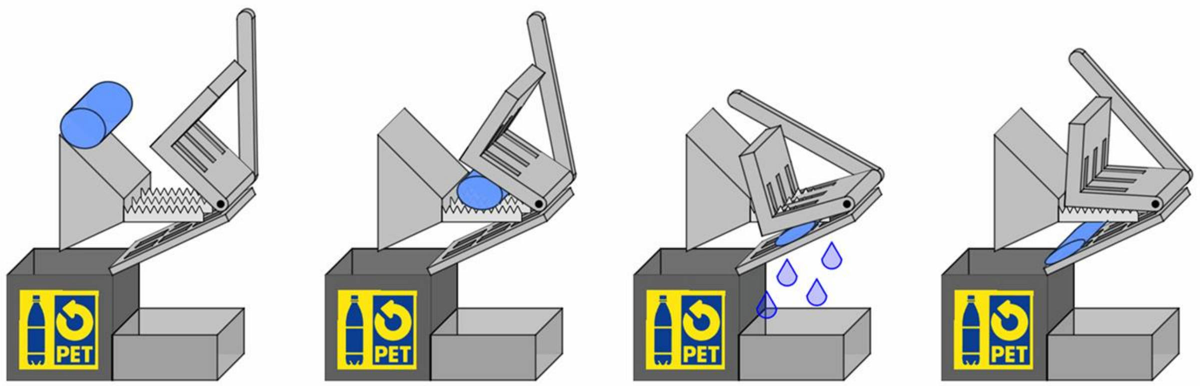


FIGURE 1 – First design of our crushing mechanism showed during Midterm presentation. Mechanism cuts and compress PET bottles. Notice that after last step, the bottle is cut in 3 parts.

Our main idea, was to use saw blades, because we thought that rotation movement of the compressor plate could reproduce the « scissor effect »and cut our PET bottle. Fortunately, we presented our concept during midterm evaluation and we received feedback from T.A. and professors. One of them pointed that some issues could happened, thus our prototype might not work as expected. Therefore, we asked ourselves if our system would still work even if a PET bottle were not properly cut ?

Obviously, we all agreed that our mechanism was an high risk point, which could impact dramatically TTB's future. We decided to go on with the other mechanical design's part and to build, in parallel, a pre-prototype, in order to have a clue about our concept's feasibility.

First Mechanical Design

Now, we will describe our first complete mechanism's design. All step are sketched on fig.2-4 shown below.

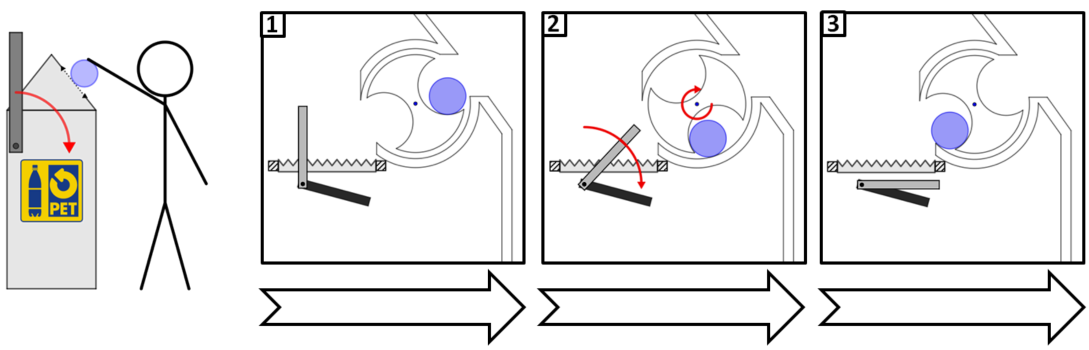


FIGURE 2 – First step

We decide to implement a two stages mechanism. Initially, one throws a blue PET bottle in the THOR trash bin (TTB) (box 1). Then, one pulls down the lever. The cylinder at the input will rotate and the crushing mechanism (rotating plate and the saw blades) will close (box 2). When the lever stops at the bottom position, the PET bottle is in a waiting state (box 3). Mechanically, the lever is directly attached to the rotating plate (transmission ratio of 1) to have a minimum torque loss, but the input cylinder has to make only one half turn (transmission ratio of $\frac{1}{2}$).

Once the lever is released, it rises to its initially state due to springs. The crushing mechanism will return to its initial state, but the cylinder will not move in order to keep the bottle in the waiting state (box 4 & 5). Mechanically, a freewheel mechanism will be placed on the axis of the input cylinder.

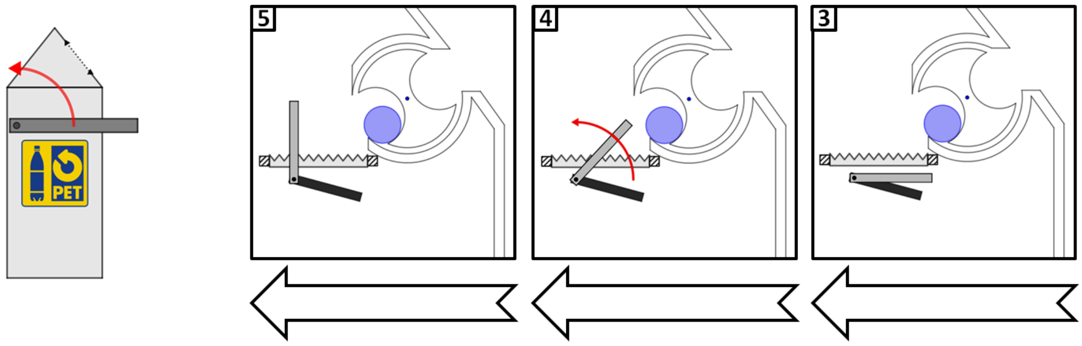


FIGURE 3 – Second step

Now, a second person throws a red PET bottle in the TTB (box 6). Then, he also pulls down the lever. The red bottle will follow the same step as the blue one before. This time, the blue PET bottle will fall in the crushing mechanism (box 7) and be cut and compressed (box 8).

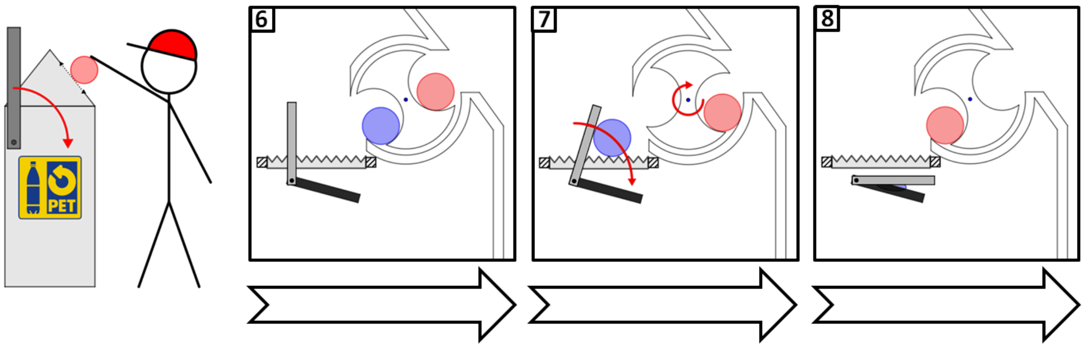


FIGURE 4 – Third step

Unfortunately, the crushing mechanism had been invalidated by our pre-prototype. Thus, we decided to throw away bottle cutting concept and to go back to brainstorming phase.

Second Mechanism Design : A New Hope

After some discussions, we decided to retake our piercing bottle concept. It was a trade-off, because as previously exposed bottles did not empty as fast as needed to fulfill our requirements, but we had a short time before the MS2 deadline (pre-prototype was finished on Monday and MS2 deadline came up to Thursday). We did not have too much delay on our schedule. So, we worked extensively to be on time and we achieved the following design, which is inspired by EPFL's cans' crusher.

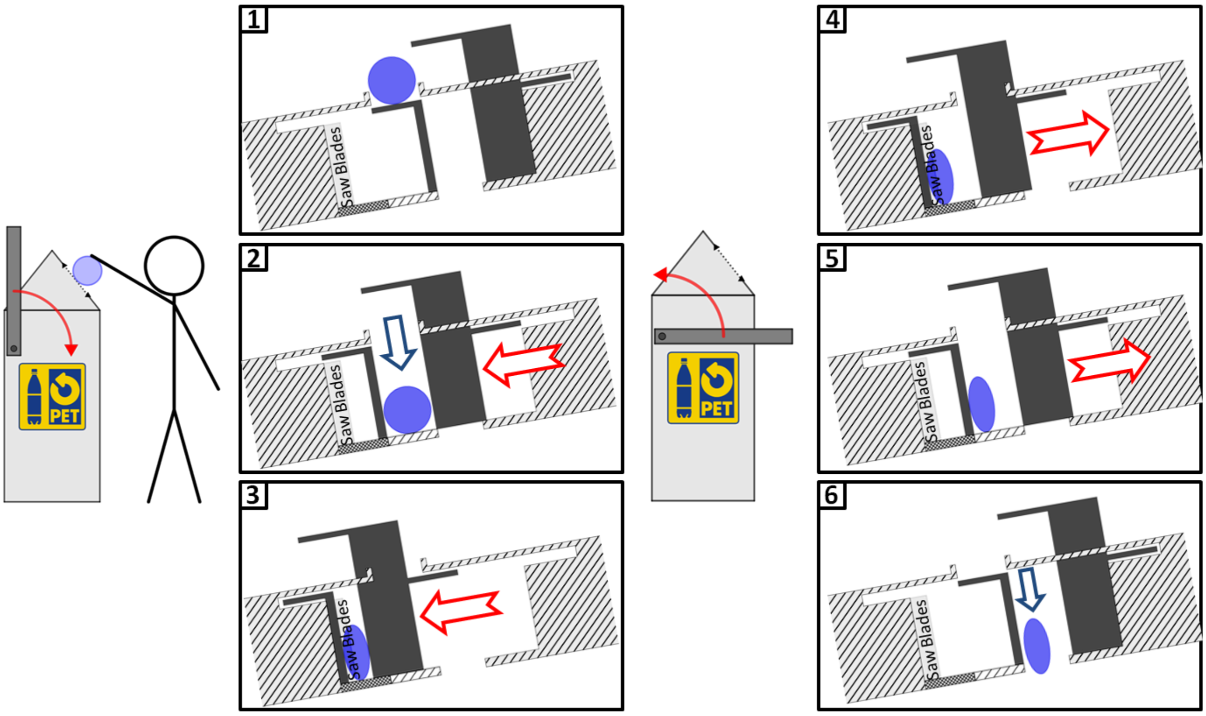


FIGURE 5 – Second design of crushing mechanism

The design is quite simple and easy to use : you put your bottle in the opening on top of the trash, you swing the lever, and this is done ! The special mechanism implemented on the TTB cannot be seen or touched by the person using the bin.

Now that we know what the customer has to do, the real question is : what is happening inside the TTB when the lever is swung ? To answer this question, we will take a careful look from the side of the trash. On figure 5, the global mechanism is described step by step :

— (Box 1) The bottle has been inserted into the bin and is ready to get crushed.
— (Box 2) At the start of the lever movement, both black pieces on the right and left side of the bottle will slide to the left together.
— (Box 3) The left black part has an array of rectangular holes so it can slide into the blades, the bottle then being pressed directly onto them. Once the left part hits the stripped wall, its movement will stop, but the right piece will continue pressing the bottle against the blades ; the specific geometry that allows one part to slide while the other does not move will be explained after. During this movement the bottle will be pierced and compressed. During the piercing process, any remaining liquid in the bottle is going to go trough a grid, part just below the saw, and inside a liquid container.
— (Box 4) The lever will now start to go back up, it is the same movement in reverse. The right piece starts to move first to the right, once the initial distance between the two black pieces is back, the left one will start to move too.
— (Box 5) By now the left piece will have pushed the bottle away from the blades, where it was stuck before. This state is similar to the second one but the bottle is compressed and emptied now.
— (Box 6) As a final step, the bottle will fall through the hole at the bottom right into the plastic bag. The mechanism is now ready to crush another bottle.

Actuation by hands mechanism

We immediately thought to use a lever. Then, we had some reflexion about simple against double lever. Relevant aspects yielded from using double lever as mechanism symmetry of force applied were an increase of the user's safety (having two hands on the lever reduces the risk of misusage), and of user friendliness (double lever is more ergonomic than simple one). We also imagined to design our lever with two hammers used as join to be consistent with our TTB concept.

Force transmission mechanism

Our main consideration was to limit the number of transmission's stage between lever and moving plate, in order to reduce as much as possible the loss of force. As discussed in the MS2 report, a force about 240N was measured to pierce PET bottle. Our first idea was to use gears and rack, because this kind of transmission allows a high repeatability and strong transmission and they are common mechanical pieces. So we dimensioned all different pieces, chose all materials and so on. Unfortunately, total cost was too expensive compared to our prototype's budget. Therefore, we imagined an second system formed by cables and pulleys. This implementation was less robust to high forces than the mechanisme with the gears, specially at fixture points of cable. Another weakness was rigidity of cable ; the cable can loosen after some use. There were also some advantages as low cost, easy fabrication, freedom to change its shape (cam = modification of relation displacement/force), and easy implementation for prototype.

Turn back lever mechanism

We decided to add two springs in order to pull the lever back up. With this solution the user does not have to do it himself. The force needed for the springs has not been exactly calculated. However, we know that it will need to compensate the weight of the mechanism and the friction. We want to avoid over-sized springs which increase the force required from the user. Therefore, we think that spring stiffness could be chosen based on direct test on pre-industrialization prototype. For the prototype, we chose to close the cables' loop and to replace springs by two counterweights fixed on both side of our force transmission mechanism. We thought this was the easiest and cheapest way to have a turn back lever mechanism. However, we will not prefer this solution over the previous one, because it is less robust than the other one.

Trash empty mechanism

One of our goals was to help the cleaning staff in their job, for this we implemented a drawer to take out the trash bag with no need to lift them. Additionally, we put on the same drawer a liquid's receptacle.

Drawers for the blades

The same idea is used for the blade part of the mechanism. It will be easy to slide out the blades from the top of the bin in case they need to be replaced or cleaned. Additionally, all blades are assembled on same stick and any screw are needed. We also used standard saw blades, which can easily be found in DIY shop.

Safety issues

The mechanism is designed in a such way that the blades are never accessible from the outside while the bin is used. This can easily be seen on fig.5. The TTB's opening is closed when the lever is pulled down and blades cannot be touched when opening is free. All the force transmission system (pulleys and cables) is mounted on the outside of our inner casing, so they are protected from the water splashes. Additionally, we used an outer casing to avoid any contact with outside.

2.2.2 Electronical Design

Based on our prior considerations, we selected several points, which needed to be implemented on our TTB.

Wastes' level measure

The most important task for the electronics is to detect when the trash bin is full, we do this with an ultrasonic sensor. This technology is cheap, easy to use and has a high enough resolution for our application.

Communication with external server

For this task, we used a microprocessor, which had an integrated Wifi module. With cost consideration, we chose *raspberry pi zero W* microprocessor. Then, severals informations, as battery level and waste level were send to an external server and they were displayed on a web site that we created.

Display informations

Another important task was to create an entertaining trash bin, our mechanism is already fun to use, but to make it even more interesting we added a screen. On there the user can see how many bottles have been crushed, how full the trash bin is and our logo. Since the display shows mostly static content and should also be readable at full sunlight, we used an e-ink display. Additionally this display technology uses no power to display static content, only the changing of the screen state requires energy.

Ways to lead to an autonomous trash bin

Optimizing the electronics in regard to the electric consumption was a crucial part. To save energy, most new phones have 2 processors : A fast one which consumes more but is only turned on when needed and a slower, energy saving one which is used when the phone is in idle. We have also implemented this strategy in our trash bin. There is a low-power *Atmega 328P* which takes care of the ultrasonic measurement and the e-ink display refresh. If communication to the internet is needed, the Atmega turns on our second microprocessor, the *raspberry pi zero W*. The raspberry pi then updates the status on the server and shuts itself back down, this process takes around 15 seconds. The two processors communicate through the I2C protocol. To push the consumption even further down, an additional library has been used to set the Atmega in a ultra low-power sleep mode while the trash bin is not being used.

To wake up the Arduino when the trash bin is being used we use simple interrupters which are closed when our mechanism is in the idle state, the lever is in the up position.

Battery and ways to refill it

As power storage we use a lithium-ion battery. The arduino has an analog to digital converter so it can read the remaining voltage of the battery easily. With the additional solar panel and step-up converter we can even recharge the battery while the bin is not being used, which makes our trash bin fully autonomous in environments where ambient light is provided.

Later, we also imagined to implement dynamos, which were directly connected to our pulleys. Unfortunately, they needed an additionally electronic circuit (to convert AC to DC and to finally refill battery) and we already had ordered solar panel. Therefore, the ideal implementation should have both systems, in order to refill, as efficiently as possible, the battery.

Complete Electronical design

A sketch of our complete electronical design is provided on Annexe *C. Circuit diagrams* on fig.18 on Annexe, page XII.

2.3 Technical choices made

2.3.1 Selected design

We will now explain our TTB final design. As previously discussed, we had implemented the *piercing bottles* concept for our crushing mechanism (see fig.5) and the other features. The final electronical design is based on fig.18. Final Thor Trash bin is shown on fig.6.

(a) CATIA of our TTB's final design. (b) Prototype our TTB's final design.

FIGURE 6 – Final design of our TTB. *Left :* 3D CAO design computed with CATIA software. *Right :* Prototype shown during the final presentation.

Mechanical implementation

Our main mechanical part is the crushing mechanism. In fig.5, we explained with sketches how did it work. We will now see how did we built it.

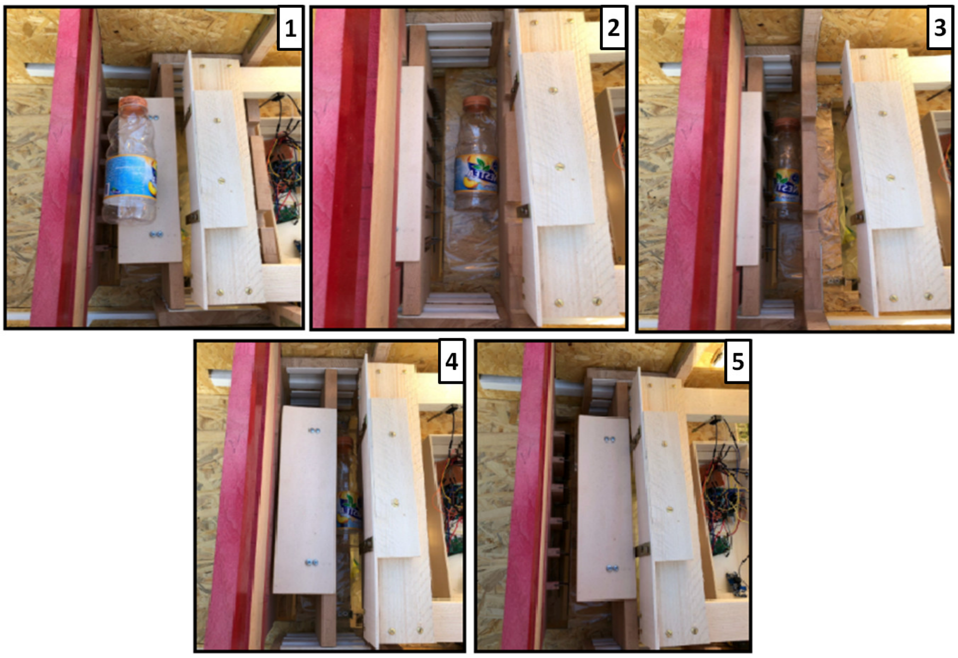


FIGURE 7 – Implemented crushing mechanism

On figure 7, the mechanism that we implemented can be seen. We took pictures of the different steps explained previously(see figure 5).

During the step 3, we talked about a special mechanism that allows one part to keep sliding while the other one is blocked by the wall holding the blades. On figure 8, you can see the sliding mechanism : the orange part is where the blades are, the green one represents the left gray part on figure 5 and the red one the right gray part. Thanks to the grooves inside the red part, which is directly connected to the lever, the green plate can be stopped by the orange part, without stopping the red part that can continue its movement. This system is at the center of the crushing mechanism. Indeed, while the green part is stopped, but still allows the blades to come out, the red part is going to compress the bottle, which is between the green and red part, on the blades.

As explained before, the bottle is going to be compressed and pierced between the green and red plates shown in figure 8. One of the key part is precision of the green part : it needs to perfectly fit between the blades, and lay flat against the orange part. If this part is not completely flat, during the compressing process, extreme pressure can appear and be a problem. This part will be analyzed during the next section.

Until now, the crushing and piercing mechanism were analyzed, but there are other interesting aspects in the TTB.

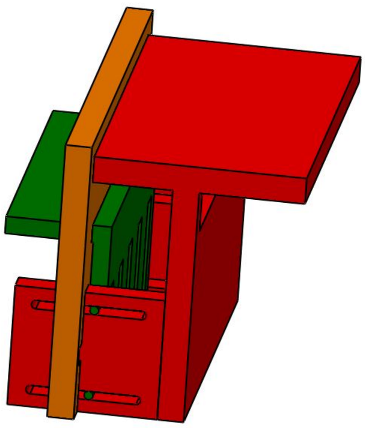


FIGURE 8 – Sliding mechanism

We wanted to create a trash as cleaners friendly as possible, this is why we implemented numerous features that help the cleaning staff. First of all, the drawer on which the actual trash bag is placed on. A special bag holder was built on the drawer in order to have an easy way to replace a bag. Moreover, the bag do not need to be lift off in order to be taken out ; the cleaner can take it from below. Another aspect is the liquid container that is also fixed to the drawer. The cleaners can take it out easily and no liquid is going to be contained inside the trash bag. On figure 9, you can see these two features. In front, the trash bag is placed on the special holder, and at the back, the liquid container.


FIGURE 9 – Drawer

Another aspect that seemed important for us was the cleaning of the blades. It is the most sensitive part in terms of wear. To remedy to this problem, we created a holder for the blades that can be taken individually out of the main frame without deassembling anything. The cleaners just have to open the top of the trash, and pull the vertical "drawer" where the blades are mounted on.

Finally, the last aspect of the trash that needs attention is how we linked the movement of the lever to the movement of the other parts in the crushing mechanism. On figure 10, the system of pulley is shown. The lever is fixed to a wheel. On this wheel, a red cable is being fixed and the other end of the red cable is mounted on the "box" that crushes the bottle, red part of the figure 8. The box is moving on grooves that have been made on the inner casing of the trash can. When the lever is pulled down, the red cable is going to wrap around the wheel and pull the "box" with it. When the lever is pulled up, the blue cable is going to have opposite effect of the red one and is going to put the "box" back into its initial place. The green cable that you can see on figure 10 is the counterweight that reposition the system to its initial state. At the beginning, the reseting system was supposed to be implemented trough springs, but due to limits in the budget, we opted for counterweights.

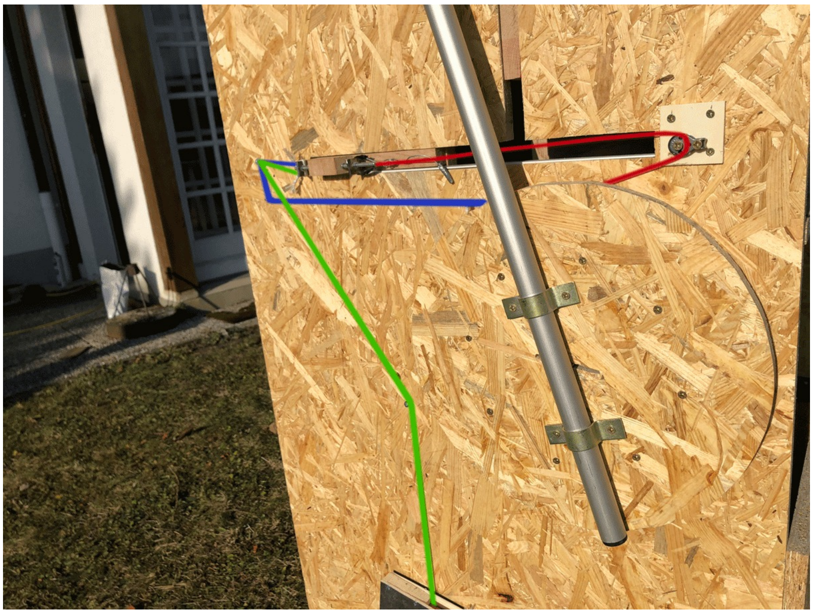


FIGURE 10 – Pulley system

2.3.2 Electronical implementation

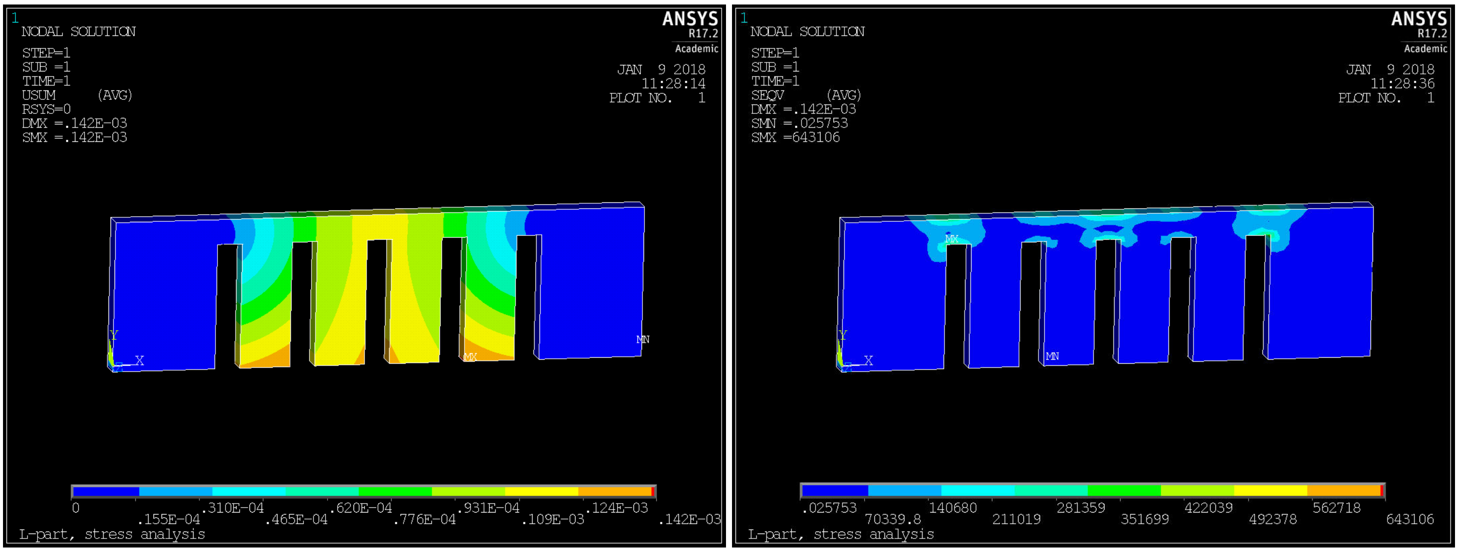
The recharging of the battery with the solar panel worked in our prototype, but due to the explosion risk of lithium-ion batteries if their voltage gets too low, we decided to replace it for the presentation. Mostly because we did not know if the trash bin would stand in a dark room during the winter break. To keep it safe we plugged in 6 AA batteries which can also easily be replaced. For the final product a dedicated lithium-ion controller will be included, this one will completely decouple the battery from our system if the battery is reaching a critical level and slowly recharge it once ambient light is available or the battery has been replaced by the staff. In such a situation, the trash bin can still be used to crush bottles and the staff has already been notified because the battery status on the server is updated before the critical battery voltage is reached.
We have also kept the *Atmega 328P* on its *Arduino Uno* board so we can use the included voltage converters for the batteries as input and the 3V output for the screens. On the final product there would of course be a PCB designed for the trash bin with all the features included.

2.3.3 Analysis/modeling of the key functions related to the unique selling points

The key point that needed the most attention was the L-part, green part on figure 8, due to the high forces that the plate had to withstand. This is why we decided to create a FEM simulation and see the maximum deformation and stresses along this piece. On figures 11a and 11b, the results of the simulations can be seen. The bottle do not take the full space of the L-part, and therefore the needed pressure to pierce and crush was only applied to a surface equal to a PET bottle, at the middle of the plate. A force of $240N$ was found during the pre-prototyping in order to pierce and crush a bottle. When dividing this force by the area of a bottle, we can find the needed pressure ; in our case $Pressure = \frac{Force}{Area} = 7.38 \cdot 10^3[Pa]$.

We can see that the maximum displacement is going to be in the middle and is around $142\mu m$, which is more than negligible when remembering that this deflection is only possible if this L-part is misaligned with the plate holding the blades. Indeed, during the compression the L-part is normally pressed against the orange part, figure 8, and no deflections should be possible. Unfortunately, as we saw during the testing of our prototype, sometimes a small misalignment could appear and lead to stress inside this L-part. For this reason, we also measured the maximum stress possible in this plate, figure 11b. This shows us that the stress is not too high, but should still be considered. That also enables us to identify the weak spots of the piece and make it tougher to these places.

The second spot that needs attention is the system of pulleys, figure 10. We saw with our prototype that the wear of the cables was quite important. Fortunately, we managed to find what was not optimized : we did not guide the cables properly, and they were taking rough paths where friction was important. With a proper implementation, with for example more pulley and good guides and fixations, we think that the pulley system is not a weak point of the structure. This also why we thought that a FEM simulation would be pointless and would give us poor or inconclusive results. Note, that the ANSYS code is provided on Annexe, *D.4. ANSYS*, on page XVI.



(a) FEM simulation of the maximum displacement (b) FEM simulation of the maximum stress

FIGURE 11 – FEM of L-part, computed with ANSYS Software.

2.3.4 Key elements in the design and how they could be further optimized

Thanks to the prototype, we verified the main principles and are now sure that the whole mechanism works. Nevertheless, for the future of the design, there are a few points that could be modified in order to have a more robust and greener system.
First of all concerning the crushing and piercing mechanism in itself. We could add more and better blades in order to have a faster process. We could also think of transforming the blades into spikes which would be more convenient and efficient. Moreover, concerning the sliding of the L- and T- part, better grooves should be designed with a proper guide between the two pieces in order to avoid misalignments when the bottle is crushed.

For the rest of the trash, as we said before, the pulley system is good, but need a better implementation. With strong fixations of the cables and good guides, pulley system is one of the best system to link our lever with the rest of the system. Also, an idea that could not be implemented on the prototype due to a lack of time is a cam design instead of a simple wheel. Indeed, at the beginning of the movement, we need a large displacement and low forces and at the end of the movement, we need to have a small displacement and large forces in order to pierce and compress the bottle. By having the lever connected to a cam design and the cable going around this cam, it would create a non-linear movement-force system that we could tune to our own desire.
Another point that could be developed is the handling of the liquid. We thought about creating a pipe system inside the trash that could be connected to the sewers if the TTB is placed near an opening. It would facilitate the work of the cleaners and make the trash more autonomous.
We also thought about implementing a sort of dynamo inside the lever in order to make the trash even greener. In this ways, we would use the full energy of the customer and charge batteries for the electronic system. Solar panels is also a solution to make this trash even better !
Finally, concerning the counterweight system, we should either redesign it or replace it with springs in order to have a cleaner final product.

2.4 Manufacturing choices and proposals for future production

2.4.1 Prototype fabrication

Preprototype

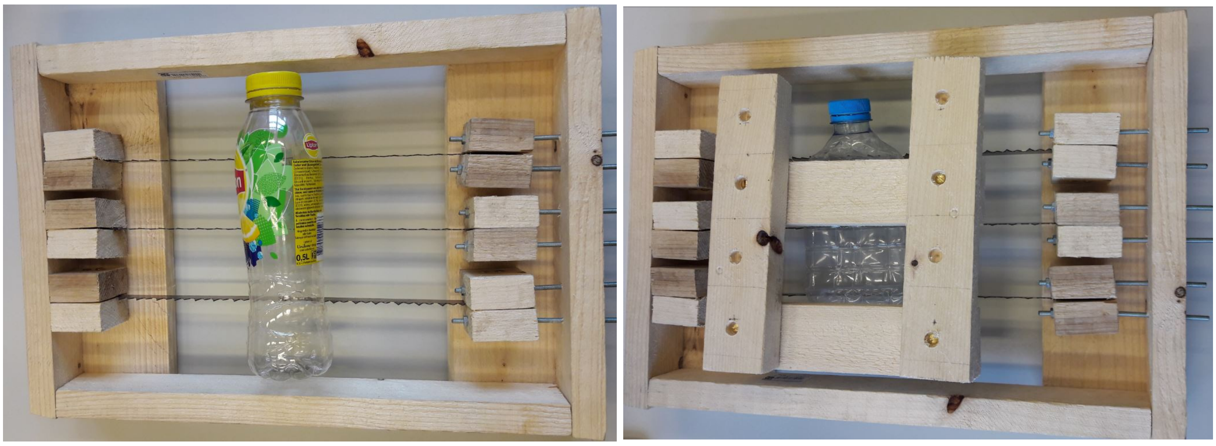
The pre-prototype consisted in 3 parallel saw blades (with big teeth) fixed on a wooden frame (see figure 12a).

In order to avoid the buckling of the blades, they needed to be under tension. Therefore, we fixed one end of the blades on mobile parts that we fixed to the frame using threaded rods, letting some space in between : by tightening the nuts, one can get very high tension (we stopped tightening only out of fear of braking the blades or the frame, while it was still very easy to tighten them).

While compressing, we apply a big vertical force to the blades. To avoid it to be transmitted to the threaded rods (that are very resistant in traction but very weak in bending), we added 2 wooden boards that could support the mobile parts and withstand the force. We also fabricated a "comb" to press on the bottles, mainly in order to avoid the risk of injuries while testing.

The testing of the pre-prototype yielded mitigated results : on the one hand, piercing and emptying the bottle worked well (we needed about 240N to pierce the bottle, and managed to empty more than 80% of the liquid from a full 0.5L bottle). However, we did not managed to cut the bottle, even with far bigger forces (we tried up to 680N).

The pre-prototype served well its purpose : we knew that our initial design did not work soon enough to change our design, keeping the piercing and the emptying, but removing the cutting.



(a) The frame with the blades

(b) The complete pre-prototype

FIGURE 12 – Pre-prototype constituted of three saw blades, a tensing blades mechanism and a « Comb »used to avoid injuries during test phase.

The final prototype

Due to its imposing size and no actual place at EPFL to store it, the location where we would build the trash was the first challenge of this long journey that was waiting us. Fortunately for us, Fabian shares a house with other fellows students next to the campus and they built a workshop in the garden at the beginning of the semester. Thanks to that, we had now a proper location where we started to built the TTB.

Moreover, due to its big size, it was not possible to use other materials than wood because even the raw materials would have been too expensive otherwise (aluminum, ...), and the manufacturing of such materials would have had to be done by EPFL workshops that would also have added a huge overcost.

For the pieces having only a structural goal, the use of wood was not a problem. However, we had also to do the mechanism in wood (even just doing this in metal would have provoked an overcost of a few hundred CHF), and that was quite challenging.

A first difficulty was to manage to make small and precise holes in the wood, especially for the sliding grooves. A solution might have been to do it by laser cutting, but once again, there was no such facility at Robopoly and we could not afford to pay a workshop to do it. So we had to do it with the jigsaw and do the finishing with the file. We also added cheap plastic pieces in order to reduce the friction. We finally managed to get some correct sliding rails, but it took tens of hours.

Another difficulty was the fact that we had some quite thin pieces of wood (2-3 cm wide), and that big plates of wood were too expensive, so we had to use plates composed of several pieces of wood glued together, which are less resistant. We therefore had to reinforce several pieces, and even repair two that broke.

Finally, the prototype showed us several little flaws in our design that we corrected, for example the fact that friction was not enough to separate the 2 mobile pieces (we added some stoppers to block the comb) or the fact that the lever did not stayed up (we added the counter-weights). These problems are what is interesting with building a prototype, we actually saw where problems could appear and we fixed them.

2.4.2 Final product (Estimated costs of manufacturing)

In order to have a product that is resistant to use, time and aesthetically pleasing we wanted to have our final product in a painted metal material. Taking inspiration from existing products, an aluminum solution seemed to be a good solution. Not only is it easy to clean, but it is also easy to paint, has a low weight for transportation and is resistant if thick enough. The critical parts on the inside (mostly the parts receiving most of the crushing and doing the crushing) can be made with steel if further prototypes prove that aluminum cannot withstand the force applied. In both cases, we can work from metal sheets on which we will do the necessary machining to obtains the hollows our system needs. As for the multiple axis, levers, those can easily extruded from metal as profiles are usually made. Those parts are easily found in DIY stores as we did for the prototype, and getting them from a sub-contractor should prove easy enough. We estimated (from the dimension, the density and the price of aluminum and steel per kg) the price of the raw material to be around 160CHF, including the pulleys and cables for the mechanism. The machining of the metal sheets can be done by water cutting for a small size production, as the only downside of the method is the cutting speed which would be an issue for mass production. For example with 4mm thick aluminum sheets we can have cutting speeds from half a meter to a meter per minute depending on the edge quality. Estimating the cut length from the prototype and adding the dimension of an outer casing, we have roughly a distance to cut of 23.5 meters, with usual HP60 pumps (used for the cost simulation), the operation price ranges from 35 to 45 CHF for an hour. By adding the cost of the operator of 60CHF/hour (if manufacturing in Switzerland for a small production) we get a price for the machining of approximately 75 CHF. Taking into account the assembly (estimated at less than a man-hour with the proper equipment and experience we lacked in the prototype) we can get 130 CHF per trash bin for machining and assembly. Including the raw materials, we have a cost of 290CHF for the product, not including the overhead, engineers, designers which makes us set the product around 400 CHF per piece as announced in our presentation.

In case of a massive production, we can use a different method : stamping. The cost approximation is harder to calculate as this production method uses a die and stamping tools whose prices vary depending on the complexity of the final piece. Our pieces being easy to make the price could be on the low side of the fork ranging from 20'000 CHF to 150'000 CHF, our only flaw being the size of some of our pieces (1200mm*650mm for the largest ones). Given the price of the tools this method is usually used for production larger than 100'000 pieces. The electricity and operating cost of the machine become insignificant in regard to the amount of pieces made per hour (roughly 1-2 cts/piece). For the dye design and cost we estimate this to less than 10CHF per trash bin (as it is spread among the number of designed products). We can estimate a price mainly composed of the raw material and can estimate the price of the trash bin to 225CHF per product of production cost with this method (as the assembly and raw materials might not be so drastically reduced with a scaling production). The main downsides of the method are first that the dye usually takes 3-4 months to make delaying the production and second that the cost of the dye only makes the method worthwhile for large productions.

2.4.3 Quality analysis and control

In order to ensure a good quality and durability of the product, we need to make sure the quality of the materials is reliable as our system puts relatively high constaints on some parts. For this reason it is also key that the geometry of the pieces is maintained. A simple control by the assembler should be sufficient for the geometry of the pieces, but the quality of the materials depends on the suppliers, as such we should choose a reliable source of materials and samples would be tested by our company's quality control's department. An other aspect we need to take into account is that our system relies on communication with the cleaning crews through the use of a server, which we need to ensure is kept working properly. Some downtime would not be critical but should be kept minimal for the user's comfort.

3 Intellectual property (IP) analysis

3.1 Prior art search (before patenting)

After some researches, we did not really find a single trash bin which has all our main functions, but we have found three different ones which regroup all of the characteristics of our THOR Trash Bin (TTB).

Model 2500 Recycling Bin with Crusher : It is a trash bin with a manual plastic bottle and can crusher. However, the cap has to be removed from the bottle's neck before crushing them. It is a funny mechanism for users, but it is not really ergonomic and does not facilitate the cleaners job. It also does not contain any electronics.

Igora Aluminium Can Crusher : It is a trash bin with a manual can crusher. It is present on the EPFL campus. It has inspired us to design our PET crushing mechanism. It's also a funny mechanism for users, and a quite ergonomic one. Full bags are easy to remove which is good for cleaners. However, it does not contain any electronics for the waste level measurement.

SmartBelly for Waste & Recycling : It is a kind of *Ecopoints* from a brand named BigBelly. The PET Bottle trash bin does not have a compactor like the general waste BigBelly. However, it has some sensors in order to measure waste level and other components to communicate with cleaners. This Trash bin is completely autonomous like our TTB.

FIGURE 13 – **Left :** Model 2500 Recycling Bin with Crusher [5] ; **Middle :** Igora Aluminium Can Crusher[4] ; **Right :** SmartBelly for Waste & Recycling [6]

We identified two critical systems that needed a more thorough research concerning the patents : the manual compactor for single plastic bottles with a cap and the ultrasonic sensor for the waste level measurements. As seen during the patent lectures, we tried to find some categories related to our two functions. First, we tried with some keywords like "plastic bottle compactor", "Bin with compactor" which are related to the trash bin in general but the results were not precise and lot of files were not related to our TTB. Then, we refined our research by adding more precise subcategories (i.e . we include some categories about presses for the mechanical part) . Finally, we found some patents which are quite close to our TTB, but not enough. So we identified some categories from this patents, we combined them to our previous ones and found interesting patents.

B	PERFORMING OPERATIONS; TRANSPORTING
30	PRESSES
B	PRESSES IN GENERAL; PRESSES NOT OTHERWISE PROVIDED FOR
9	Presses specially adapted for particular purposes
B	PERFORMING OPERATIONS; TRANSPORTING
09	DISPOSAL OF SOLID WASTE; RECLAMATION OF CONTAMINATED SOIL
B	DISPOSAL OF SOLID WASTE
3	Destroying solid waste or transforming solid waste into something useful or harmless
B	PERFORMING OPERATIONS; TRANSPORTING
30	PRESSES
B	PRESSES IN GENERAL; PRESSES NOT OTHERWISE PROVIDED FOR
1	Presses, using a press ram, characterised by the features of the drive therefor, pressure being transmitted directly, or through simple thrust or tension members only, to the press ram or platen
02	by lever mechanism
04	operated by hand or foot
B	PERFORMING OPERATIONS; TRANSPORTING
65	CONVEYING; PACKING; STORING; HANDLING THIN OR FILAMENTARY MATERIAL
F	GATHERING OR REMOVAL OF DOMESTIC OR LIKE REFUSE
1	Refuse receptacles
14	Other constructional features
B	PERFORMING OPERATIONS; TRANSPORTING
65	CONVEYING; PACKING; STORING; HANDLING THIN OR FILAMENTARY MATERIAL
F	GATHERING OR REMOVAL OF DOMESTIC OR LIKE REFUSE (disinfecting refuse A61L; refuse disintegrators B02C; sorting refuse B03B; B07B; handcarts for transporting refuse receptacles B62B; sack holders B65B67/00; converting refuse into fertilisers C05F; converting refuse into solid fuels C10L; sewers, cesspools E03F; arrangements in buildings for the disposal of refuse E04F17/10; refuse-consuming furnaces F23G; for surgical articles A61B50/36)
1/00	Refuse receptacles; Accessories therefor (containers not specially adapted for refuse, features of refuse receptacles of general interest B65D)

G	PHYSICS
01	MEASURING; TESTING
F	MEASURING VOLUME, VOLUME FLOW, MASS FLOW, OR LIQUID LEVEL; METERING BY VOLUME
23	Indicating or measuring liquid level, or level of fluent solid material, e.g. indicating in terms of volume, indicating by means of an alarm
22	by measurement of physical variables, other than linear dimensions, pressure, or weight, dependent on the level to be measured, e.g. by difference of heat transfer of steam or water
28	by measuring the variations of parameters of electromagnetic or acoustic waves applied directly to the liquid or fluent solid material
296	Acoustic waves

FIGURE 14 – *Table left :* Identify categories for mechanical part ; *Table right :* Identify categories for electronic part

3.2 Patent search (freedom to operate)

We found three different patents which are more or less close to our compacting mechanism in the trash bin. The first (WO2013111135) [7] PLASTIC-BOTTLE COMPACTOR is only related to our product by its main function (Plastic-bottle compacting) and by the fact that "the displacing mechanism is configured with a force amplifying mechanism". But there are several implementation differences with our TTB. In this patent, the bottle caps have to be taken away to allow a compression. Furthermore, the bottle is compacted in longitudinal while we do it transversely. And to finish, the mechanism to transmit the force from the user to the compacting is slightly different : in this system it is a ratchet-bar whereas we have a lever fixed on a wheel.

Another patent, the (US20110283899)[2] Bottle compactor, is also comparable in terms of functionality. The system is quite similar to the previous patent (longitudinal compression, overall shape like a bottle) except that the force is transmitted thanks to a lever, similar to how we do it in our trash bin. But this is also the only similarity with our mechanism.

The patent we found which is the closest to our mechanical concept is the KR1020130118522 [1]. It allows to crush Aluminum cans but also non-open plastic bottles, thanks to spikes, which pierce it. Furthermore, it compresses transversely. And once it is done, the bottles can freely fall from this mechanism into the bag, exactly as we do. In order to do the compression, there is a moving plate with the spikes which move linearly in the system, thanks to four guides, and come to compress the bottles against a fixed wall. The principles of this system are exactly the same as ours, so this could be a problem. However, it seems that this patent is not active in Europe.

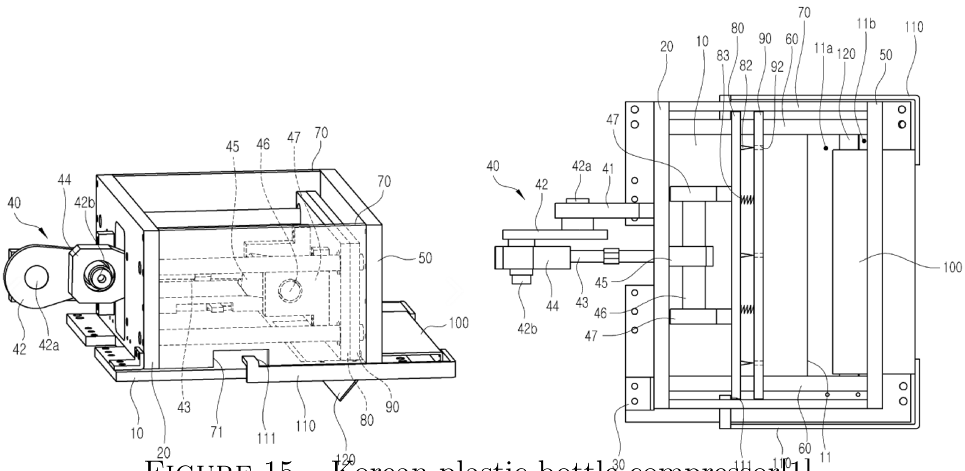


FIGURE 15 – Korean plastic bottle compressor[1]

For the "smart" part of our trash bin, we found the patent FR2853059 [3] which detects the level of the waste with an ultrasound sensor, exactly like we do it. However we go further by propagating this information to a web site in order to let ISS have information about the trash.

PUBLICATION NUMBER	TITLE OF INVENTION	APPLICATION DATE
	Mechanical part	
US20110283899	*BOTTLE COMPACTOR*	19.05.2010
KR1020130118522	*COMPRESSOR FOR A RECYCLED PRODUCT, CAPABLE OF COLLECTING AN OBJECT BY ENABLING THE OBJECT TO FALL FREE WHEN COMPRESSION IS COMPLETED*	20.04.2012
WO2013111135	*PLASTIC-BOTTLE COMPACTOR*	01.08.2013
	Electronic part	
FR2853059	*DOMESTIC WASTE CONTAINER FILLING RATE INDICATING DEVICE, HAS ELECTRONIC PROCESSING CARD CALCULATING DISTANCE BETWEEN CONTAINER TOP AND UPPER LEVEL OF WASTE, AND ILLUMINATING GREEN LAMP IF CONTAINER IS FORTY PERCENT FILLED*	27.03.2003

FIGURE 16 – List of patents that we found using previous categories.

3.3 Discussion on opportunities for IP and possible IP strategy

As seen in the previous section, our electronic part is not directly blocked by the previous patent, but the two systems are quite similar. Therefore, we decided to focus our patent claim only on the manual compactor for plastic bottle. In fact, by reducing our claim field, we expect to not overlap any other patents. We think that our mechanism is enough innovative and not so trivial to be patented.

Apparatus for trash storing of plastic bottles comprising a frame (1) made out of two perpendicular walls (2) onto which are fixed : a horizontal sliding mean (3) composed of two parts (4) that can slide into each other and crush a bottle and a another vertical sliding mean (5) onto which a piercing mean (6) can be attached. One of the two part of the sliding means (7) is specifically manufactured in order to have the possibility to partially go through the vertical sliding mean (5). By applying a force onto the horizontal sliding mean (3), the system is do such that (3) is going to get closer to the vertical sliding mean (5). When one of the part (7) of the horizontal sliding mean (3) stops after having partially go trough (5), the second part of (3) is going to crush the bottle, which is between the two part of (3), onto the piercing mean (6). During this crushing, a container (8) is going to collect the remaining liquid inside the plastic bottle. When doing the reverse gesture, the crushed and emptied plastic bottle is going to fall inside a mean of containment (9). The two containers (8) and (9) are also fixed onto the frame (1).

4 Pre-Business plan

4.1 Market

Since the beginning of our thought process, we focused on developing a smart trash bin suitable for the EPFL environment, and by extension, to all public area. On one hand, today, more and more waste is produced every day, and a not negligible part ends up in public trash bins. On the other hand, at the same time, cities, collectives, universities and many others suffer from budget cuts. So, to allow the same service to all users of these public arena, they need new solutions.
Their costs depend mainly on the emptying frequency by the maintenance agent and with our compacting system they need to come three time less often. Furthermore, by knowing in advance the filling state, they can optimize their cleaning path and avoid useless trash emptying. They also want a completely safe and easy-to-use system, for both user and cleaner. Our TTB offers high warranty for these two features. Finally, with our conception of a nearly autonomous system, no matter its location, they can place our trash bin wherever they want. These concerns are met all over the world, so eventually we can aim for a global market.
As these concerns are met all over the world and that our solution could be quite universal, so eventually we can aim for a global market. In the current state of the market, specially in Europe and North America, our main competitor will be BIG BELLY. They also propose a smart autonomous compacting trash bin. However, we have a few key advantages over their product. Indeed, our is much cheaper (1000 vs3000), needs no special knowledge to be manipulated and is easier to maintain and greener.

4.2 Strategy towards commercialization

Since our product corresponds to a niche product, not directly sold to individual, we do not need to advert in the public arena. However, to make us known by the collectivities we should directly contact them. We will also participate to the different trade show on the topic urbanization. Finally, the general public needs to know what is done with its money, so we will provide a complete website and flyer that the institutions can distribute. We will articulate our communication around 4 axes : value for money, safe, easy-to-use and eco-friendly. As the demand is going to be very fluctuating, we will not be able to implement our own factory. Furthermore, there won't be a stressful time constraint and our system is not too complicated, so we can outsource the production in any country. We will directly be in charge of developing and selling our product.

4.3 Your organization

Our company will be a PME because for now we only sell one product. To assure the success of our TTB, we first need engineers from different field to develop and improve our trash bin. The mechanical ones must be pragmatic and look for the easiest solution, in order to keep a reliable and cheap mechanism. We need no over-engineering because the market does not want it. Furthermore, they need to be creative and able to put themselves in the shoes of the average user, to deliver a user-friendly device. We will also need some IT engineers to develop the tools to exploit the data collected in an efficient way. Now that we have our best product, adapted to the market, the main part of the job will be to sell it. In order to do so, we need commercials that are able to convince the authorities that we have the best solution.

4.4 Financing of your project

We were able to produce a first prototype which shows our principle functionalities for 500 CHF. However, this prototype won't be sufficient to attract future customers or to find financing. In order to have a presentable prototype in start-up contest. Winning contests would provide us cash flow and good points for discussion with Banks. We need an extra 500 CHF to make it more visaully pleasing. Since its our own project and this could done quickly and easily, we won't take into account the the hourly wage we could ask for. Then, to produce a final prototype which we could present in the public call for tenders, we estimate it on around 2000 CHF. This second part will be done after we have found an investor who trust in our product, so we will now take into account the working time needed to produce it : around 80 CHF/H $\times$ 40H $\times$ 4 people $\times$ 3 weeks $\approx$ 40.000 CHF. This will be our main needs in money in a first time. Another development axes could be to associate us with other companies which produce other type of trash bins to offer a more complete service (carry all type of waste).

4.5 Planning

Once our business has been launched we could could break even quite quickly. Since We target mainly contracts with public institutions, so they will order a large number of trash bin (EPFL typically around 20/30, cities more than 100).

4.6 SWOT analysis (Strengths, Weaknesses, Opportunities, Threats)

	Helpful	Harmful
Internal origin	S • Innovative product : no direct competitor • Market-oriented : no useless features	W • Application limited • Irregular sale
External origin	O • Market growth • Ecological awareness from public	T • Drop of institution budget • Competitor could offer more complete solutions

5 Project Management

5.1 General strategy

The general idea was to divide the team into two groups. One that would work on the mechanical part and the other one on the electronic parts. As the mechanical part was going to take most of our time, we decided to let the electronics to Fabian while the rest of the team started the brainstorming of the mechanical parts.

As expected, the final system took us a lot of time and multiple iteration had to be done in order to get a working final idea. For the mechanical ideas, we tried to brainstorm every Friday with the whole team and Arun, our assistant. By doing these meetings, we could see the progress of everyone and we could also distribute the work for the following week.

5.2 Work breakdown structure

See fig.19 on Annexe *D.1 Work breakdown structure*, on page XIII.

5.3 Stakeholder analysis

See Table-1 on Annexe *D.2 Stakeholder analysis*, on page XIV.

5.4 Gantt chart

5.4.1 Initial plan

See fig.20 on Annexe *D.3 Initial Gantt chart*, on page XV.

5.4.2 Reflection on how the project went : difficulties encountered, remedies, etc.

We encountered our first big problem after the testing of the pre-prototype. The cutting of the pet bottle required too much force and our mechanism required that the saw blades cut through the whole bottle. We had to rethink our main mechanism and go back to the concept phase even though the prototyping phase was approaching fast. To be sure that our new mechanism would work as intended, we were running short on time, we arranged a meeting with Prof. Yves Bellouard who shared his knowledge and discuss with us the different possibilities we had and hurdles we might encounter.
During the prototyping we were surprised by the cost for the wood and metal parts needed. We chose solid, more expensive wood for our main mechanism due to the strong forces acting there. The cost problem forced us to rethink the casing, that's how we came up with the idea to only do one side of the casing. At the end we were happy with it, since it showed on one side what we have planned for the final product but all the other sides stayed open, as to show the inner works and how we implemented everything.

5.4.3 Deviation from the original planning

We pushed this section after the reflection on the difficulties encountered, so we can explain the deviations we had from the planning, due to the above described problems.
After the pre-prototype problem we had to redesign our main mechanism from scratch, thus we had to reallocate concept time during the implementation phase. To still be able to deliver the finished prototype, the prototyping phase had to be accelerated. Once the final mechanism was agreed on we worked in small groups of 2-3 every day on the prototype. The problem also induced another change in the plan, the Catia plans had to be redone too. This was done in parallel while the prototype assembly started based on sketches we drew by hand during our group meetings after the failed prototype.
After the prototyping phase already being shortened, we experienced some minor issues and design changes during the building. This made the prototyping much more time consuming than anticipated. In the end we were happy that we planned a buffer week, which was needed to finish our prototype and make it also visually appealing.

5.5 Who did what ?

Charles-Théophile

By having quite a lot of CAD during the previous years, I decided to create the different CATIA models for the different ideas we had. This plans helped us to see the different problems that could arise during the prototyping. They helped us a little bit during the prototyping, but as we now know, a lot of difficulties come from nowhere and small adjustments had to be done throughout the whole project.

Fabian

After having done some electronics projects in my spare time I was interested in doing the electronic parts. I have never done a project with the Arduino platform, so I have learned a lot during this semester. The communication between the Arduino and the Raspberry Pi was challenging but rewarding once it worked. The server side took not much time, since it was not the unique selling point and just a proof of concept, we chose a simple solution which I already knew how to do, but still fulfilled all the group's requirements.

Felix

Having had no practical experience in mechanics so far, but already a fair amount of knowledge in electronics, I wanted to do as much mechanics as possible. At the beginning I was part of the group doing the design of the mechanism, then I built most of the pre-prototype and tested it. For the second part of the project, I spend nearly all my time in the workshop, improving greatly my skills in the use of the various tools.

Harold

I initialy wanted to take the opportunity to help Fabian with the Electronics, but it turned out he did not need much help and was doing well on his own. Therefore I went back to mecanism team. Having done a similar product design course in my bachelor, I was able to evaluate the feasability (or lack there of) of some ideas we had along the way, and provide easy-to-implement substituation ideas when needed. For the protorype part, I spent most of my time assisting my colleagues in their endeavours, pre-marking pieces for holes, holding pieces in place.

Hugo

I didn't have any particular abilities in electronic design, in prototyping, in how to manage a team or in presentation. So, I learned a lot by doing a bit of everything, excepted electronic part. I did the small Midterm animation and some schematics to explain TTB mechanism. I participated for mechanical design part. I have done patents researches. I helped to build pre-prototype and prototype.

Lucas

As the electronic part was carried by Fabian, I mainly focused on the mechanical part of our TTB. At the beginning, I worked on the development of our mechanism. Then, I participated to the transition from technical drawing to the concrete application, in our workshop. We had to spend quite a lot of time to be able to present a working mechanism and approximately good looking. Finally, I also studied what could be our business plan.

6 Conclusion

The main conclusion that comes in mind of everyone of the group is the pre-prototyping that we did. By looking back, we think that we had the good reflex to analyze the weak and risky points of our system and test them in real life. Thanks to that, we had at the end a working prototype that implemented an interesting and innovative mechanism.

We are also really happy with the management of this project. We encountered a lot of problems : we had to change several times our idea. But at the end, due to numerous deadlines that we fixed every week, a scrupulous following of the plans and an amazing assistant that led us during the whole project, the final product that we presented was more than satisfying.

The team in general was also a strong point that enabled us to trust each other and work in a good atmosphere. Indeed, everyone knew what he had to do, for when and with whom ; we learned to work individually, but within a group with everyone and with its own strong skills.

A good exercise would be to ask ourselves what could we have done differently throughout this whole project. For the first part of the semester, we think that we had the good reflexes concerning the TTB. We analyzed well the problems and solved them. Of course, some of the deadlines were really though to deal with, but we always managed to hand in our reports in time. For the second part of the semester, we could have been more prepared for the assembling of the prototype. Unfortunately, no one really had any experiences in this field, and we tried to learn the most that we could while doing it.

Finally, we can proudly say that this trash bin was the highlight of this semester. From the beginning to the end, multiple obstacles came across our path, but we always managed to find a solution to overcome these problems. We would like to specially thank our assistant Arun who were always behind us to motivate and push us to our limits. Without him we would probably not have found the courage and strength to finish this amazing trash.

Figure 17 – Team Fire

Annexes

A Your initial project idea

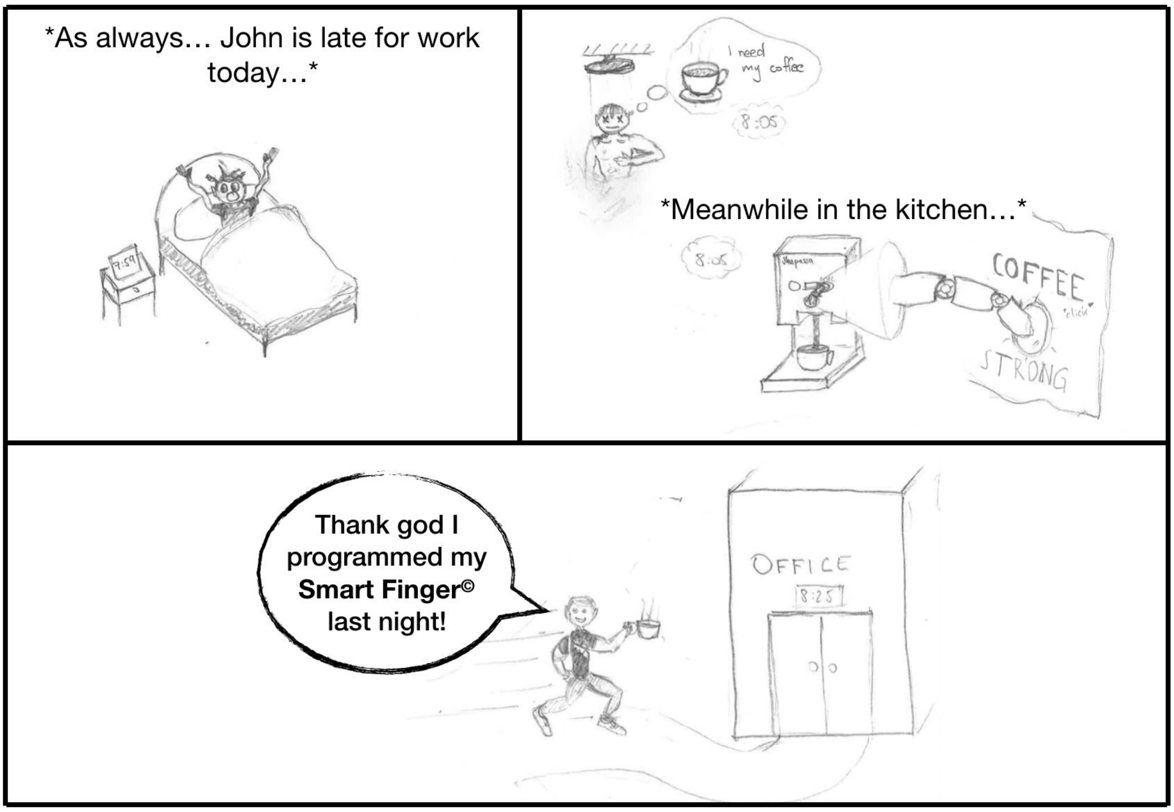
Description

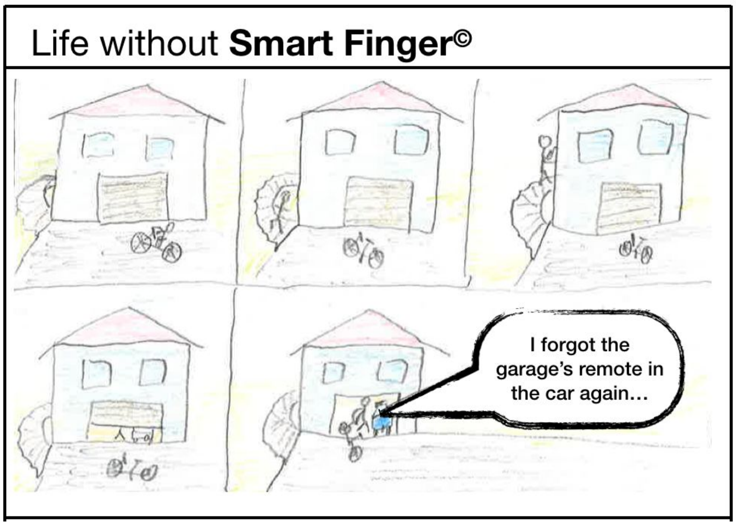
First, we observed two things : Students are hyperconnected and lazy. So, we imagined to combine both and we achieved our main concept, which would facilitate our day-to-day lives : **Smart Finger**
Smart Finger'll transform « dumb devices »in smart ones. Moreover, it's a removable and adaptive device, which can be fixed on divers analogical buttons. Our device is actuated via various ways (i.e. smartphone application, remote, and so on). Power supply'll assured by embedded electronic and battery.

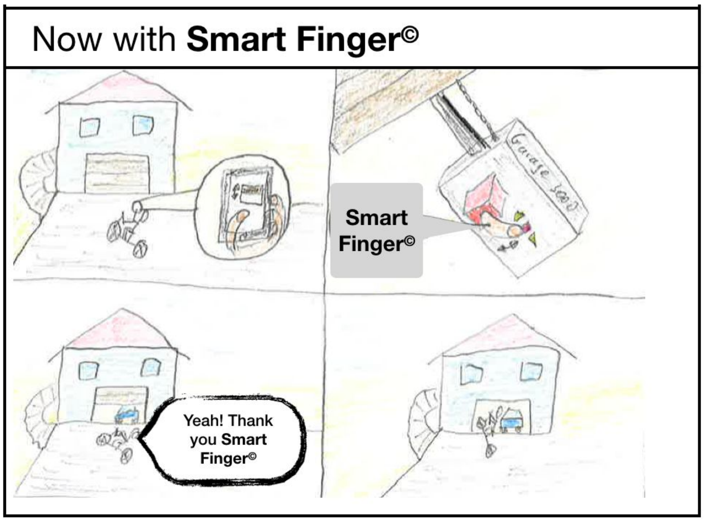
Project idea presentation

One device to rule them all

Lucas Burget, Hugo Grall Lucas, Harold Sussmilch, Felix Nilius, Fabian Schulz, Charles-Théophile Coen
TA: Arunkhrisnan Radakrishnan
Team FIRE (Team 4)


As always… John is late for work today…
I need my coffee
8:05
Meanwhile in the kitchen…
8:05
COFFEE
STRONG
Thank god I programmed my **Smart Finger©** last night!
OFFICE
8:25


Life without **Smart Finger©**
I forgot the garage's remote in the car again…


Now with **Smart Finger©**
Smart Finger©
Yeah! Thank you **Smart Finger©**

What is Smart Finger?

Home automation anywhere at the tip of a finger

Connecting your existing household items with a simple Add-on

Why this ?

OBJECTIVES

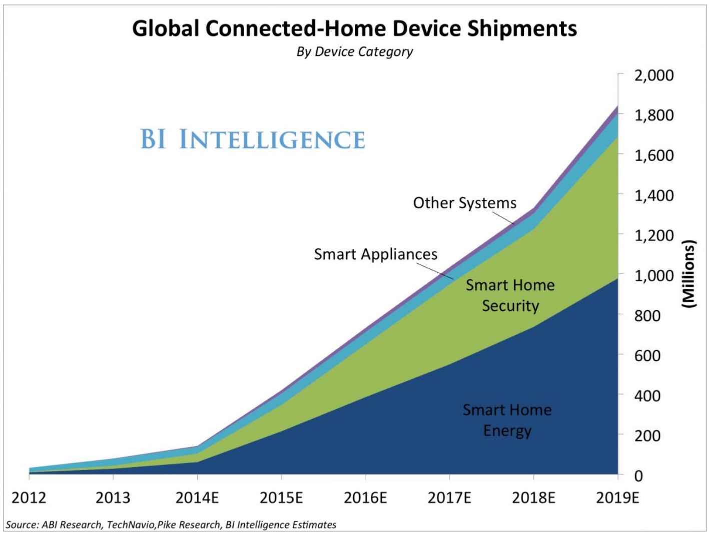
- Easy home automation
- Connect your favorite objects
- No engineering required
- Make your life easier
- Affordable solution

FUNCTIONS

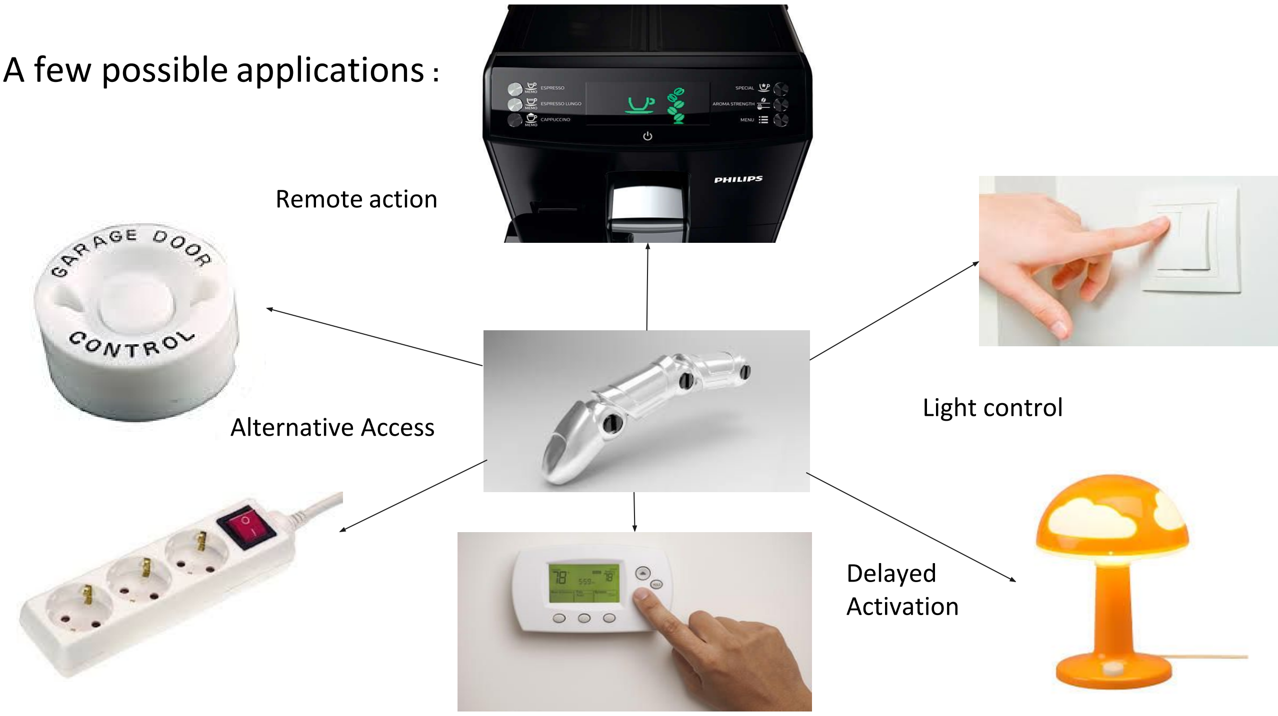
- Push a button
- Remote control
- Different objects compatibility
- Non-invasive system
- Keep a manual system to trigger the button

Why now ?

- Trend Internet of Things
- Economical & Ecological aspects (make your dumb devices smart)
- Lots of development tools for IoT
- Home automation is still expensive
- Most household devices are not connected



A few possible applications :



What are the challenges ?

- Mount on different surfaces (wall switch, coffee machine, etc…)
- Trigger different switches (push buttons, sliders, dimmers, etc...)
- Communication (mobile application, remote, voice, etc…)
- Power supply (battery, usb powered, charging method, etc…)

Why for us ?

- Prototype for the simple main function achievable in 10 weeks (trigger buttons)
- Lots of implementation possibilities (linear actuator, membrane, motors, etc…)
- Multiple separable subtasks (communication, fixation, actuator)
- Merging the different parts (tradeoff fixation/actuator, power supply/communication)
- Feasible with existing hardware and IoT development tools
- Within the budget (no specific machining required)

Why for microengineering ?

Multidisciplinary :

- Mechanics (actuators, fixation)
- Electronics (hardware control, communication)
- Programmation (software control , mobile application)
- Miniaturization
- Energy
- Material
- Design

How to implement ?

- Actuators
- Energy supply
- Controller and electronics
- Fabrication (3D-machining) and assembly
- Communication system
- Fixation system

How to evaluate ?

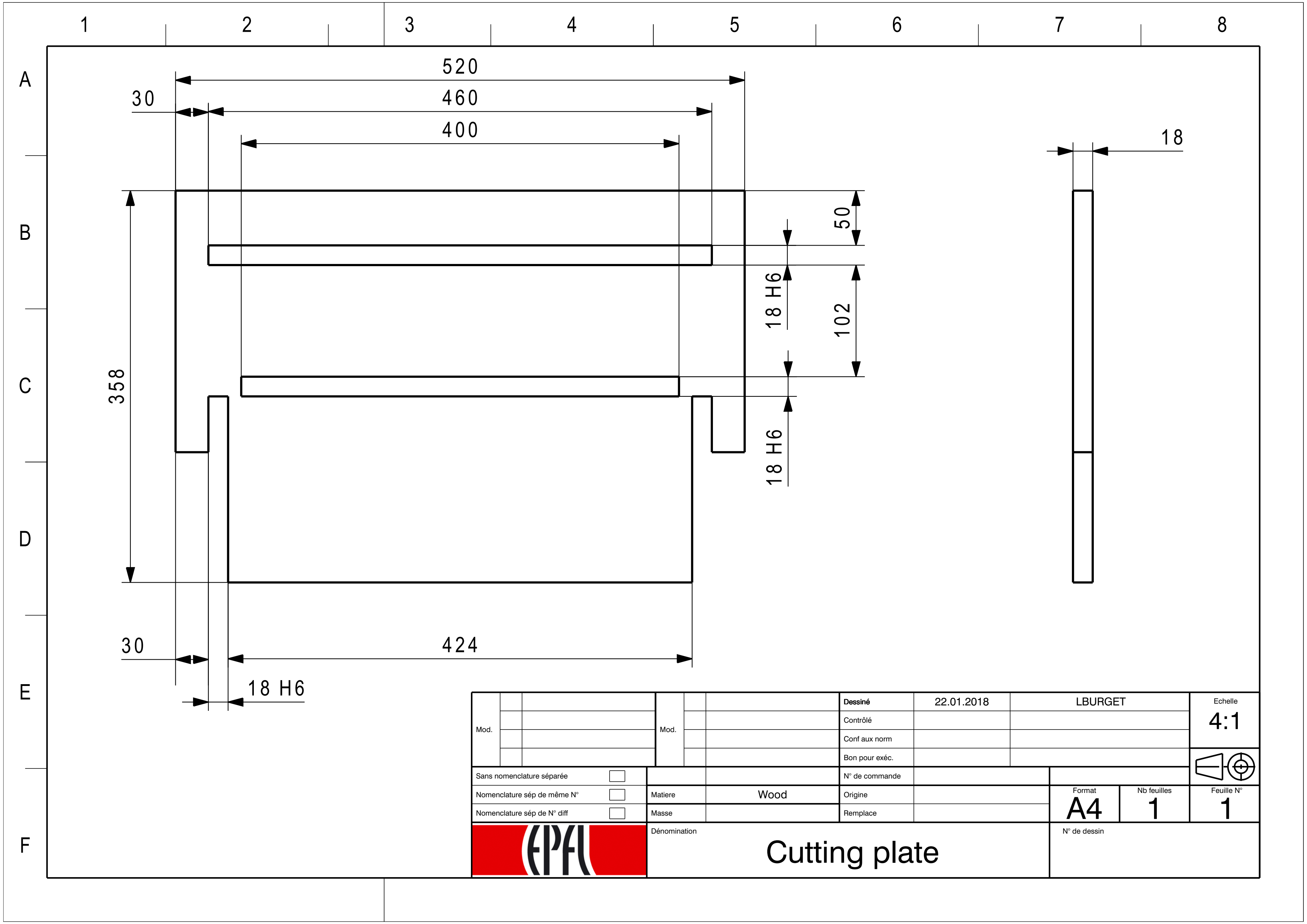
Assessment:

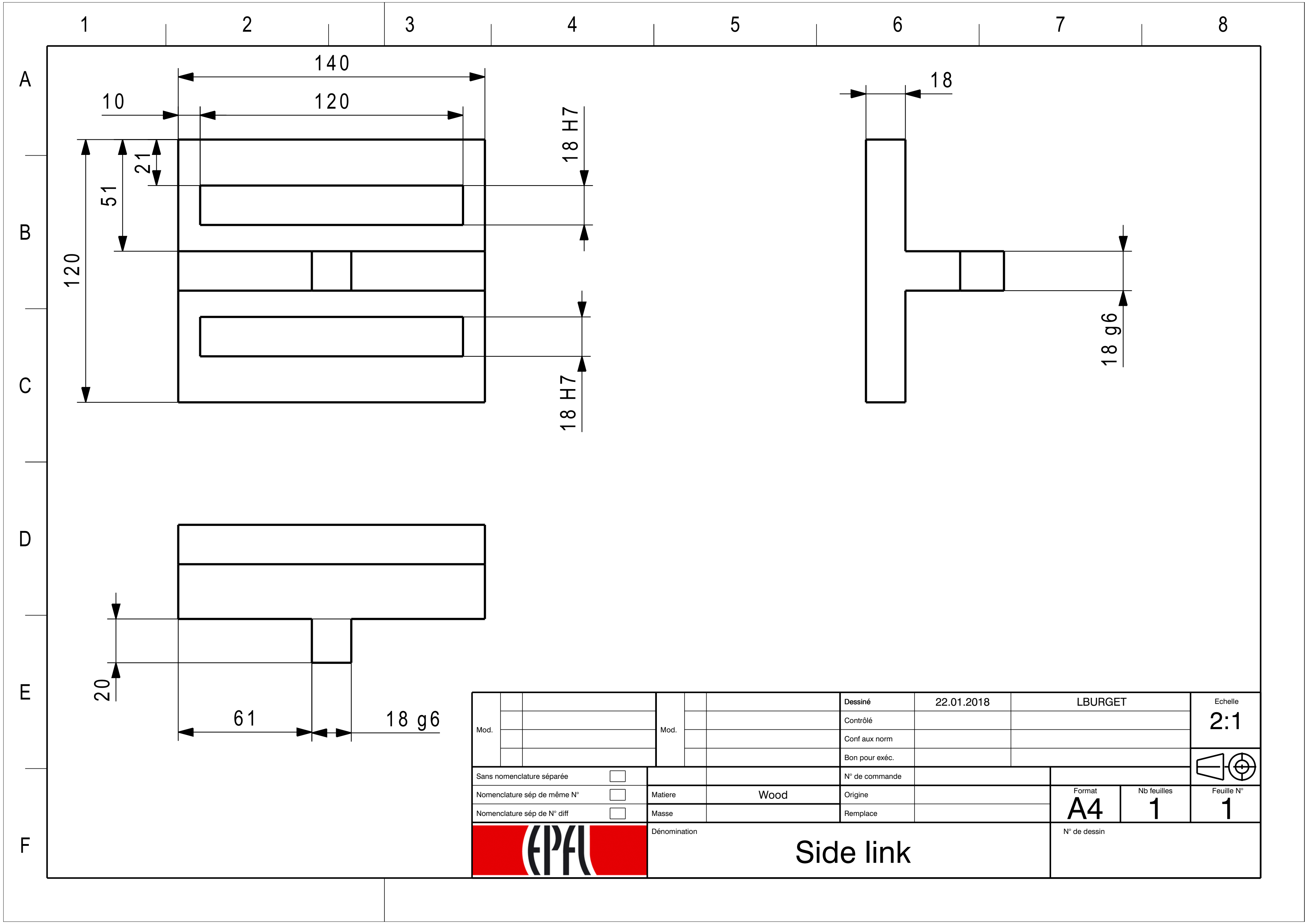
- Accomplishes main task
- Adaptability (possibility to use it with various switches)
- Simplicity of use
- Maximal range of utilization
- Quality of power management (user-friendly)

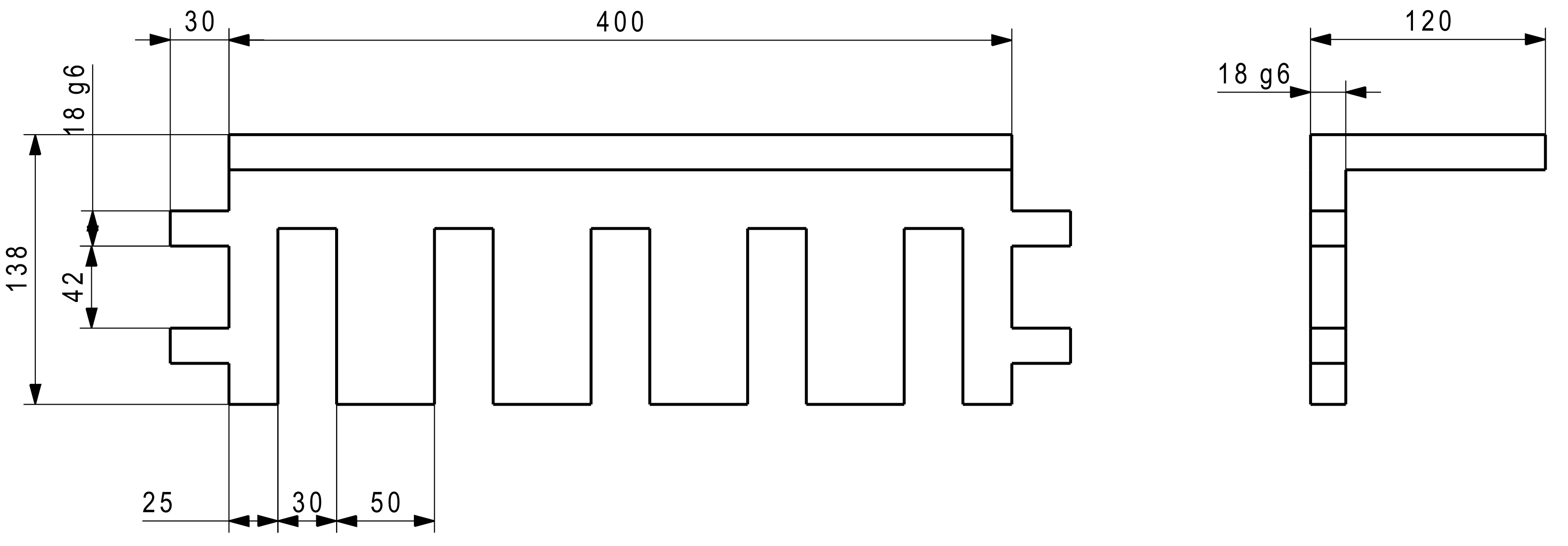
Demonstration :

- Test on various switches in the classroom
- Test on « small » devices (ex : coffee machine)

B Technical drawings




140
10
120
120
51
21
18 H7
18 H7
18
18 g6
20
61
18 g6
Mod.
Mod.
Dessiné
22.01.2018
LBURGET
Contrôlé
Conf aux norm
Bon pour exéc.
Echelle
2:1
Sans nomenclature séparée
Nomenclature sép de même N°
Nomenclature sép de N° diff
Matiere
Wood
Masse
N° de commande
Origine
Remplace
Format
A4
Nb feuilles
1
Feuille N°
1
Dénomination
Side link
N° de dessin

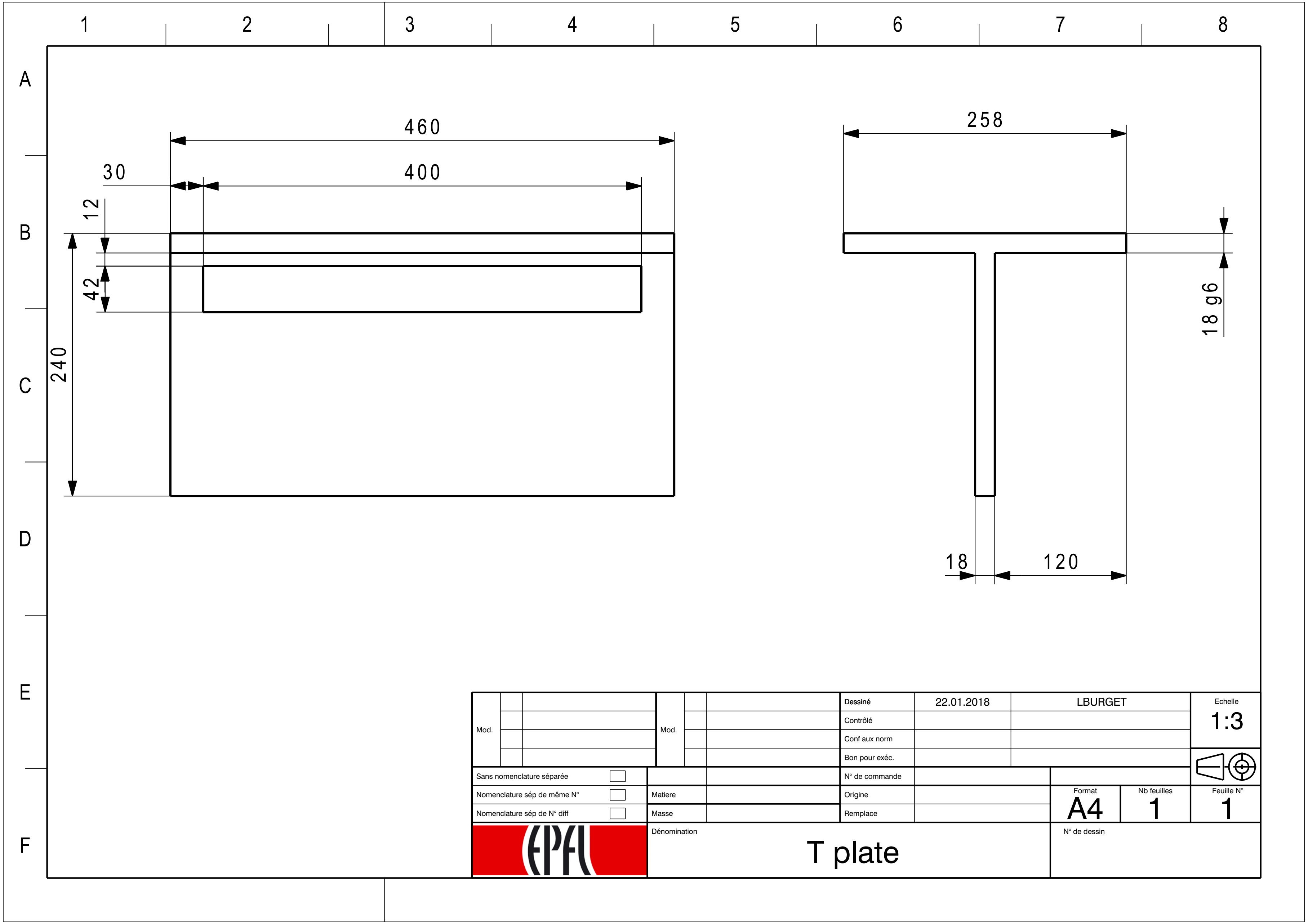


Dessiné	22.01.2018	LBURGET	Echelle 3:1
Contrôlé			
Conf aux norm			
Bon pour exéc.			
N° de commande			
Origine			
Remplace			

Mod.	
Sans nomenclature séparée	
Nomenclature sép de même N°	
Nomenclature sép de N° diff	
Matiere	Wood
Masse	
Format	A4
Nb feuilles	1
Feuille N°	1
N° de dessin	

Dénomination

Moving plate


460
30
400
12
42
240
258
18 g6
18
120
Mod.
Mod.
Dessiné
22.01.2018
LBURGET
Contrôlé
Conf aux norm
Bon pour exéc.
Echelle
1:3
Sans nomenclature séparée
Nomenclature sép de même N°
Nomenclature sép de N° diff
Matiere
Masse
N° de commande
Origine
Remplace
Format
A4
Nb feuilles
1
Feuille N°
1
Dénomination
T plate
N° de dessin

C Circuit diagrams

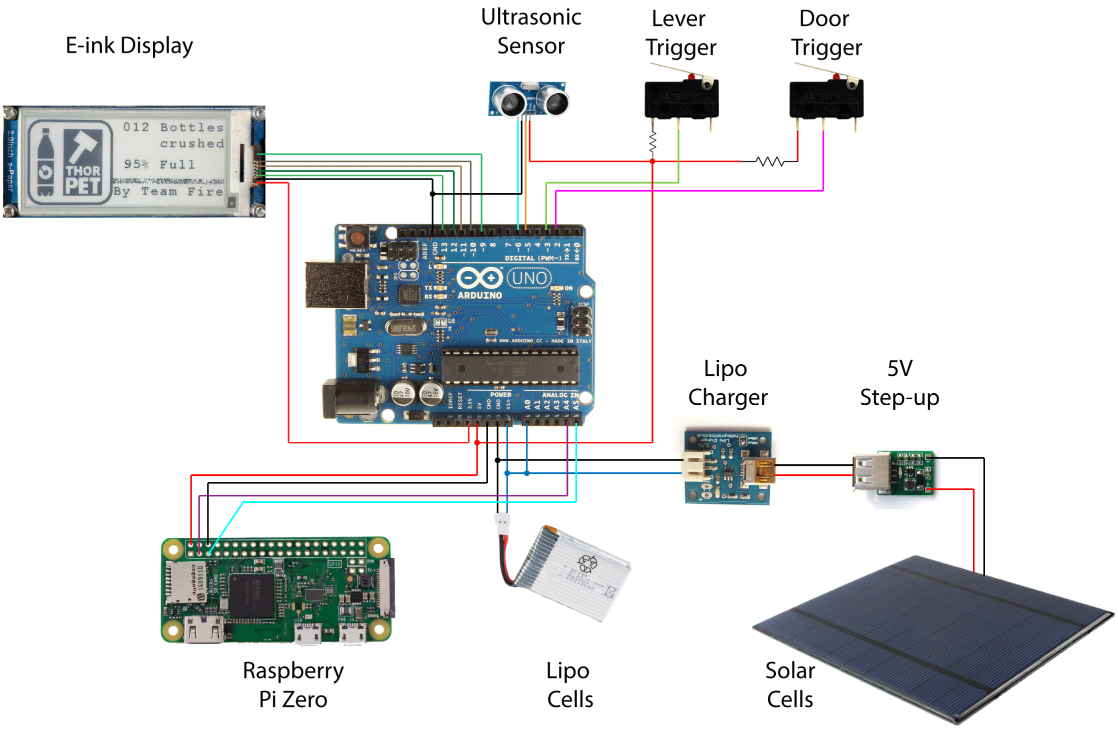


Figure 18 – Electric Circuit Diagram

D Others

D.1 Work breakdown structure

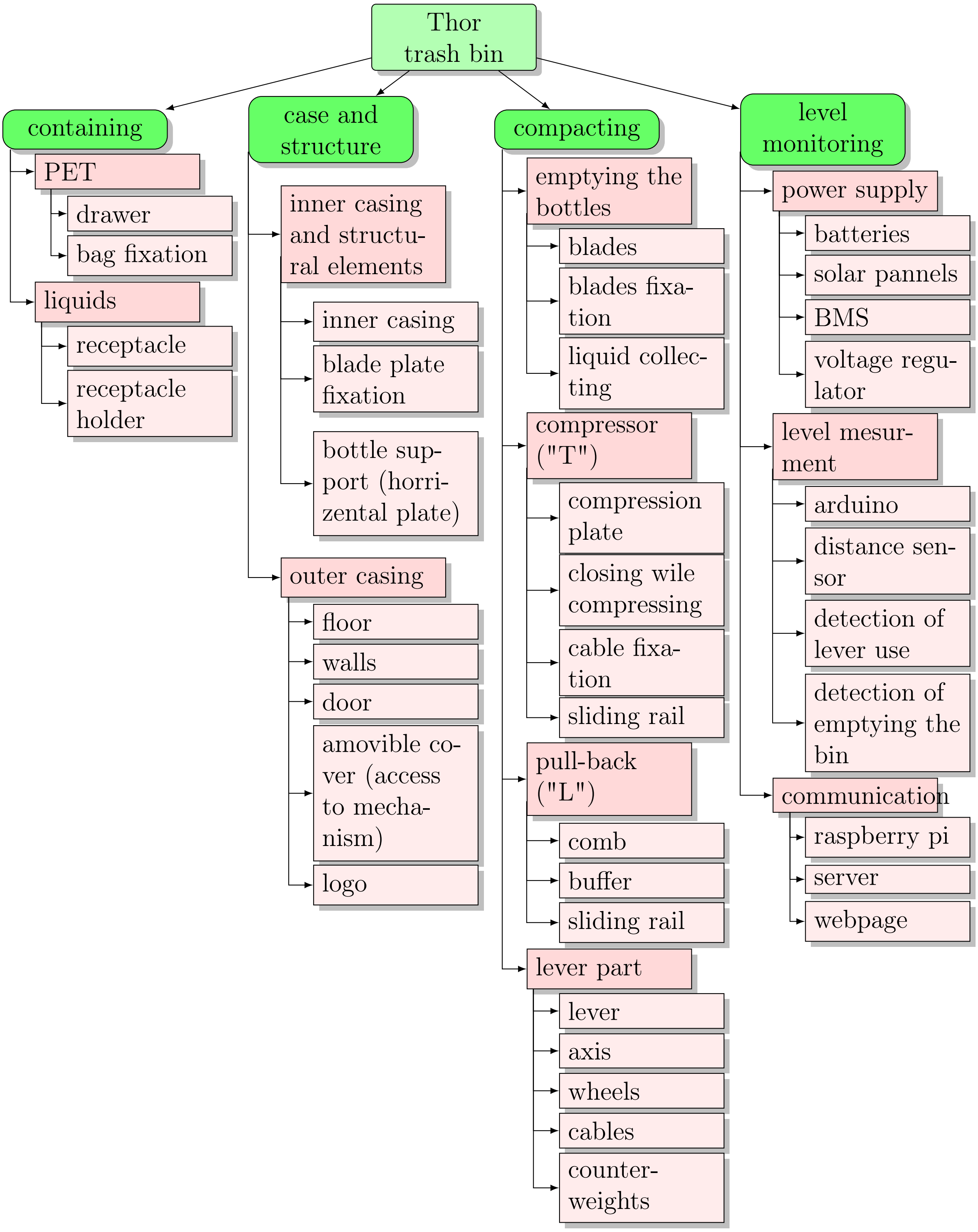


FIGURE 19 – WBS of the final Thor Trash Bin

D.2 Stakeholder analysis

	Stakeholders	Power Level	Expectations	Influence	Strategy
Internal	Project sponsors ; Yves Bellouard and Edoardo Charbon	5	— high quality final product — requirements reached — precise schedule	Project sponsors and teachers	— weekly feedback — clear and specific progress report
	TA ; Arunkhrisnan Radakrishnan	4	— high quality final product — good communication with the PM and the team	Advisor	— direct contact 24/7 — feedback after every team meetings
	Project manager	4	— high quality final product — good communication with the technical team — precise schedule	Lead the team	— day-to-day updates — direct communications with the technical team — open to extra hours depending on the workload
	Technical team	3	— high quality final product — good communication — precise schedule	Provide specific analyses and informations	— direct communications with the PM — update and adaptation of the personal calendar after each meetings — open to extra hours depending on the workload
External	EPFL	4	— high quality final product — good communication with the technical team — precise schedule	Lead the team	— day-to-day updates — direct communications with the technical team — open to extra hours depending on the workload
	Cleaners	4	— easy to clean — easy to operate	Operate the product	— meeting with the head of the waste management — analyze of the current market
	Competitors	2	— respect their product's identity	Operate the product	— meeting with the head of the waste management — analyze of the current market
	Suppliers	2	— easy manufacturing — precise schematics — precise and manageable deadline — paid on time	Provide resources	— respect of the ISO norms — talk with the suppliers and introduction of the product — plan ahead for the manufacturing — decide on appropriate manufacture methods — efficient payment strategy
	Users	1	— intuitive — at least as good as other trashes — time efficient	Use the product	— stick to the stakeholders analysis — test of the prototype with random people

TABLE 1 – Stakeholders analysis for the Smart Thor Bin

D.3 Initial Gantt chart

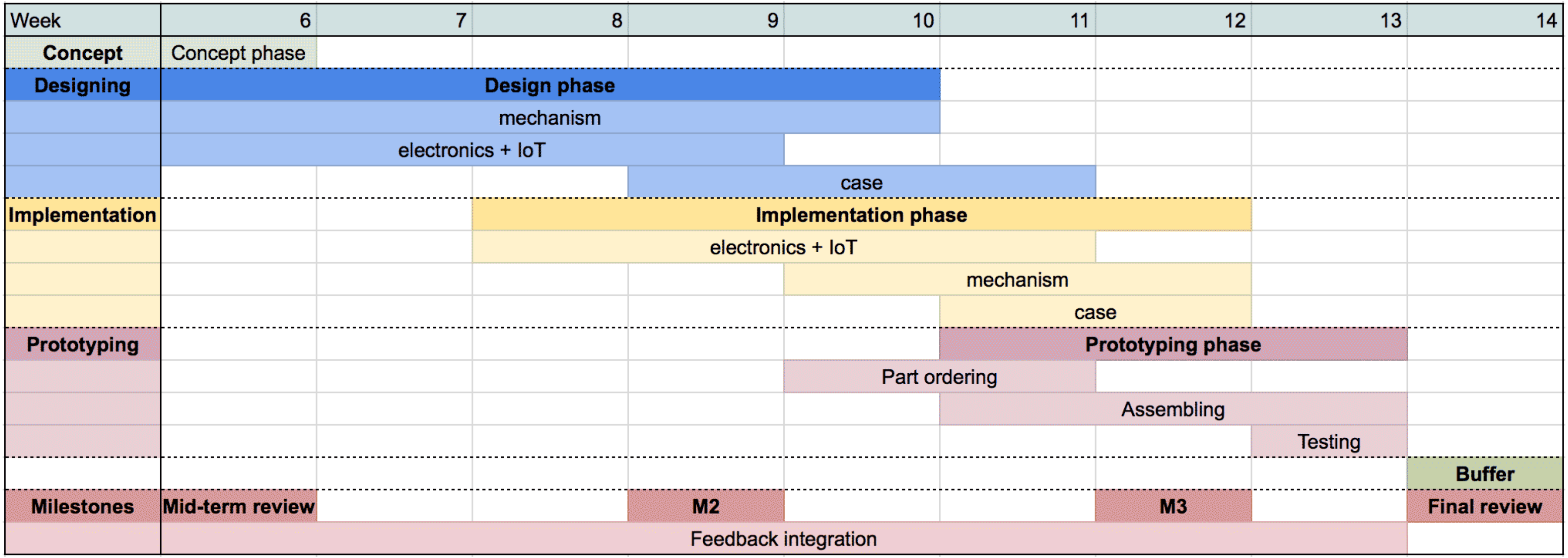


FIGURE 20 – Initial Planing as presented at Midterm Presentation

D.4 ANSYS

ANSYS code for the simulation :

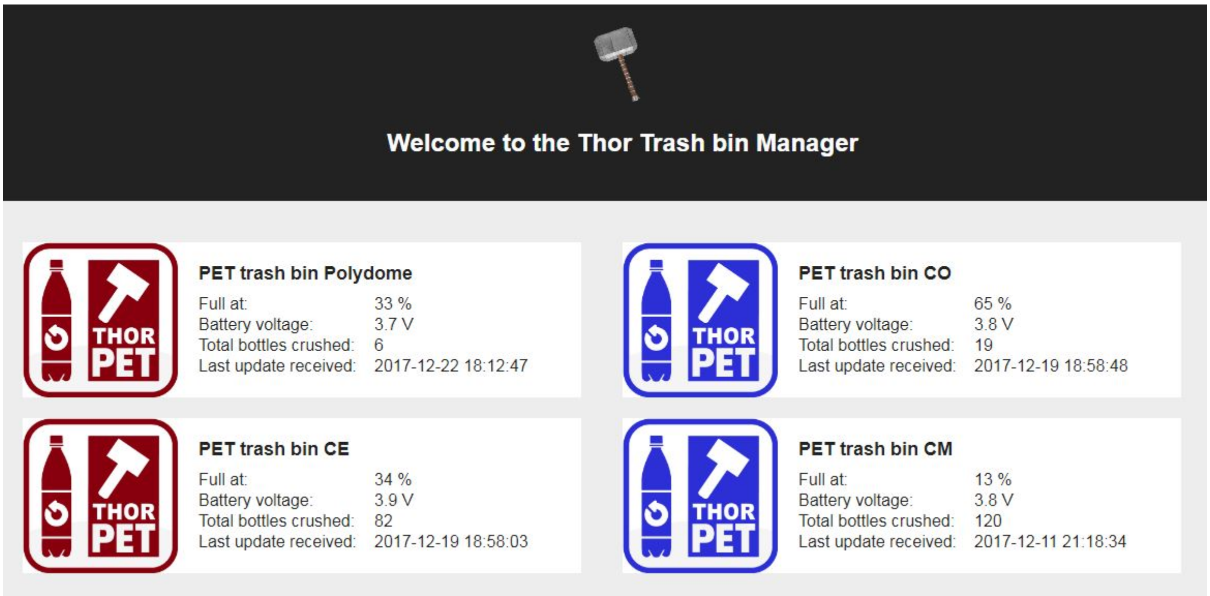
```
FINISH
/CLEAR

/TITLE, 1 layers 2D model, view on top


/COM
********************************************************************
***
/COM ****  Model Parameters
****
/COM
********************************************************************
***


h_holes = 100e-3
w_begi = 82e-3
w_holes = 20e-3
w_teeth = 40e-3
number_holes = 5

w_total = 425e-3
h_total = 120e-3

prof = 18e-3

Y_wood = 1e9                         ! Young's modulus for Isotropic
Material Model (simplifcation)
ro_wood = 600
nu = 0.35                            ! Poisson coefficient


/COM
********************************************************************
***
/COM **********************   PREPROCESSOR
******************************
/COM
********************************************************************
***


/PREP7


/COM
********************************************************************
***
/COM ****  Element and materials
****
/COM
********************************************************************
***
```

```
ET,1,SOLID186                    ! Set the element

MP, EX, 1, Y_wood                ! Young's modulus of the SMP
MP, NUXY, 1, nu                  ! Poisson Coefficient
MP, DENS, 1, ro_wood             ! Density


/COM
********************************************************************
***
/COM ****  Geometry
        ****
/COM
********************************************************************
***


K,01,0,h_total,0
K,02,0,0,0
K,03,w_begi,0,0
K,04,w_begi,h_holes,0
K,05,w_begi+w_holes,h_holes,0
K,06,w_begi+w_holes,0,0
K,07,w_begi+w_holes+w_teeth,0,0
K,08,w_begi+w_holes+w_teeth,h_holes,0
K,09,w_begi+2*w_holes+w_teeth,h_holes,0
K,10,w_begi+2*w_holes+w_teeth,0,0
K,11,w_begi+2*w_holes+2*w_teeth,0,0
K,12,w_begi+2*w_holes+2*w_teeth,h_holes,0
K,13,w_begi+3*w_holes+2*w_teeth,h_holes,0
K,14,w_begi+3*w_holes+2*w_teeth,0,0
K,15,w_begi+3*w_holes+3*w_teeth,0,0
K,16,w_begi+3*w_holes+3*w_teeth,h_holes,0
K,17,w_begi+4*w_holes+3*w_teeth,h_holes,0
K,18,w_begi+4*w_holes+3*w_teeth,0,0
K,19,w_begi+4*w_holes+4*w_teeth,0,0
K,20,w_begi+4*w_holes+4*w_teeth,h_holes,0
K,21,w_begi+5*w_holes+4*w_teeth,h_holes,0
K,22,w_begi+5*w_holes+4*w_teeth,0,0
K,23,2*w_begi+5*w_holes+4*w_teeth,0,0
K,24,2*w_begi+5*w_holes+4*w_teeth,h_total,0

FLST,2,24,3
FITEM,2,1
FITEM,2,2
FITEM,2,3
FITEM,2,4
FITEM,2,5
FITEM,2,6
FITEM,2,7
FITEM,2,8
FITEM,2,9
```

```
FITEM,2,10
FITEM,2,11
FITEM,2,12
FITEM,2,13
FITEM,2,14
FITEM,2,15
FITEM,2,16
FITEM,2,17
FITEM,2,18
FITEM,2,19
FITEM,2,20
FITEM,2,21
FITEM,2,22
FITEM,2,23
FITEM,2,24
A,P51X

VOFFST, 1, prof

/COM
*******************************************************************
***
/COM ****  Meshing
        ****
/COM
*******************************************************************
***


MSHAPE,1,3D
MSHKEY,0

ESIZE, prof/3
VMESH, all


/COM
*******************************************************************
***
/COM ****  Loads & Boundary conditions
        ****
/COM
*******************************************************************
***


ASEL, S, LOC, X, -1e-9, 18e-3
DA,ALL,ALL, 0

ASEL, S, LOC, X, 2*w_begi+5*w_holes+4*w_teeth - 18e-3,
2*w_begi+5*w_holes+4*w_teeth
DA,ALL,ALL, 0

NSEL, S, LOC, Y, 0, 70e-3
```

```
NSEL, R, LOC, X, 212e-3 - 150e-3, 212e-3 + 150e-3
SF,ALL,PRES,7.3846e03            ! Definition of the pressure on
the area
!D,ALL,ALL,0

ALLSEL, ALL, ALL

ALLSEL,ALL
SBCTRAN

FINISH


/COM
*********************************************************************
***
/COM **********************       SOLVER
******************************
/COM
*********************************************************************
***


/SOL


ANTYPE,0                 ! Static analysis
NLGEOM,1                 ! Enable the large deflection mode (VERY
IMPORTANT)
SOLVE


FINISH


/COM
*********************************************************************
***
/COM **********************       RESULTS
******************************
/COM
*********************************************************************
***


/POST1


/DSCALE,ALL,1.0          ! Scales DOF constraint values
/CONTOUR,ALL,128 ! Specifies contour values on stress display



FINISH                   ! Exits the postprocessor
```

D.5 Thor Trash Bin's website



Website's link : `https://thor.fabianschulz.ch`

D.6 Thor Trash Bin's Logo

E Append here the exercise from two lectures introducing the topic of "Production Engineering"

E.1 Summary of the two exercises

These two exercises, or workflows, that what add to work with helped us understand what are the important parameters when working with the modeling of manufacturing systems.

In the first exercise, we used the theory learned in class to model the conception of a small gadget. Each machine has specific characteristics : a production rate, a failure rate and a repair rate. Thanks to this exercise, we had the chance to familiarize with these concepts. We also learned how to apply the aggregation method to transform a complex ensemble of machines into one single machine with the same characteristics. Finally, we saw the impact of having a buffer and how its location impact the system.

During the second exercise, we used the software *AnyLogic* and try to implement a given assembly line. By having 3 buffers and a total buffer space of 10, we had to maximize the throughput of the chain.

E.2 Exercise 1

For this problem, we first had to use the aggregation method in order to simplify the two systems we had. You can see the starting system for exercise 1a) in figure 21. Each machines, $M1, M2, M3$ and $M4$ have a production rate $U = 8000 pce/min$, a rate of breakdown $p = 0.001 sec^{-1}$ and a rate of repair $r = 0.005 sec^{-1}$. We also know that the buffer $B23$ has a space of $3h$. We are asked to obtain its mean production rate as a function of h.

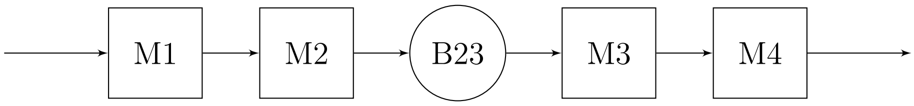


FIGURE 21 – System a

We know from the theory that a good approach is to join the machines with the smallest buffers first, *i.e.* machines $M1$ and $M2$ together and $M3$ and $M4$. For both subsystems, we have the indisposability, I, equal for the machines : $I_1 = I_2$ and $I_3 = I_4$. We can therefore use the formula :

$$I_{12,dip}(h) = I_{34,dip}(h) = I_1\left(1 + \frac{1}{1 + \frac{\alpha}{\alpha+1} F(1 + I_1)}\right) \tag{1}$$

$$F(h) = \frac{r_1 h}{U} \tag{2}$$

In our case, there are no buffer between $M1$,$M2$ and $M3$,$M4$ therefore $h = 0$ in equation 2 and we get $I_{dip}(0) = 2I_1$ from equation 1. The simplified new system can be seen on figure 22.

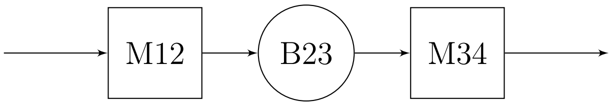


FIGURE 22 – System a'

The new machines $M12$ and $M34$ have an indisposability $I_{12} = I_{34} = 2I_1$ meaning that $\alpha_{12} = \alpha_{34} = 2$. For the next step, as $I_{12} = I_{34}$, we can use the same equations, 1 and 2, as we used before. We get :

$$I_{a,1234,disp}(h) = 2I_1(1 + \frac{1}{1 + \frac{\alpha_{12}}{\alpha_{12}+1}F(1 + 2I_1)}) \tag{3}$$

$$F(h) = \frac{r_1 3h}{U} \tag{4}$$

For equation 7, the buffer is equal to $3h$, hence the definition of F. We know have a system to get the mean production rate, MPR, of the whole system. We can easily have it by using the formula :

$$MPR_a(h) = \frac{U}{1 + I_{a,1234,disp}(h)} \tag{5}$$

Now that we finished with the system a, let's see what can be done for the system b, figure 23. As $B12$, $B23$ and $B34$ have the same size, equal to h, there are no right order to start. We decided to first regroup $M1$ and $M2$ and also the machines $M3$ and $M4$.

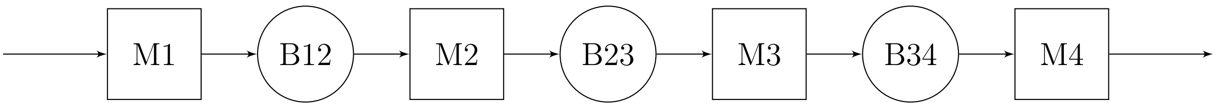


FIGURE 23 – System b

When grouping the machines, we see that $I_1 = I_2$ and $I_3 = I_4$; we can therefore use the equations 1 and 2. This time, the $h \neq 0$ for equation 2, and thus the F is not null. The new system is represented in figure 24. We have $I_{12} = I_{34} = I_1(1 + \frac{1}{1+\frac{\alpha_1}{\alpha_1+1}F(1+I_1)})$ with $\alpha_1 = 1$.

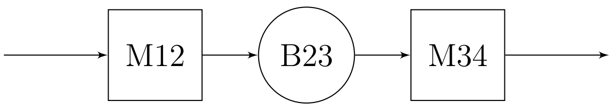


FIGURE 24 – System b'

The last step consists of grouping the $M12$ and $M34$. As $I_{12} = I_{34}$, and the $\alpha_{12} = \frac{I_{12}}{I_1} = (1 + \frac{1}{1+\frac{\alpha_1}{\alpha_1+1}F(1+I_1)})$, we can calculate it :

$$I_{b,1234,disp}(h) = I_{12}(1 + \frac{1}{1 + \frac{\alpha_{12}}{\alpha_{12}+1}F(1 + I_{12})}) \tag{6}$$

$$F(h) = \frac{r_1 h}{U} \tag{7}$$

and the mean production rate is equal to :

$$MPR_b(h) = \frac{U}{1 + I_{b,1234,disp}(h)} \quad (8)$$

On figure 25, we created a plot with the two mean production rate, described by equation 5 and 8. An interesting aspect is that, depending on the size of the buffer, one option is better than the other. In example a, we have one big buffer of $3h$ in the middle of the production line. In example b, we have three small buffer of h which are placed between the machines. What we can see is that if $h < 3$, the better option is to use one big buffer, see the blue line on the graph. On the other hand, if our size of buff $h > 3$, the best option to get a higher MPR is to choose the three smaller buffer.

It is really interesting to see that depending of the size of the buffer we have, the best option changes. This kind of result is highly important if someone wants to create an effective production line and optimize it in his factory.

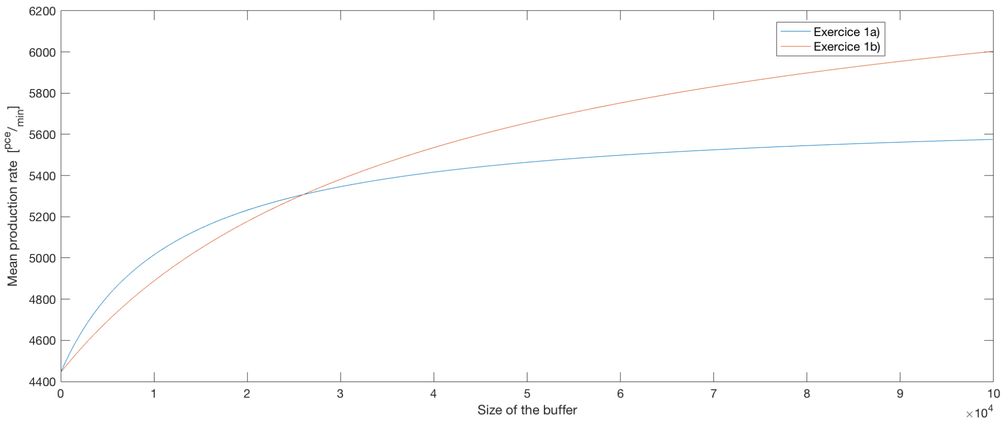


FIGURE 25 – Mean Production Rate of the two subsystems

E.3 Exercise 2

In this exercise, we had to recreate in *AnyLogic* a production line that was given to us. On figure 26, you can see the line implemented on the software. We first had to implement the distribution of each machines :

- $M1 : exponential(0.25)$
- $M2 : 2 + 8 \cdot bernoulli(0.25)$
- $M3 : exponential(0.25)$
- $M4 : uniform(3, 5)$

Next, we had at disposition a total buffer size of 10 that we had to distribute between $B12$, $B23$ and $B34$. First of all, we need to analyze the production line before simulate it and spot where the bottleneck in the circuit would be.
As $M3$ is going to receive product from $M1$ and $M2$, we can imagine that an accumulation can be possible at the start of $M3$. Thus, it would be interesting to have big buffers in front of this machine in order to avoid any slowdown in the production line.
Nevertheless, having no buffer between $M3$ and $M4$ is dangerous in case the machine 4 breaks down ; indeed, it would lead to a complete stop of production.

By bearing these two assumptions, we tested different repartition of the total buffer size. In order to have a meaningful parameter to compare between the different systems, we decided to compare the throughput of each one, *i.e.* one many pieces were created by unit of time.

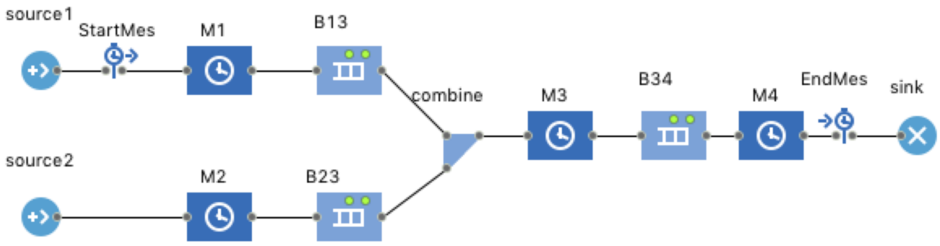


FIGURE 26 – *AnyLogic* model

After having tried different distribution of the buffer, we saw that the two previous assumptions were correct. Indeed, when using a configuration $B12 = 5, B23 = 5, B34 = 0$, we got a productivity of 0.1853. It was the lowest value we could simulate. It shows us that a buffer is needed between the machine $M3$ and $M4$. The second assumption was concerning which buffers were the most important. We tried two different simulation : one with $B12 = 2, B23 = 2, B34 = 6$ and the other with $B12 = 5, B23 = 3, B34 = 2$. For the simulation S_{226}, we got a productivity of 0.194, and for S_{532}, a productivity of 0.2041. We can now conclude that bigger buffers are needed before $M3$. But what is the best size for $B34$? By computing different combination, we came to the conclusion that a size of 3 for $B34$ was the best. The last step was to distribute the 7 size remaining.

We tried to find the best combination and obtained the best throughput with this distribution :

- $B12 = 3$
- $B23 = 4$
- $B34 = 3$

It gave us a productivity of 0.2056. One thing to take into account is the other results that were very close to this one. We conclude that this model was a good first approximation, but could not be 100% reliable if we want to implement it. We usually took large sample of time, minimum of $20000 sec$, but it is still not an assurance that we can trust this combination.

Références

[1] 1020130118522 COMPRESSOR FOR A RECYCLED PRODUCT, CAPABLE OF COLLECTING AN OBJECT BY ENABLING THE OBJECT TO FALL FREE WHEN COMPRESSION IS COMPLETED, . URL https://patentscope.wipo.int/search/en/detail.jsf?docId=KR95744698.

[2] 20110283899 Bottle compactor, . URL https://patentscope.wipo.int/search/en/detail.jsf?docId=US73409924&recNum=3&maxRec=627&office=&prevFilter=&sortOption=Relevance&queryString=EN_ALLTXT%3A%28manual+compactor+plastic+bottle%29&tab=NationalBiblio.

[3] 2853059 Domestic waste container filling rate indicating device, has electronic processing card calculating distance between container top and upper level of waste, and illuminating green lamp if container is forty percent filled, . URL https://patentscope.wipo.int/search/en/detail.jsf?docId=FR186314883&recNum=1&maxRec=&office=&prevFilter=&sortOption=&queryString=&tab=NationalBiblio.

[4] Igora_aluminium_can_crusher.jpg, . URL https://www.frontwork.ch/wp-content/uploads/2017/03/Alu_Dosenpressen_IGORA_02.jpg.

[5] Model_2500_recycling_bin_with_crusher.jpg, . URL http://plasticbottlecrusher.com/wp-content/uploads/2017/05/2500-01-white-front-e1504252972902.jpg.

[6] SmartBelly_for_waste_and_recycling.png, . URL https://info.waxie.com/hs-fs/hub/43298/file-14077758-png/images/bigbelly-recycle-set.png.

[7] Amir Pundak, Or Henkin, and Didi Linn. Plastic-Bottle Compactor. URL https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2013111135&redirectedID=true.