Climbing Lego© Robot

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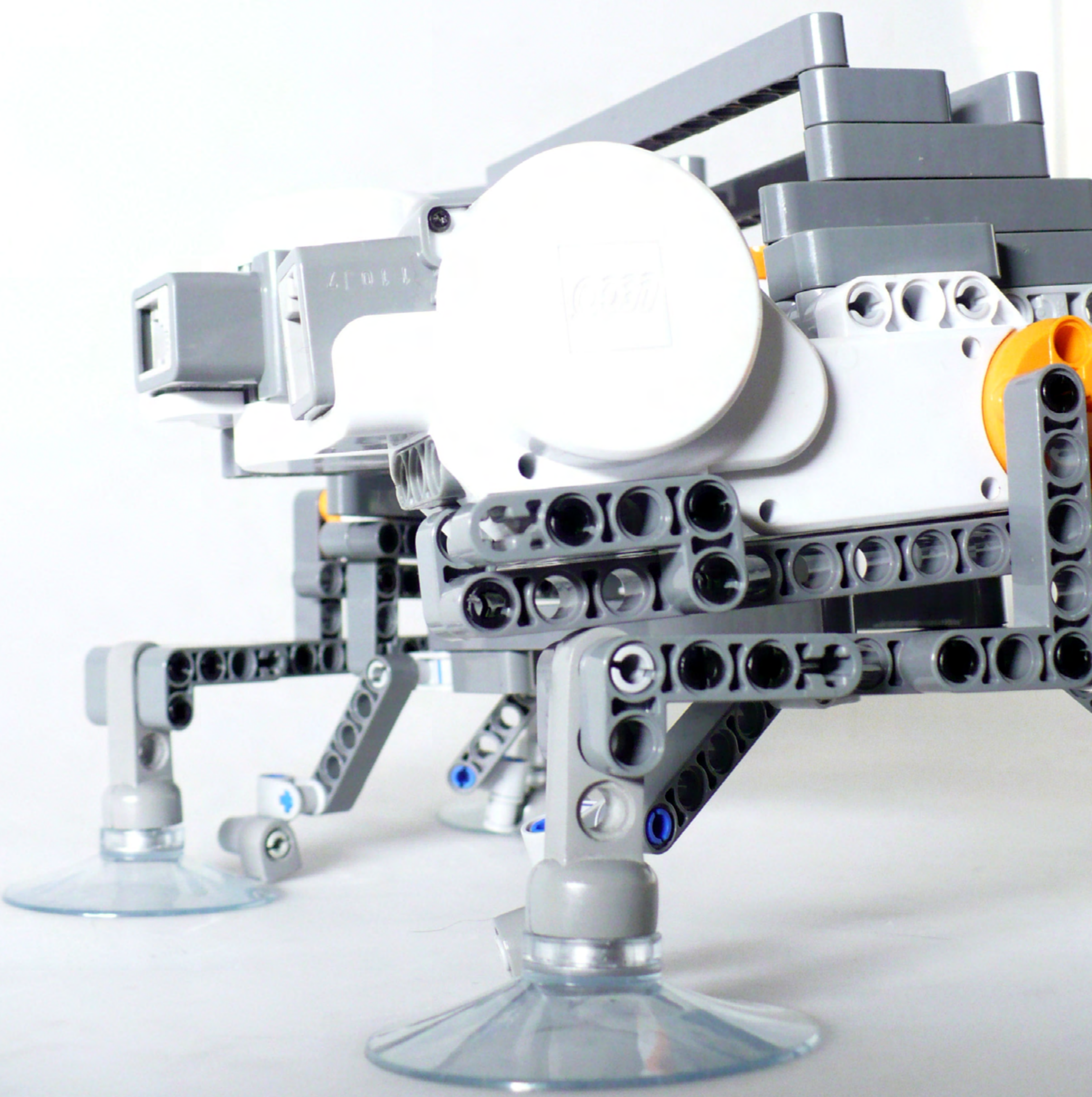

TU/e Industrial Design - Techno Master Class, autumn 2009

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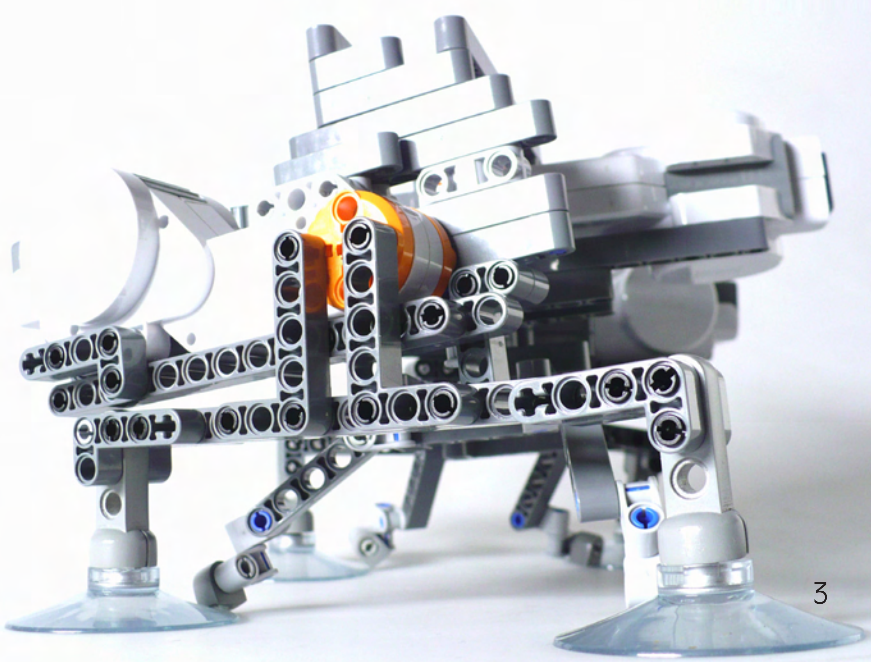


Exploration of theory

During the master class several topics passed by that were explored through practical implementation. These implementations originated from challenges that we gave ourselves or challenges that were given.

Mechanics

The challenge that related to the classes on mechanics was to develop a servo motor. Issues like transmission, construction and mechanical constraints clearly passed by. It was interesting to take the principle of the servo motor and translate this to a concept that was mechanically clever; reducing the arm of the force by placing the motor on the outside instead of the inside of the construction and controlling the transmission by the ratio of radii.

Figure 1. Reversed servo motor

Sensors

Another challenge was to create a robot that could play jeux-de-boule. This robot had to sense the target, calculate its place and perform the corresponding throwing action. This gave an insight in the abilities of the Lego NXT sensors and showed how inaccuracy and resolution are big problems in robotics.

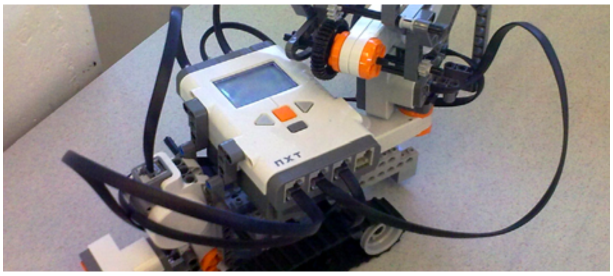


Figure 2. Jeux-de-boule robot

To have practice with the theory about dealing with sensor input (probabilistic robotics) a 'sneaky bot' was developed. This robot measured the surrounding sound level and compared this with its own noise. If the robot found the surrounding sound to be louder the robot would start driving, keeping its own noise below the surrounding sound level. To deal with the uncertainty of the sensors simple filtering methods were implemented.

Figure 3. Sneaky robot

Q-learning

Regarding the q-learning theory we played a challenge of making a robot to learn hitting a ball like a baseball player. A simple learning algorithm was implemented to teach the robot performing the hitting action, in order to hit the ball correctly. It didn't involve a true q-learning system because the assessment of the result of every action was done manually, not by the system itself. Varying the explorative ratio and the speed of learning clearly showed different levels of behavior.

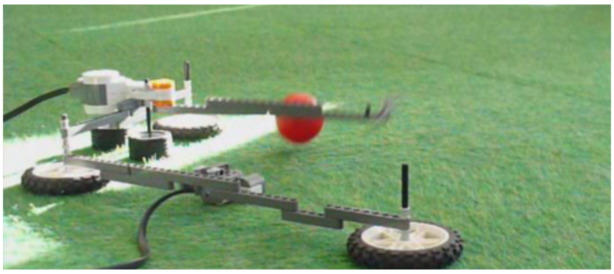


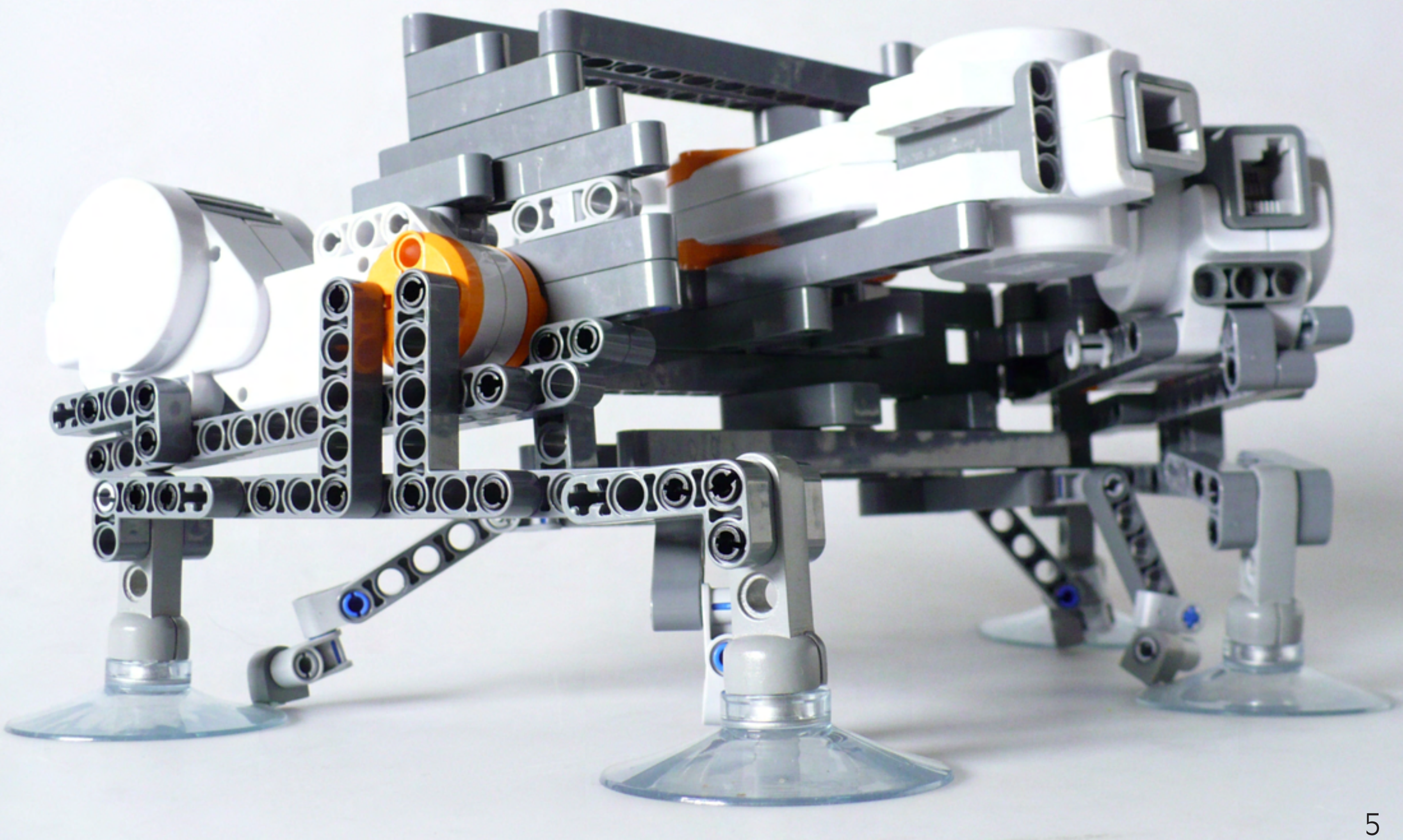
Figure 4. Learning baseball robot

Introduction

The main assignment for this class was to develop a new Lego© NXT sensor or actuator. Developing a robot that could climb seemed an interesting challenge to me and isn't much done with Lego©.

Climbing robots are developed for many reasons. They drive across buildings to spy on people or just to clean the windows. Many different kinds of technologies are available to get a robot climbing. The most famous example is the 'Stickybot' from Stanford University using microfiber synthetic material to achieve adhesion. This method was derived from mimicking the way a gecko climbs.

For this project the goal was to develop a robot that can climb windows and develop a Lego© actuator that supports this. Several methods of climbing were investigated and mechanical structures were developed to achieve the right motion. This resulted into two proof-of-principle structures that show the mechanics, but also the boundaries of Lego© and a list of improvements that are needed in order to make a Lego© robot, using passive suction cups climb.



Climbing concept

Several different ways of making a robot climb were investigated and assessed in terms of its suitability for Lego©. Many robotics departments at universities all over the world are working on different climbing methods. Several methods are described and evaluated in this chapter.

Magnetism

In one of my previous projects I developed a robot that used electro magnets to climb metal surfaces. During this project it became clear how much electric power is needed to achieve enough magnetic force to carry an acceptable load. This could definitely not be powered by the NXT Lego© brick and therefore isn't suitable to make a Lego© robot climb.

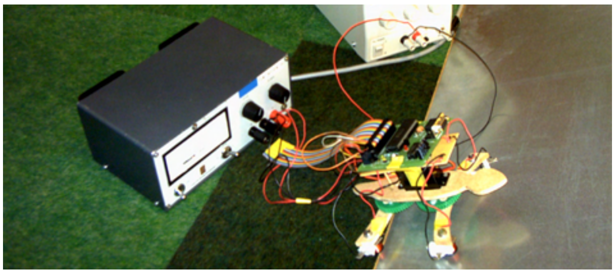


Figure 5. Magnetic gecko

Vortex vacuum

Another power consuming method is to use a vacuum vortex. This is a reversed hovercraft system where a vacuum is created under a skirt instead of pressure. Having such vacuum continuously is a power consuming task though and not likely to be feasible for Lego© NXT.

Figure 6. Vortex technology robot [2]

Vacuum pump powered suction cup

One of the most promising ways to make a Lego© robot climb are vacuum pumps and suction cups. Projects on this have been done before using the air pumps and vacuum tank of Lego© Technic. In this way vacuum was stored in a tank and released on suction cups in a controlled manner. Several mini-vacuum pumps from different developers were checked on their specifications. They suited the power supply of Lego© NXT but didn't supply much vacuum power. The electric power consumption of the vacuum pumps is high because a continuous vacuum is needed to keep on hanging on a wall or window. This isn't desirable for the battery powered NXT brick.

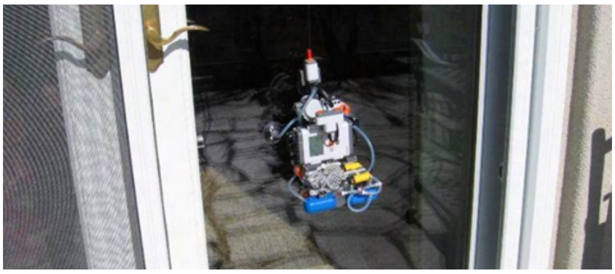


Figure 7. Lego© climber (Vertigo III) [3]

Micro fiber adhesion

The micro fiber adhesion technology developed for the 'Stickybot' at Stanford University is interesting for Lego© NXT. It's a passive way of sticking, so no extra power is needed to stay on a window. Only the climbing would cost energy. The development of such micro fiber material is very delicate though and it was not considered feasible within the scope of this project.

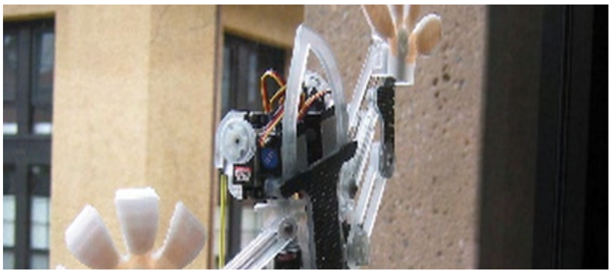


Figure 8. 'Stickybot' [1]

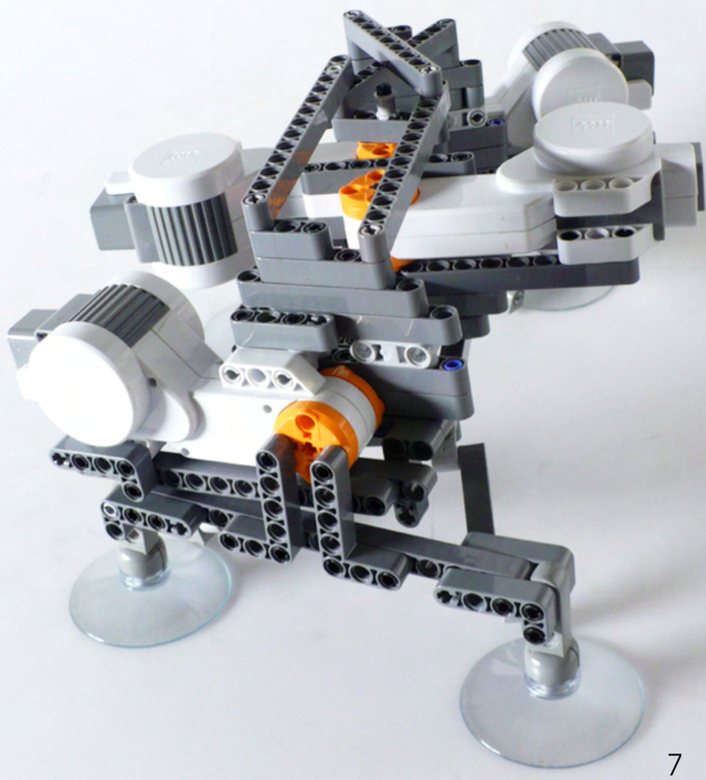
Hooking

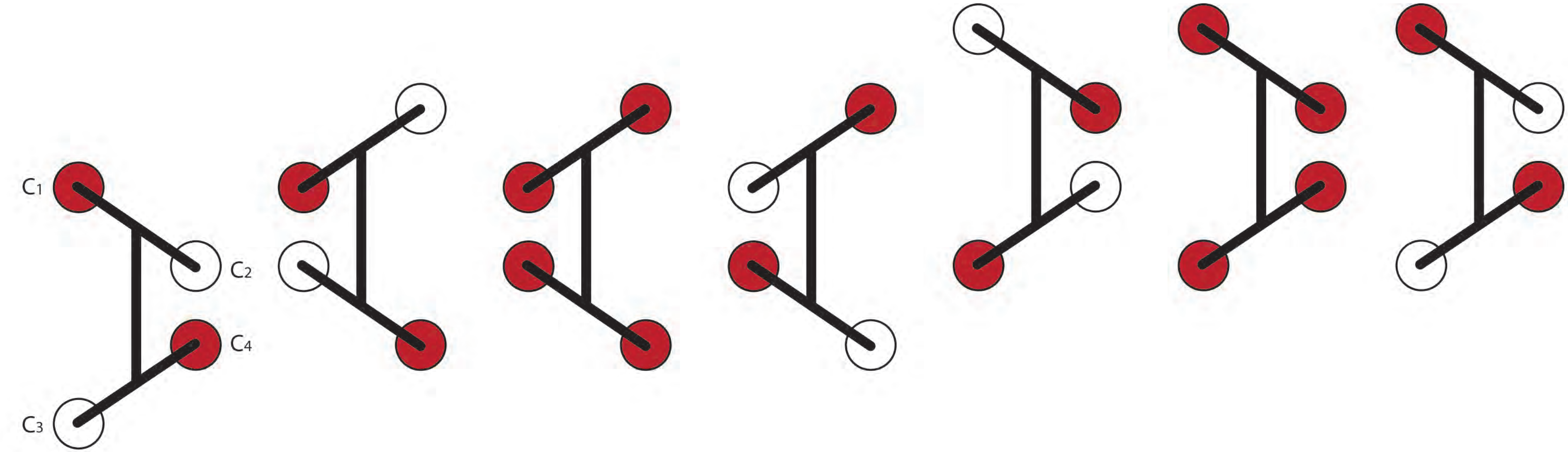
Another passive and therefore interesting way of sticking to a wall is making use of thousands of small hooks. These hooks are mounted flexibly so that they are more likely to find a projection to hook on. When using a very large amount of hooks the load is divided and the chance of a hook to 'hook on' is increased. For this method it is assumed though that the surface to climb is rough enough to make the hooks hold, so this can't be used for climbing windows.

Passive suction cup

A paper by Brockmann et al gave inspiration for developing a passive suction cup for Lego© NXT [4]. They showed that with a pulling mechanism it is very easy to release suction cups and that pushing them on a surface takes less energy than continuous pumping. This seemed to suit Lego© very much, in terms of energy consumption and the constructive character of the Lego© system. When searching for existing suction cups for Lego© there were no significant results. It appeared that there doesn't exist a suction cup brick that can be used to make Lego© constuctions stick to a surface.

So it was decided to develop a robot that climbs walls through a passive suction cup mechanism. This would involve the development of a Lego© compatible suction cup and a construction for the climbing motion.





C1	S	S	S	L	L	S	S
C2	L	L	S	S	S	S	L
C3	L	L	S	S	S	S	L
C4	S	S	S	L	L	S	S
Bt	B1	B2	B2	B2	B1	B1	B1
Bb	B1	B2	B2	B2	B1	B1	B1

S Suction cup sticks

L Suction cup loose

B Body posture state (top legs, bottom legs)

→ Movement (colour is actuator)

Figure 9. Transition state diagram of climbing movement

Mechanical structure

In order to make use of suction cups three actions have to be performed by the robot. The suction cup needs to be pressed on the window; the robot has to move upward and finally the suction cups need to be released from the window again. Different methods of performing these actions were explored. The physics involved explain the choices made for certain structures.

The basic movement is derived from the way a gecko climbs walls. This is an energy efficient way of climbing and suitable for a passive sticking method. One of the difficulties to solve is the assignment of actions to actuators. The Lego© NXT brick can't steer as much actuators as there are actions in the climbing movement. The actions that are needed to get to a certain state are outlined in figure 9.

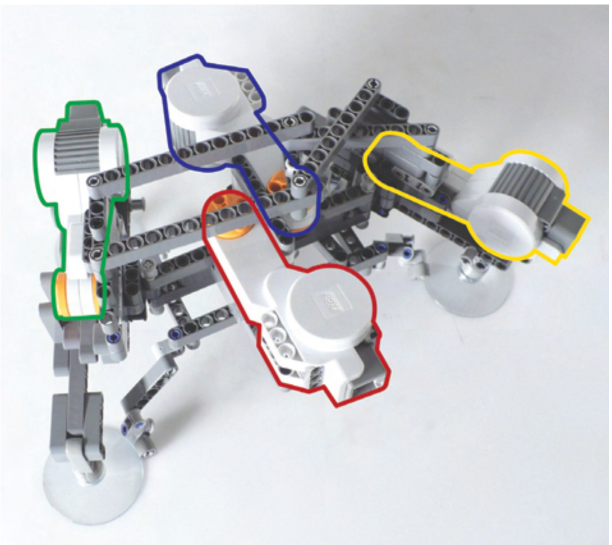


Figure 10. Actuators on final construction (colour relates to figure 9)

It can be seen that for one sequence 12 actions have to be performed. In the starting position the upper suction cups of the top and bottom leg are sticking. To get the robot move upwards the legs have to be rotated in opposite directions. This can be achieved with one actuator by oppositely connecting the legs to it, as shown in figure 11. Ideally the bottom leg isn't connected to the actuator because it only functions as stabilizer, therefore its connection to the floor and body provide enough restrictions. For more solidity in the construction they were connected in the final construction though.

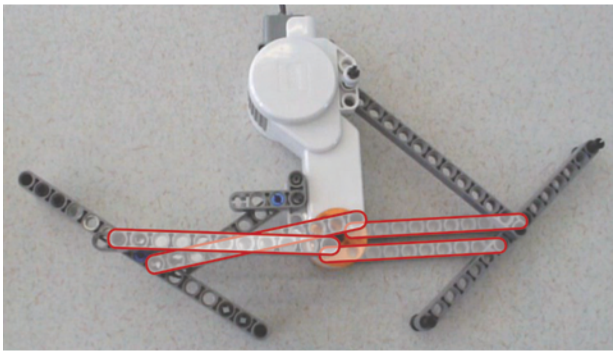


Figure 11. Construction to shift body posture

The top leg carries the load. In physical terms the body can be seen as a lever where the bottom suction cup is the fulcrum and the length to the top suction cup (body length) is the arm (shown in figure 12). In this way it can be calculated what the size of the robot should be in order to carry its own mass. This mass has also an arm: the body height. In order to keep the robot in a stable state (not fall off) the moment of the top suction cup needs to be at least equal to the moment of the body mass. The moment of the body mass can most effectively be reduced by decreasing the body height (mass centre to surface), so the robot body needs to be as close to the wall as possible. This is clearly illustrated by the posture of a gecko; the body touches the wall and the legs are on the side. If the body height raises, the body length needs to increase as well, because the suction force and body mass are about constant.

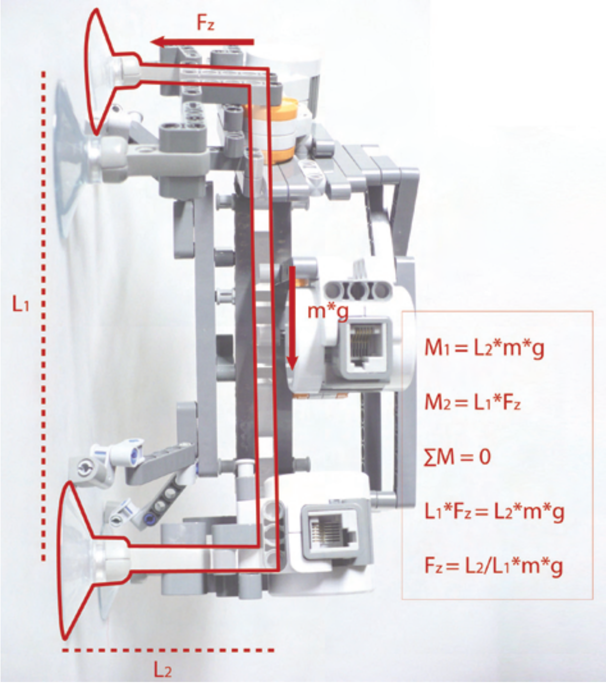


Figure 12. Lever principle in robot construction

Measured

Fz	500g (5N)
NXT brick	254g
Motor	80g
Robot	628g
Construction bricks	134g
L2	70mm
L1'	254mm

Estimated

m = 700g

Calculated

L1 * Fz = L2 * m * g
L1 = (L2 * m * g) / Fz
L1 = (70 * 7) / 5
L1 = 98mm
L1' = 254mm > L1 = 98mm

In order to define the size of the robot the load that the suction cup can hold needs to be known. Therefore a pulling test was carried out. Besides holding to the glass, slippage is a factor. So to test the suction cup it was attached to a window (vertical) and weights were attached to it pulling downwards. It became clear that slippage was less decisive than sticking. With a load above 500 grams the suction cup slowly came off the glass but didn't slip. So the maximum force on the suction cup to stick to glass is 5 Newton.

The other known variable is the mass of the robot. This mass could differ due to the adjustments in its construction, so therefore the separate elements were measured. The NXT brick appeared to be the main factor, followed by the motors. The final construction (figure 10) weighed +/- 700g (NXT brick + 4 motors + construction bricks). The body height of the final construction (towards the mass centre) was 70mm. So the needed body length was calculated on 98mm. The actual length of the construction was 254mm though, so the construction wouldn't fall from the window.

To achieve the right Fz (suction cup force) the suction cup needs to be pushed on the wall moderately. A firm push increases the load it can hold, but the motors can't provide the amount of power needed to achieve this. In figure 9 it can be seen that there are 4 push actions in one sequence. They can be clustered into two actuators or one actuator. Two constructions were built to test the push action with one or two motors. The system with one motor (figure 13) couldn't deliver enough power to press the suction cups due to the flexibility of Lego and therefore loose transmission construction. When distributing the needed actions over two motors (figure 14) and connecting them tightly the suction cups could hold after being pressed.

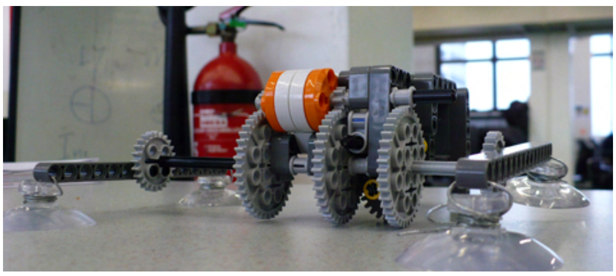


Figure 13. One-motor pushing mechanism

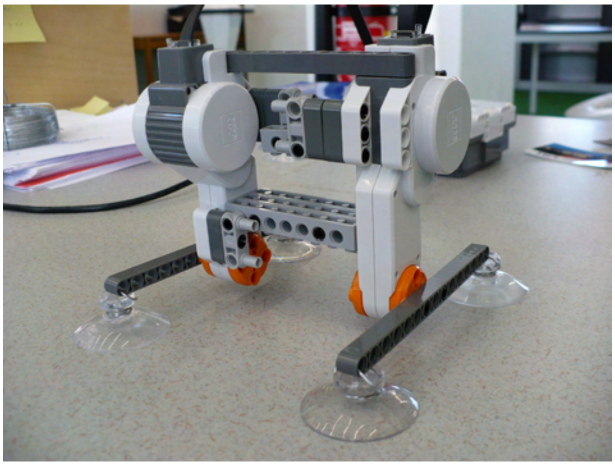


Figure 14. Two-motor pushing mechanism

The final action that had to be taken care of in the construction was the pulling mechanism (red arrows in figure 9). After pressing two suction cups to the window two had to be released again. This was done by pulling the lips that are part of the suction cup. This is a rather light activity where not much force is involved. To decrease the amount of motors (which is one of the main factors for the robots mass) there was sought after a mechanism that would only involve one actuator. This was found in the fact that the suction cups that have to be pulled off at the same time are the diagonal opposites. Therefore one rotational action could be used in both directions to perform all 4 transitions from 'sticking' to 'loose'.

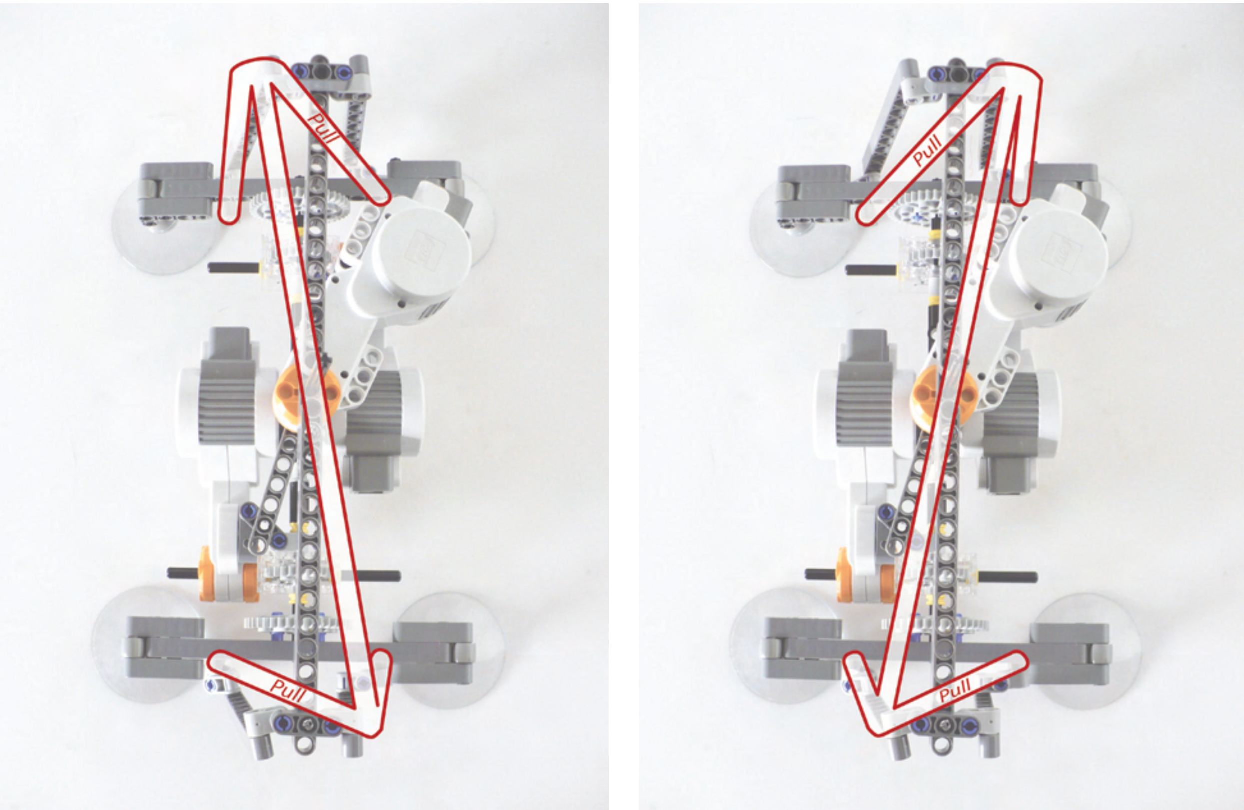


Figure 15. Pulling mechanism

In order to demonstrate possible improvements in the structure, as learned from the physical principles above, a second construction was build. This shows a pushing mechanism with transmission, a lower mass centre point and an improved pulling mechanism making use of the rotation principle.

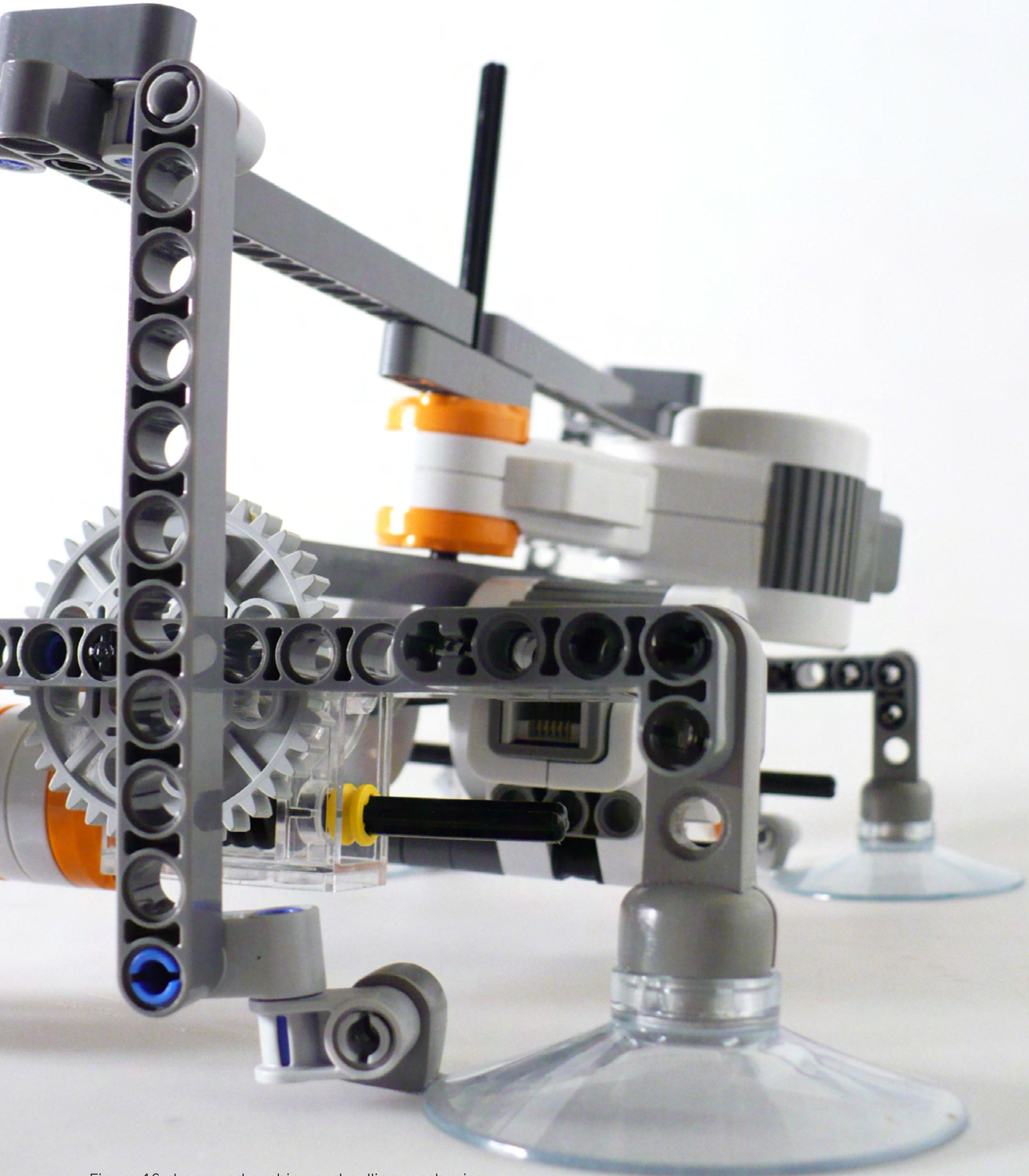


Figure 16. Improved pushing and pulling mechanism

Lego© NXT suction cup

To accommodate passive suction cup climbing a Lego© compatible suction cup needed to be developed. The first idea was to select the right material and produce the cup by hand, enabling a fully integrated Lego© suction cup brick.

Suction cup material is synthetic and needs to be flexible. The more flexibility the better the cup will grip to the surface reducing slippage and increased load bearing. The physics behind a suction cup doesn't rely on suction but on air pressure. By pressing the cup, most of the air between the cup and the surface is pressed out, so the pressure is reduced. The outside air pressure presses the cup to the surface. If a suction cup is made out of flexible material it is easier to press the air out and connect better to the surface. The downside of more flexibility is that the cup will deform easier with a load and therefore can come off quicker. Increased flexibility also makes it more difficult to pull the cup off with a lip due to this deformation.

For this project developing a suction cup isn't feasible though. The manufacturing of suction cups needs high surface finish which is very difficult to achieve manually. Suction cups aren't expensive, so for prototyping purposes it is better to buy them.

The suction cups that were tested best were equipped with a screw thread making it easier to attach a Lego© piece and they had a lip that enabled the pulling off. A piece of three Lego© holes with a cavity for attachment to the suction cup was developed and a piece with one hole to attach to the suction cup lip. There was chosen for a brick with three holes to make it applicable for many Lego© structures. The connection between the Lego© part and suction cup was made in such a way that it could rotate. This was needed for the robot construction because the legs turn around the cups during the climbing movement.

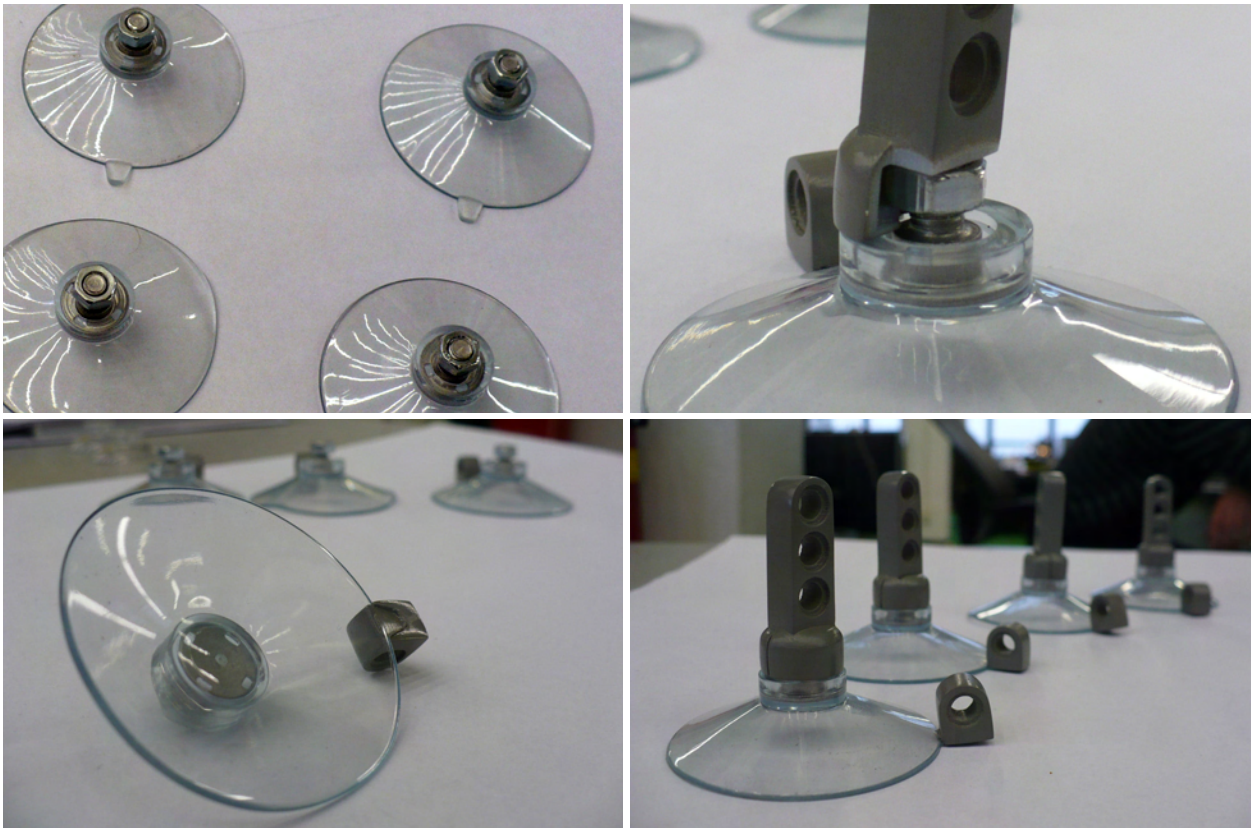


Figure 17. Suction cup assemby

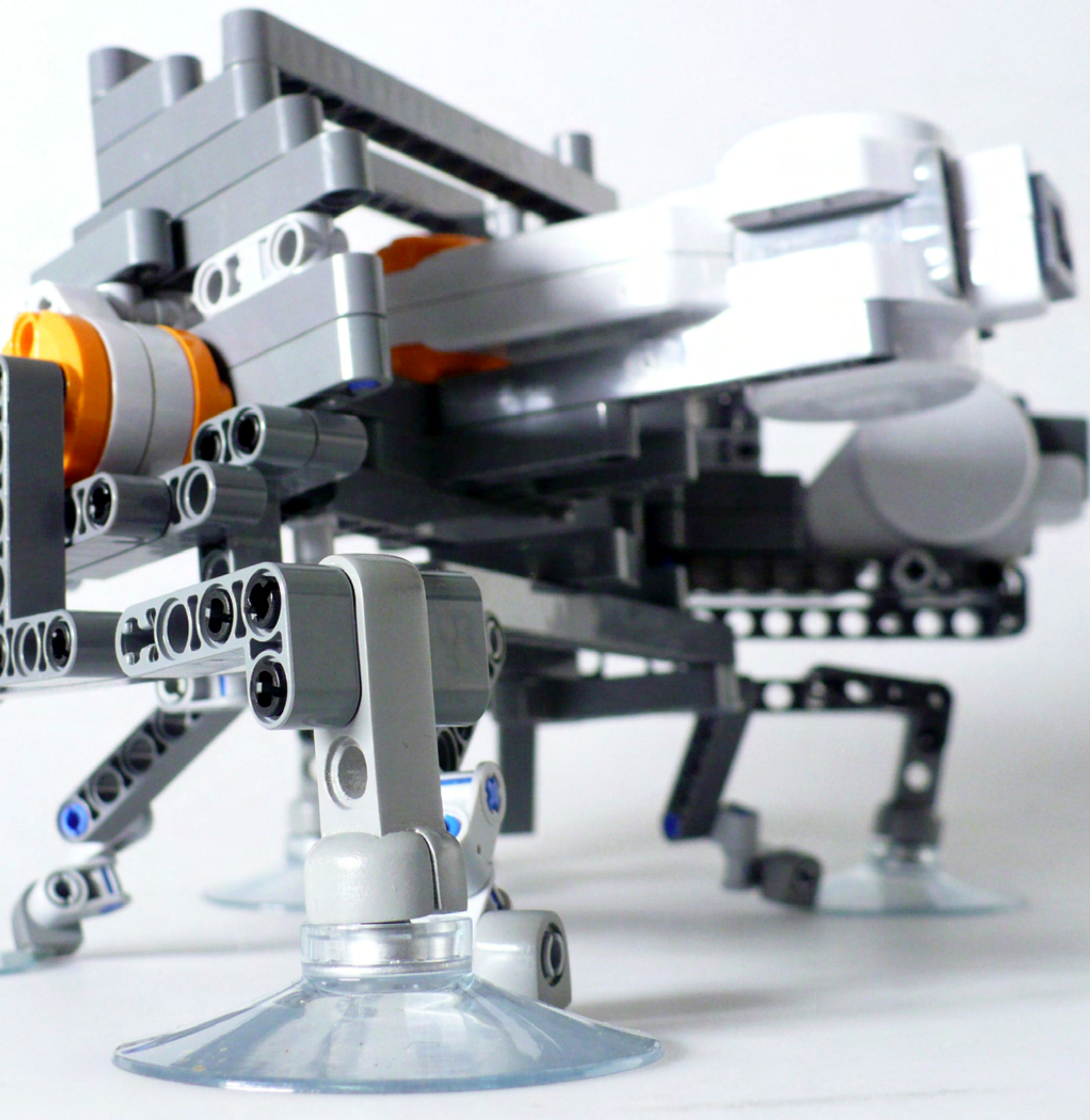
Conclusion

As described, the mechanism should in theory enable climbing. In practice the climbing wasn't evident at all though. It appeared that the motors weren't powerful enough in any action in the vertical direction. The motors didn't press the suction cups with enough power, so they didn't stick tightly to the window. The motor attached to the legs to perform the climbing motion couldn't produce enough power to make the robot move. It seemed that the robot was too heavy. When looking closer at the malfunctioning robot it became clear that the force put into the mechanism mainly went into bending the Lego© beams. The motors couldn't produce enough power to overcome the flexibility of the Lego© components and actually make the construction move.

The robot did perform the actions correctly in the horizontal direction, but when going vertical all loads change and the construction needs to carry itself. With much stiffer material this could have worked, but Lego© is too flexible for the chosen construction. The chosen motion needed too much degrees of freedom with movements in two dimensions. This decreased the construction stiffness heavily and because the material stiffness is low the construction is crucial. So when producing a climbing Lego© robot with the passive suction cups all moving parts should stay in one dimension. Making use of passive suction cups works in theory, but the material properties, selected mechanism and construction are crucial to put it into practice.

Discussion

During this class I found how important proper selection of a technological platform can be. The properties of the platform had a crucial impact on the final result. Using Lego© for constructing a climbing robot introduced several mechanical problems, with the main issue being the stiffness of the material. Eventually this, in combination with the chosen mechanism and construction, made the robot fail to climb, although theoretically it was possible. The platform was a given, so I should have analyzed its specifications more thoroughly and adapt the mechanical choices to it. In this assignment my focus was too much on creating this Gecko-like movement (concept oriented), although this mechanism wasn't suitable for Lego©. This insight and the experience with mechanics will help a lot in making use of technology properly; being a surplus value in my designs.



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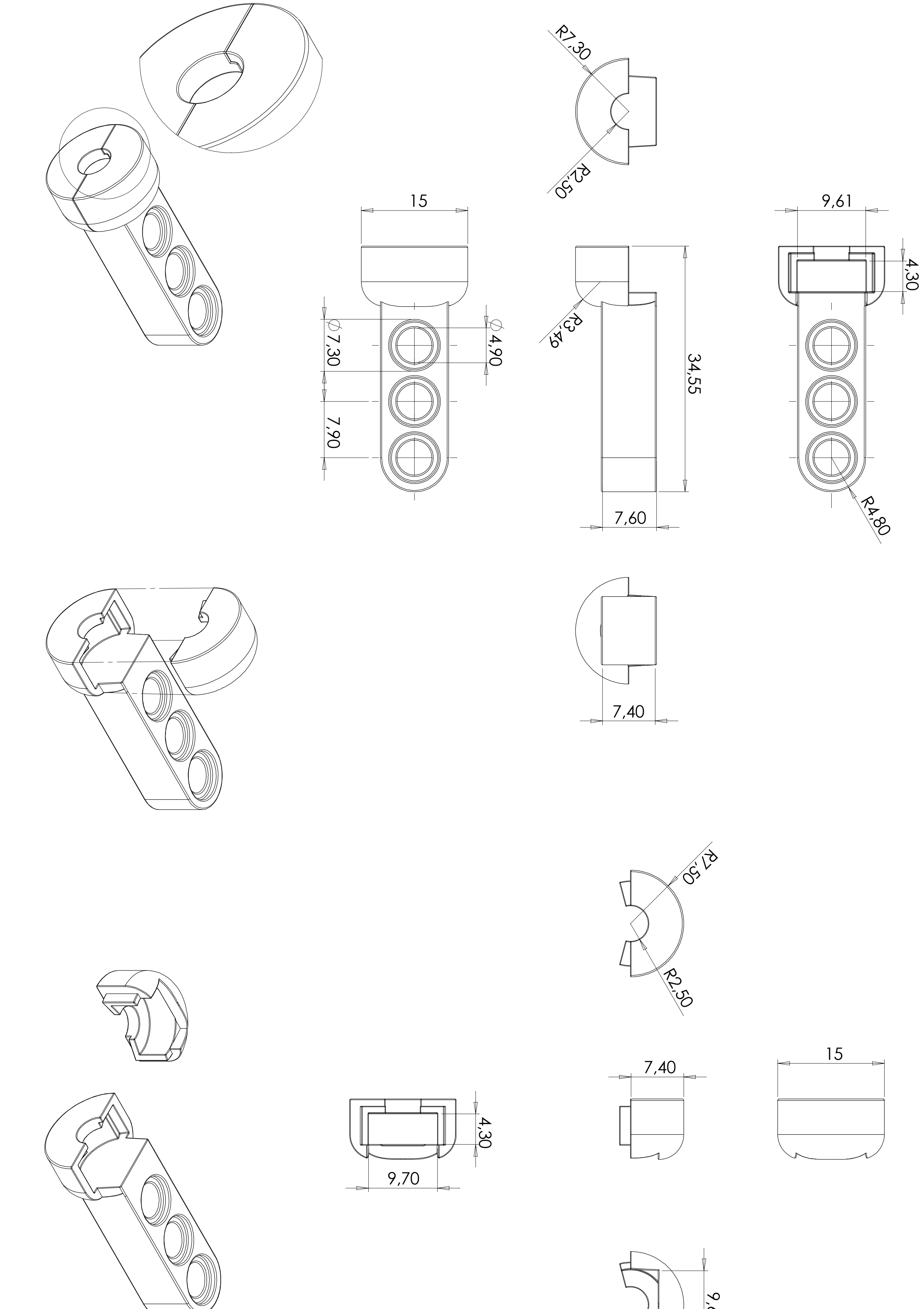
Appendix

Technical drawing suction cup



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