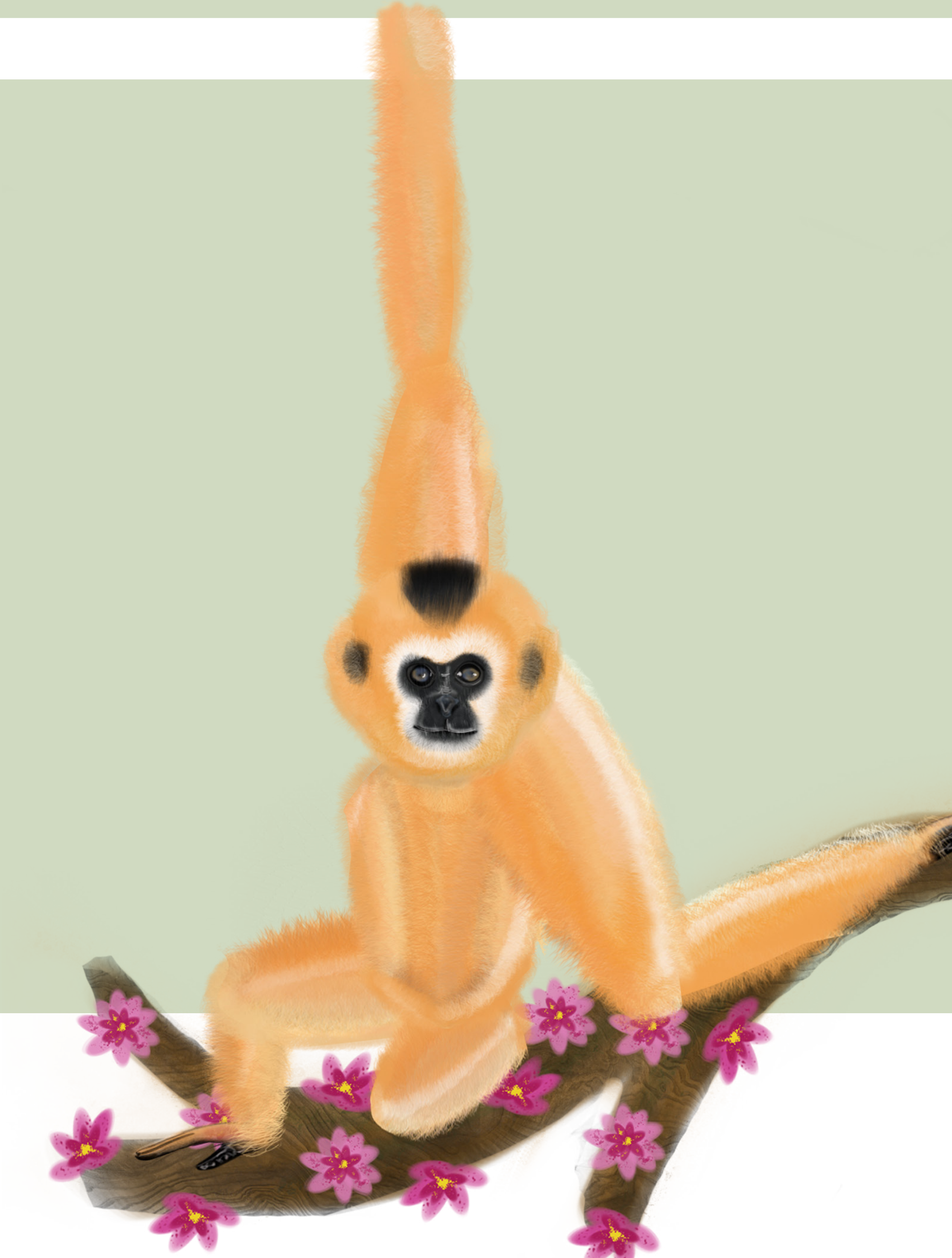
# A-PEEL

## A foraging enrichment device

Master thesis
Integrated product design
Roos Hack



**Master thesis Integrated product design**
1 November 2023
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# Content

# 1. Executive summary

▶ **Introduction & Client |** Over the last decade, there has been a notable increase of interest in discussions surrounding animal welfare, driven by a deeper understanding of the mental states of animals. This growing awareness has triggered a global push to improve laws and regulations in animal welfare, prompting zoos worldwide to increase their efforts in **enhancing the quality of life for their captive animals.**

**Environmental enrichment** has emerged as a crucial tool in increasing animal welfare, supported by studies showcasing its positive impact on reducing aggression and abnormal behaviour in captive animals. ARTIS Zoo actively applies environmental enrichment into its practices and collaborates with the University of Amsterdam to delve deeper into the behaviour and needs of their animals. Scientific research at ARTIS Zoo includes an ongoing exploration into whether primates can recognize time intervals.

▶ **Project Scope |** In an effort to further enhance the lives of their animals, ARTIS Zoo has joined forces with the faculty of Industrial Design Engineering of TU Delft to design a versatile device serving as both an enrichment tool and a research device. The project focusses on designing a feeding solution that mimics the natural foraging behaviour of the yellow cheeked gibbon and black crested macaque, taking into account both physical behaviour as well as cognitive abilities.

▶ **Literature research |** Literature research has delved deeper into **animal welfare, environmental enrichment, and primate behaviour,** resulting into important insights. Primates can forage efficiently because of their physical advantages over other animals while also using the WWW-memory (What, where and when). Primates use synchrony, temperature, solar cues and sensory cues to locate ripe fruit. Yellow cheeked gibbons forage in the high trees for fruit, while black crested macaques forage mostly on the ground between bushes and grass.

A vision has been shaped: **The product should give the primates more autonomy over their feeding process while triggering the cognitive memory, decision making and problem solving abilities.**

▶ **Requirements |** The design considerations for the device were carefully outlined, addressing the distinct needs of stakeholders:

**Primate Usage**: Concentrated on promoting foraging behaviour to reduce inactive periods.

**Zookeeper Usage**: Prioritizing a user-friendly design to maximize usability.

**Researcher Usage:** Enabling dual-purpose functionality for both enrichment and research, with remote control capabilities.

**Safety Considerations:** Ensuring material, assembly, and food safety through detailed specifications.

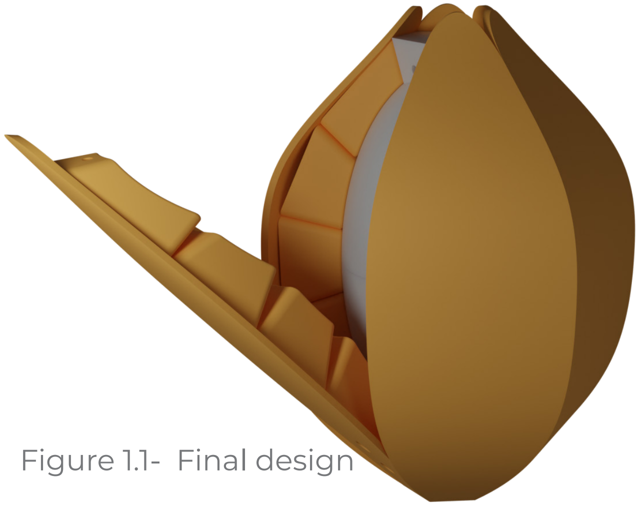


Figure 1.1- Final design

▶ **Design |** The final design (Figure 1.1) takes the form of a fruit, which needs to be peeled by primates to reveal food inside. The device closes automatically and can be locked and unlocked remotely. Iterative design improvements enhance user usability, material sturdiness, and food safety.

▶ **User testing |** User testing with gibbons at ARTIS Zoo showcases significant interest and interaction, supported by observational data indicating heightened engagement between gibbons, increased foraging activities, social behaviour and extended active periods in the presence of the device.

# Part A: Objectives

In this section of the report, research has been conducted to get a better understanding of the context and scope of the design.

**Chapters**

# 2. Project Introduction

## 2.1 Introduction

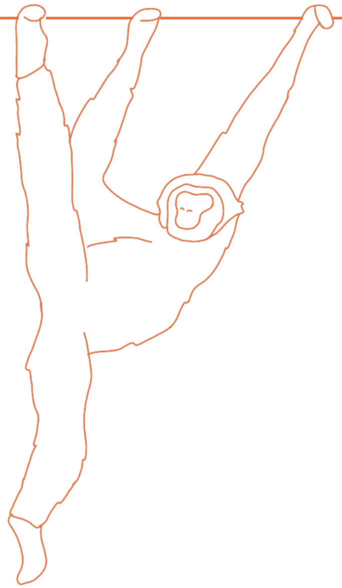
**Animal welfare**[1] is a topic that has been discussed extensively in the past decade. Growing concerns regarding the well-being of animals can be explained by the increase in evidence found on the existence of a mental state in animals (Wolfensohn and Honess, 2005). Change in awareness is seen as the motive behind the demand for better laws and regulations concerning animal welfare. As a result, zoos all over the world are attempting to improve the quality of life for their captive animals.

The primary tool used for improving animal well-being is **environmental enrichment**[2] (Shepherson, 2013). Even though this field of study is relatively new, the benefits of enrichment can already be seen in numerous studies. Research has shown that enrichment which is species, sex, age and background appropriate can reduce aggression, eliminate abnormal behaviour and improve the welfare of animals maintained in captivity (Honnes and Marin, 2006).

ARTIS zoo is one of many zoos that is using environmental enrichment to enhance the well-being of their animals. Besides attempting to provide animals with the necessary tools to enrich their environment, they also work together with the University of Amsterdam to better understand the behaviour and associated needs of their captive animals.

ARTIS is particularly interested in applying enrichment, along with observational research, to their **non-human primates**[3]. Evidence shows species with increased cognitive abilities, such as primates, may suffer more from lack of stimulation than other animals (Brydges & Braithwaite, 2008; Kirkwood & Hubrecht, 2001).

ARTIS contacted the faculty of Industrial Design Engineering of TUDelft to create a device that can be used as an **enrichment tool, as well as a research device**. The design brief can be found in Appendix I.



The scope of the project is to **design** and **prototype a feeding solution** to mimic the natural foraging behaviour of primates. The physical behaviour as well as the cognitive abilities should be kept in mind.

The challenge is to make a dispenser that stimulates the natural foraging behaviour. Simultaneously, any product that is placed inside an animal enclosure should be primate-proof and sturdy.

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[1] *Animal welfare focusses on providing better conditions for non-human animals in circuses, zoos, laboratories, shelters, and factory farms (Nonhumanrights, n.d.).*

[2] *Evironmental enrichment is "A dynamic process which structures and changes an animal's environment in a way that provides behavioural choices to animals and draws out their species-appropriate behaviour and abilities and enhances their welfare" (Shepherdson, 2010).*

[3] *Non-human primates are a group of mammals composed of simians - monkeys and apes and prosimians. When referring to primates in this report, humans are excluded despite being primates.*

# 2.2 ARTIS zoo

ARTIS is a city zoo located in Amsterdam. In addition to providing an enriching environment for their animals and everyone visiting, they are committed to making an impact in nature conservation. This can be seen in their vision described below.

*"ARTIS loves everything that lives. From the smallest microbes and insects to the largest predators, like the jaguar. That's why ARTIS pays special attention to the park's own endangered animals, plants and trees, supports various conservation projects around the world to protect endangered species and their habitats and participates in international breeding programs" (ARTIS, n.d.).*

## 2.2.1 Nature conservation

Nature conservation includes conserving, restoring and developing nature. ARTIS contributes through breeding programs, supporting nature conservation organisations and doing research.

Numerous animals of ARTIS participate in breeding programs designed to oversee the genetic well-being of populations. The primary focus of these programs is preservation of animal species that face growing threats of extinction in their natural habitats.

Additionally, ARTIS supports organisations and projects that contribute to conservation of the wild populations.

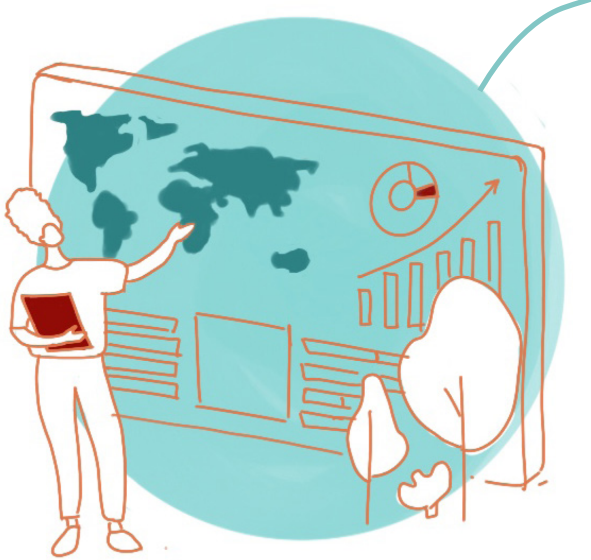

Figure 2.1- Scientific research

Figure 2.2- Nature conservation

## 2.2.2 Scientific research

*"Natura Artis Magistra" translates to "Nature is the teacher of art and science." And from that nature, we can still learn an enormous amount. Since its establishment, ARTIS has opened the park for scientific research (ARTIS, n.d.).*

Examples of scientific research are the studies into cognitive behaviour of primates, animal welfare and biodiversity. In this thesis, references will be made to the relevant studies conducted in Artis zoo. Especially important to this thesis is the research question that is currently being investigated:

***Do primates know when the time is ripe?***

Research into the recognition of time intervals and the ability to understand fruit seasons provides insights on how these abilities evolved million of years ago and what drove this evolution. Prof. dr. Karline Janmaat of the University of Amsterdam and her students investigate time perception within red ruffed lemurs, mandrills, chimpanzees, and western lowland gorillas at ARTIS Zoo.

These studies are conducted to get a greater understanding of the intelligence and cognitive abilities of animals. This is used to better accommodate to their well-being in captivity and simultaneously learn how to improve preservation of the animal population in the wild.

# 2.3 Stakeholder analysis

Based on meetings with the concerning stakeholders, a stakeholder analysis has been made to better understand the different interests (Figure 2.3) which is used to identify important requirements for the design of the feeder (Appendix A).

The direct and indirect stakeholders all have one concern in common: "Enhancing animal welfare". However, there are some differences regarding their main objectives. In Figure 2.3, the interests for each of the stakeholders can be seen in relation to the others. Below they will be analysed further.

**The zookeepers**;
They want to enhance the well-being of their captive animals. The device must be an addition to the environment and challenge the animal to become more active during the day. The functionality and operability of the device is also an important factor as they often do not have a lot of time to set up the device.

**Researchers;**
As mentioned in section 2.2, research is conducted to better accommodate to the well-being of animals in captivity and simultaneously learn how to improve preservation of the animal population in the wild. For this device, the research question is; Do primates know when the time is ripe? The device will be used to test the hypothesis whether primates understand time intervals. Therefore it's necessary to be able to remotely control the device.

**ARTIS board;**
For the ARTIS board, both the enrichment and research qualities of the device are equally important. Besides this, the aesthetics of the device should resemble the nature as close as possible.

**Animals;**
For the animal, the wishes are harder to define. Based on observations and literature research, the assumption; "**the animal wants to express species-specific behaviour**", is made.

**Visitors;**
The main interest of the visitors is the animal welfare and the activity us the animals during their visit to the zoo.

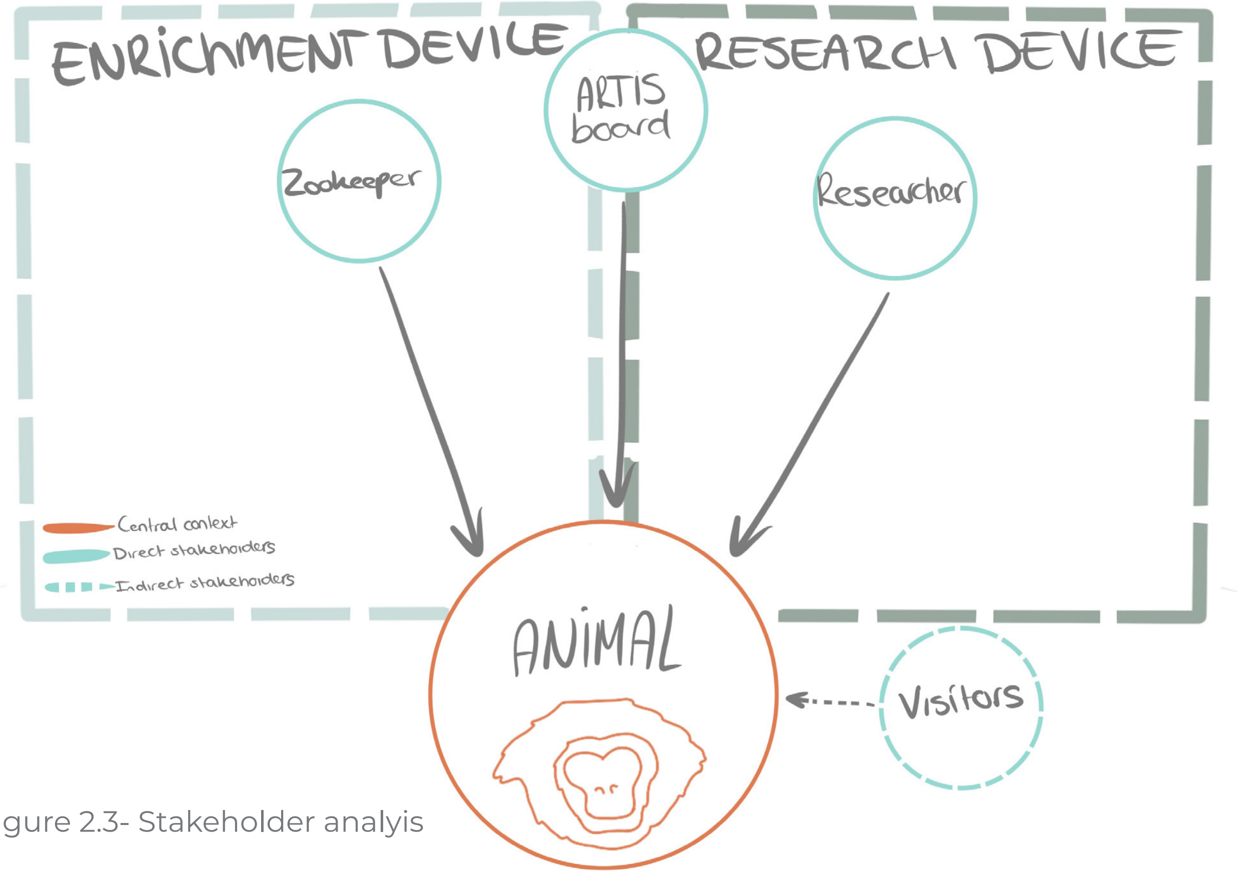

Figure 2.3- Stakeholder analyis

# 3. Analysis

In this chapter, the most important insights found while conducting the research will be elaborated on. To gain a better understanding of the context of the project, literature research has been conducted on **animal welfare, environmental enrichment** and the **behaviour of primates**. The analysis overview can be found below.

| Research question | Insights used in the design |
|---|---|
| **Animal welfare**<br>How is animal welfare defined and how can it be improved for zoo animals? | Animal welfare is defined using the Five Domains model. The method commonly used in zoos to improve animal welfare is environmental enrichment. Ensuring quality of life involves providing opportunities for positive experiences like anticipation, satisfaction, and satiation. |
| **Environmental enrichment**<br>What is the effect of environmental enrichments and which types are valuable for the project? | If done correctly, environmental enrichment can reduce abnormal behaviour, tackle the cause of the problem or improve animal welfare. Applying environmental enrichment to enclosures of captive animals reduces the time animals are inactive or resting. This is necessary as zoos want to encourage natural behaviour profiles of animals in the wild as close as possible. Feeding, cognitive and sensory enrichment are particularly interesting and can be combined for this project. |
| **Behaviour of primates in the wild**<br>What is the foraging behaviour of primates in the wild and how do primates forage efficiently using fruit ripening signals? | Primates can forage efficiently because of their physical advantages over other animals while also using the WWW-memory (What, where and when). Primates use synchrony, temperature and solar cues as well as sensory cues. |
| **Choice of species**<br>Which primates in ARTIS benefit the most from the enrichment device? | The yellow cheeked gibbons and black crested macaque are chosen to design an enrichment device for. These primate species have strong cognitive abilities and are curious in nature, making them therefore the ideal subjects. |
| **Behaviour of species**<br>What is the difference between the two primates and how they forage?<br>What is the difference between the captive and wild behaviour of the primates? | Yellow cheeked gibbons forage in the high trees for fruit, while black crested macaques forage mostly on the ground between bushes and grass. A difference in activity patterns between the captive and wild populations exists for of both species. For the gibbon however, the difference between the activity budget of the wild and captive populations is the largest. Therefore, the device is designed and tested for the gibbons. |

# 3.1 Animal welfare

## 3.1.1 Animal welfare models

For years, the Five Freedoms method from the early 1990s has served as a benchmark for assessing animal welfare. These freedoms include fundamental rights, such as freedom from hunger, discomfort, pain, and fear, as well as, the freedom to express normal behaviour. However, recent advancements in scientific research regarding animal welfare suggests the need for a re-evaluation of this framework.

The acknowledgement that animals experience a range of emotions caused discussions regarding the limitations of the Five Freedoms model. Scientific insights highlighted the need to distinguish between practises aimed mainly to keeping animals alive and those that enable animals to thrive (Mellor, 2016). While the Five Freedoms focus on eliminating negative experiences, it falls short in addressing the complexity of animal well-being, particularly in creating environments that foster both negative and positive sensory inputs (Brydges & Braithwaite, 2008; Etim et al., 2014; Mellor, 2016).

Contrary to the strict elimination of negative experiences, it is argued that certain discomforts play a vital role in the behavioural mechanisms crucial for survival. Negative experiences, whether physical or functional, are embedded elements that drive specific behaviours in response to adversity (Mellor, 2016). Panksepp's work (2005) emphasizes that eliminating these negative effects can create a conflict between an animal's preprogrammed survival behaviour and their expressions in captivity.

The key lies in finding a balance, avoiding extremes while still motivating life-sustaining behaviours. Mellor and Beausoleil (2015) advocate for a nuanced approach that acknowledges the intrinsic connection between negative and positive experiences. Simply eliminating negative effects does not automatically translate into positive experiences. Nevertheless, an excess of negative effects can discourage the motivation to engage in rewarding behaviours Held and Špinka, 2011).

In 1994, Professor David Mellor and Dr Cam Reid proposed a new model as a result of these insights; the Five Domains (Figure 3.1). The Five Freedoms are reformulated as the **Five Domains of nutrition, environment, health, behaviour and mental state/ experiences.**

The Five Freedoms and the Five Domains frameworks share the same fundamental elements. However, the Five Domains explores how these elements affect the mental state of animals. This approach emphasizes the importance of acknowledging emotional needs equally as important as physical needs in animal care.

As mentioned above, the Five Domains clarifies that solely eliminating negative experiences does not automatically lead to positive welfare. Ensuring quality of life involves providing opportunities for positive experiences like anticipation, satisfaction, and satiation. Caretakers must create environments that not only allow, but actively encourage animals in rewarding behaviours (Shepherson, 2013).

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[4] *Animal welfare in this research is defined as "the treatment and well-being of animals while they provide for human needs; human use" (Etim et al., 2014).*

### 3.1.2 Animal welfare in zoos

Efforts to improve animal welfare in zoos have increased with the years. However, the important question still remaining is;

**What are possible signs to indicate compromised mental health due to bad animal welfare?**

Research found abnormal behaviour[5] is one of the signs indicating pour captive conditions (Birkett & Newton-Fisher, 2011). These behaviours are common in environments with the following, non-mutually exclusive conditions: physical confinement, low stimulation, social isolation, stress and fear (Mason et al., 2007).

Based on a large number of publications investigating the relationship between abnormal behaviour and animal welfare, the following consistent pattern can be seen; Environments where abnormal behaviour is caused and reinforced are likely to decrease welfare (Mason et al., 2007). Six approaches are identified to reduce and/or prevent abnormal behaviour:

1. Genetic selection,
2. Positive reinforcement
3. Pharmacological compounds,
4. Alternative behaviour,
5. Physical prevention or punishment
6. Environmental enrichment.

From these methods, environmental enrichment is the most commonly used method to approach abnormal behaviour in zoos. This will also be the method used in this project. The other approaches are hardly used in zoos because they (1) can not be applied to small populations, (2) are labour intensive or (3, 4, 5) treating the symptoms rather than eliminating the cause (Mason et al., 2007).

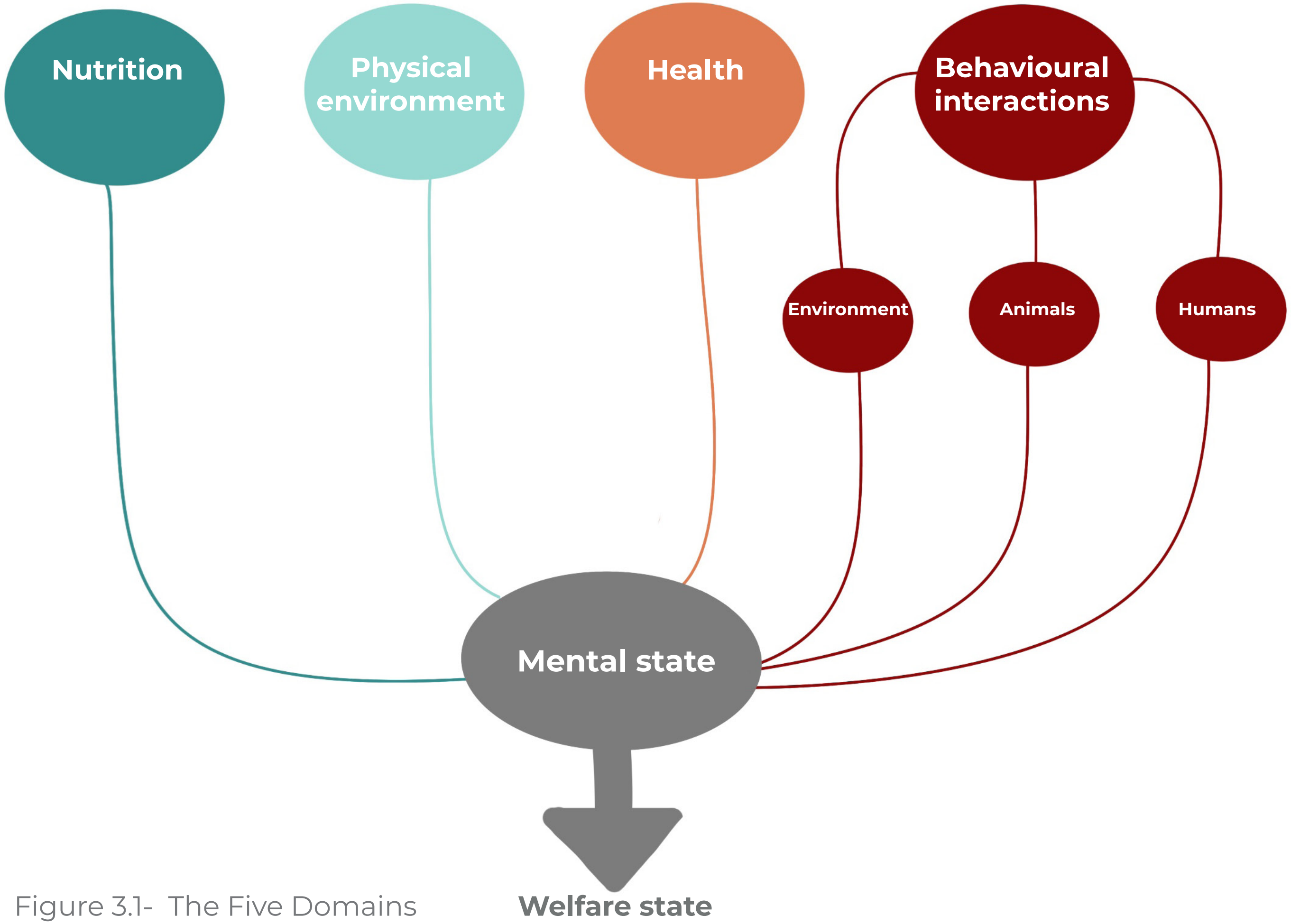

Figure 3.1- The Five Domains

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[5] *Abnormal behaviour refers to behaviour that is not seen in nature and is caused by shortcomings of the captive housing environment (Birkett & Newton-Fisher, 2011)*

# 3.2 Environmental enrichment

If done correctly, environmental enrichment can reduce abnormal behaviour, tackle the cause of the problem and improve animal welfare (Mason et al., 2007). Applying environmental enrichment to enclosures of captive animals can reduce the time animals are inactive or resting. This is necessary as zoos want to encourage natural behaviour profiles of animals into the wild, resulting in more psychologically healthy animals (Mason, 1991; Honess & Marin, 2006).

"The goals and benefits of environmental enrichment are:

1. Increase behavioural diversity;
2. Reduce the frequencies of abnormal behaviour;
3. Increase the range of normal (i.e., wild) behaviour patterns;
4. Increase positive utilization of the environment;
5. Increase the ability to cope with challenges in a more normal way (Young, 2003)".

Despite the efforts of environmental enrichment, it is not always successful. Therefore it is extremely important to keep in mind the species, context and implementation (Maple & Perdue, 2012). The different types of enrichment are discussed in the rest of this sub-chapter.

## 3.2.1 Social enrichment

Social enrichment for zoo animals can either be, animal-animal or human-animal interactions. The social interactions of species provide a continuous stream of mental stimulation that cannot be fully replicated through any form of environmental enrichment (Humphrey, 1976). Examples of efforts from ARTIS to enhance social stimulation can be seen in figure 3.2 and 3.3. Interacting positively with humans can enhance the social environment for captive primates (Bayne et al., 1993; Bloomsmith et al., 1997; K.C. Baker, 1997). Human-animal interactions in captive settings are most frequently observed between caregivers, researchers and visitors.

Figure 3.2- Interaction between black crested macaque and a lonely anoa

Figure 3.3.- Interaction between researcher and chimanzee in Artis zoo

Valuable for this project is the animal-researcher interaction. This interaction can vary from direct, hands-on training to participation in research projects to more indirect involvement, such as behavioural observation. Even in cases of observational research, the presence of the researcher can provide stimulation to the animal, even without direct contact (Maple & Perdue, 2012). This type of interaction can also be seen at ARTIS zoo, where students of the University of Amsterdam are observing the cognitive abilities of animals. For most animals, behaviour suggests these interactions spark curiosity and engagement seen in Figure 3.3. Additional information on social enrichment can be found in Appendix B.

## 3.2.2 Cognitive enrichment

Cognitive enrichment can range from simple manipulation, to complex systems and can be applied to any species. It refers to the process of challenging and stimulating the cognitive[6] abilities of animals. These abilities can be "memory, decision-making, judgment, perception, attention, problem solving, executive functioning and learning (Maple & Perdue, 2012)". At ARTIS zoo, research with chimpanzees, red ruffed lemurs (Figure 3.4), gorillas and mandrills was done to understand the recognition of time intervals and perception of time. Additionally, with the chimpanzees, a touch-screen experiment is currently being conducted to investigate decision making (Allritz et al., 2022). Animals that engage in cognitive research programs, exhibit activity patterns more similar to their wild relatives than those not participating in such research (Yamanashi and Hayashi 2011).

Figure 3.4- Red-ruffed lemur looking for food at Artis Zoo while participating in time interval experiment (van Weeren, n.d.)

## 3.2.3 Sensory enrichment

Figure 3.5- Sensory enrichment (Maple & Perdue, 2012)

In the wild, animals are continually exposed to different stimuli registered by the senses. Providing these different stimuli to animals in captivity can enrich the environment. A unique example of an effort to recreate the different stimuli can be seen in Jakarta zoo in the 1990's. Orangutans were driven with a horse carrier around the park (Figure 3.5). The orangutans were offered motion, auditory, olfactory, visual, and social stimulation (Maple & Perdue, 2012).

- ▶ **Auditory |** Auditory stimuli can have a positive effect on animal welfare when done with knowledge of species-appropriate sounds (Maple & Perdue, 2012). For example, forest and bird sounds are found to have a positive effect on stress related and abnormal behaviour (e.g., Ogden et al. 1994; Wells and Irwin 2008).

- ▶ **Olfactory |** The zoo offers an excellent environment to take advantage of the diverse range of scents already available. Research found that interactions where a combination of different environmental enrichments methods are used, the positive effects are stronger (Szokalski et al., 2012).

- ▶ **Visual |** Visual enrichment is commonly used with non-human primates. Given that all primates have full colour vision, the effectiveness is higher compared to other animals. Research found that videotapes can be enriching for chimpanzees (Bloomsmith et al. 1990; Bloomsmith and Lambeth 2000; Ogura, 2012). While conducting the touch-screen experiment at ARTIS zoo, one individual displayed interesting behaviour as a result of the visual enrichment. While walking in a virtual forest with apple trees and bushes, the chimpanzee chose to walk repeatedly trough the bush creating an enriching experience on the screen (Allritz et al., 2022).

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[6] *Cognition, "the states and processes involved in knowing, which in their completeness include perception and judgment. Cognition includes all conscious and unconscious processes by which knowledge is accumulated, such as perceiving, recognizing, conceiving, and reasoning" (Britannica, n.d.).*

### 3.2.4 Feeding enrichment

In the wild, primates spent a large amount of their time, about 25% till 90%, foraging[7] (Tresz, 2003). To enhance animal welfare in captivity, solely providing a nutritional diet is not sufficient. The shortcomings of current methods have been investigated. Research shows that short feeding times may be the reason for the development of abnormal behaviour (Mason, 1990), as it is not an accurate representation of the foraging behaviour of species in the wild.

Opportunities to promote healthy foraging behaviour are “(1) increase processing time (Figure 3.6), (2) stimulate the senses by providing foods other than the typical pellets, and (3) periodically change the availability of food in time and space” (Tretsz, 2003).

These three opportunities will all be used in the design of the feeding device for this project.

Figure 3.6- Example of increasing prosessing by making it harder to retrieve the food (AussieDog, 2018)

In the wild, gathering food is the most time consuming species-typical behaviour. However, captive animals are often deprived of this behaviour. Stimulating this natural foraging behaviour in captive animals is advised.

Instead of delivering the animals’ daily nutritional diet in an easy way, zoos changed their approach to scatter feeding, food manipulation or other specific behaviour (Maple & Perdue, 2012). Research already showed spatial and temporal scattering of food reduces animal aggression (Young, 1997). Students of Georgia tech designed an automatic feeder for the gorillas that scatters the food around the enclosure (Figure 3.7) (Maderer, 2023).

Figure 3.7- Scattering device (Maderer, 2023).

Species-specific behaviour is the most important factor when choosing or designing an enrichment device. Eisenberg’s categories can be used to identify the exact nature of the behaviour when foraging (Young, 2003) (Appendix B). Foraging enrichment is the main type of enrichment used in this projects and therefore will be investigated further.

#### 3.2.4.1 Foraging enrichment devices

Current foraging devices have already shown positive effects on the well-being of the different primates; cynomolgus monkeys, Rhesus Macaques and Moloch Gibbons. They encourage species-specific behaviour, decrease stereotypic behaviour, reduce aggression, provide multi-sensory stimulation and cognitive challenges (Bennett et al., 2014; Bennett et al., 2014b; Gottlieb et al., 2011; Wells & Irwin, 2008;

Examples of current enrichment devices are shown in Figure 3.8. As can be seen, none of these devices are remote controlled. Most of them are also self made products from construction materials. These insights give opportunity for improvement in these categories.

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[7] *Foraging is the act of gathering food trough the means of searching, retrieving, picking and hunting (Tresz, 2003).*

Figure 3.8- Foraging enrichments devices

# 3.3 Foraging behaviour of primates

Where the development of human intelligence evolved from is a research question that has sparked the interest of humans for decades. A long-held theory is that primates have evolved their relative large brains as a result of social complexity (DeCasien et al., 2017; Zuberbühler & Janmaat, 2010). However, new research indicates bigger brains may be a result of diet rather than social complexity (DeCasien et al., 2017). In this research, the difference in brain size, diet and social system is analysed for over 140 different non-human primates. No evidence was found that bigger brain size was linked to social factors. However, the results do suggest a relation with the dietary choices. Results show primates that are frugivores[8] with the same body mass as folivores[9] have 25% more brain tissue (DeCasien et al., 2017).

These results support the belief that more energy is obtained by eating fruit than leaves. It also indicates the complex cognitive abilities needed for fruit foraging could be an important factor in the development of larger brain sizes (DeCasien et al., 2017). Meaning the development of intelligence of primates is a cause of the scarcity of high-quality food resources (Milton, 1981).

## 3.3.1 Physical advantages

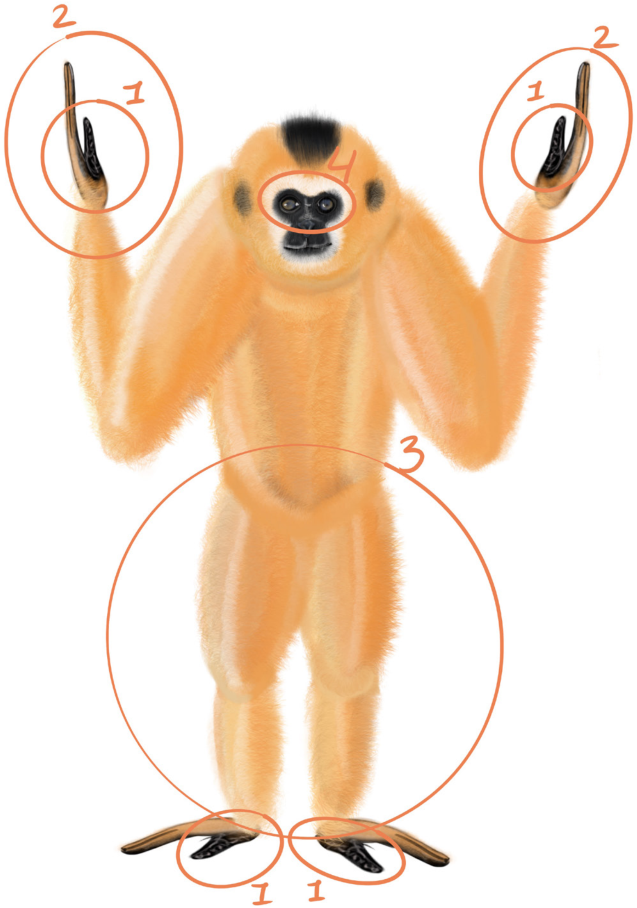

Figure 3.9- Illustration of physical advantages primates

Being able to forage efficiently creates a substantial advantage over other animals. Primates in particular, have a few physical advantages (Figure 3.9) over other animals that are specifically suitable for fruit foraging in arboreal[10] situations.

**▶ 1. Opposable thumbs |** Opposable thumbs[11] and toes allows primates to grasp and reach for fruit located on the outermost branches of trees, which are out of reach for many other animals.

**▶ 2. Grasping abilities and 3. hindlimp dominance |** Many primates are skilled at leaping between trees with their hindlimb dominance[12] and strong grasping abilities, which is a highly energy-efficient mode of movement (Gebo, 2004; Sussman, 1991; Taylor et al., 1972).

**▶ 4. Forward facing stereoscopic eyes and diurnal activity |** Forward-facing eyes and stereoscopic vision[13], enhances the hand-eye coordination of primates and enables them to forage rapidly (Cartmill, 1972; Gebo, 2004). Likewise, their diurnal activity[14] and ability to perceive colours allows them to spot fruit and assess its nutritional value from great distances (Barton, 2000; Polyak, 1957; Sumner & Mollon, 2000).

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[8] *Frugivores are animals that supports oneself completely or primarily on fruit (Britannica, n.d.).*

[9] *Folivores are herbivores that feed primary on leaves (Britannica, n.d.).*

[10] *Arboreal animals are animals who living in trees (Britannica, n.d.)*

[11] *Opposable thumbs, a thumb same as humans, that is capable of moving freely and independently (Britannica, n.d.).*

[12] *Hindlimp dominance, is the dominance in the legs (Britannica, n.d.).*

[13] *Stereoscopic vision, is the ability to recognise and register three-dimensional shape from visual inputs (Britannica, n.d.).*

[14] *Diurnal activity, is activity during the daytime (Britannica, n.d.).*

### 3.3.2 Foraging cognition

To forage efficiently, animals have to process different types of information. The three basic types of information needed for efficiency is called the WWW (Where, what and when) memory system[14]. Animals that have developed this memory system can remember the specifics where (spatial location), what (type of food in each location) and when (time) of their food caches (Clayton and Dickinson, 1999).

▶ **Where |** The ability to remember where food is located has extensively been researched in many primates ranging from monkeys to the great apes. Numerous studies conducted on captive primates show they can remember the location of food (Menzel, 1991; Menzel, 1973; Gibeault and MacDonald, 2000). Research on wild populations also suggest the presence of these abilities. Gray-cheeked and sooty mangabeys showed more interest in trees where fruit was produced compared to the same species that which had not produced fruit (Janmaat et al., 2006b). These fruit producing trees were also approached faster by the mangabeys than the other trees (Janmaat, 2006; Janmaat et al., 2006b).

▶ **What |** What kind of food is located where is studied significantly less. Nevertheless evidence shows macaques, gorillas and chimpanzees are able to remember this. Menzel's study revealed the macaques's first search location was related to the preferred food, when two types of different foods were presented at different locations (1991). Not only the location was memorized, but also the amount of food had a big influence on the decision making of foraging (Garber & Paciulli, 1997). This ability has also been proven to exist in chimpanzees and gorillas (Menzel, 1973; Menzel, 1999; Schwartz et al., 2002).

A more recent study investigated this advanced spatial foraging skill in orangutans and the yellow-cheeked crested gibbons. It confirmed the hypothesis that these two primates indeed use information on the where and what, while foraging. For frugivores, this skill appears to be even more crucial due to the limited time availability of fruits. From session to session, the gibbons and orangutans remembered the food locations for the different types of food. Within a session they remembered the already visited location (Scheumann & Call, 2006).

Interesting was the performance of the gibbon at the locations where bananas were present (in the trees) compared to the grape locations (on the ground). The gibbon discovered only one grape location yet multiple banana locations. This suggests gibbons have a preference for foraging in trees rather than on the ground as they prefer grapes over bananas (Scheumann & Call, 2006).

▶ **When |** On the episodic memory[15] and the ability to anticipate future events, , only a handful of studies have been conducted with primates. Research on capuchin monkeys in captivity showed an understanding of "prior food patch use, including where the patch is relative to their current location, how productive the patch is and how long it has been since they last visited the patch" (Janson, 2016). Additionally, the mandrills of ARTIS zoo learned two-day time intervals. This means they recognized two days has passed and therefore food would be present at a specific location (Ozturk et al., 2020). Other studies on captive primates showed these abilities were also present in chimpanzees (Dufour et al., 2007).

In the wild, this future thinking has also been implied. Findings on observations of chacma baboons supports the presence of episodic-like memory (Noser & Byrne, 2015). Similar results have been found in wild mangabeys (Janmaat et al,. 2006a). Wild chimpanzees observations show that they plan for the future by choosing the location of their nests and departure time for locomotion to "get breakfast". These choices were based on several factors such as time of the day, distance to and the type of food (Janmaat et al., 2014).

# 3.4 Fruit ripening signals

## 3.4.1 Synchrony

In the tropical rainforest, there is a great diversity of plant species that produce fruit. There are two categories; synchronous and asynchronous species. When a synchronous tree produces fruit as well, it means that all the other trees of the same species produce fruit. Finding a fruit of a synchronous species can be an indication for primates to search at different locations with the same species. The ripening rates of asynchronous species on the other hand, are influenced by temperature and solar rather than time. Whether primates can make these predictions and can make a distinction between these two fruiting patterns, has been studied (Zuberbühler & Janmaat, 2010). From research conducted on Japanese macaques (Macaca fuscata), they found evidence to support these primates have an understanding of these patterns. Not only did the macaques search for fruits of the same species they were provisioned with, but also searched for a different species that fruits simultaneously (Menzel, 1991). Mangabeys likewise follow a synchrony-based inspection strategy (Janmaat et al., 2011).

Observational research on Javan gibbons (Hylobates moloch) was conducted to investigate if they have “knowledge on synchronous characteristics of fruiting trees and whether they can further distinguish fruit species with different synchrony levels” (Jang et al., 2021a). The observations showed fruit discovery leads to visiting the same fruit species. However, there was no clear distinction between synchronous and asynchronous species. This suggest they do have a simple understanding of the synchronous characteristics yet, do not differentiate between the two different fruiting patterns (Jang et al., 2021a).

## 3.4.2 Temperature and solar

The ripening rates of fruits are strongly influenced by temperature and solar radiation. A study on wild mangabeys suggests that these monkeys used episodic-like memories combined with a simple understanding of the association between ripening rates and the temperature and solar radiation (Zuberbühler & Janmaat, 2010).

## 3.4.3 Sensory cues

Fruit ripening is associated with change in colour, puncture resistance, sucrose, and ethanol content. The sensational selection process of food is dependent on touch (softening texture and puncture resistance), sight (the colour), taste (Sucrose and ethanol content) and smell (odour profiles). Often the external cues, such as colour are not enough to make an evaluation on the ripeness of a fruit. Therefore colour is most of the time used as a cue from a distance (Figure 3.10), while other sensory cues are used for up close (Dominy, 2004; Dudley, 2004; Nevo et al., 2015; Nevo et al., 2016a; Pablo-Rodríguez et al., 2015).

Figure 3.10- Illustration of visual cues of fruit ripening

Primates use olfaction not only to detect food but also to select food. They possess well-developed olfactory sensitivity that can differentiate between different odours. Research showed captive spider monkeys (Ateles geoffroyi) can differentiate between synthetic odours imitating ripe and unripe fruits (Nevo et al., 2015). Other research on spider monkeys shows the sucrose concentration of fruit is closely linked to the ripening process. The sensory cues, sucrose concentration and ethanol content are important factors of fruit selection (Dudley, 2004; Pablo-Rodríguez et al., 2015). Research shows the relation between different sensory cues are closely linked together rather than being separate cues (Nevo et al., 2016a).

# 3.5 Choice of species

Prioritising one species over another when choosing to provide environmental enrichment is something that is never intended, but may sometimes occur, due to a lack of resources. Young (2003) proposes a set of rules for prioritising:

"Does the species have the ability to predict future events?

Do cognition experiments support the proposition that the species functions at a high cognitive level?

Does the species live in large social groups with complex and long-lived interactions?

Does the species demonstrate high levels of curiosity or exploratory behaviour?

Is the species known to usually display abnormal behaviour in captivity? (Young, 2003)"

For this graduation project, a specific species had to be selected. ARTIS zoo houses 16 different primates. As they are interested in providing enrichment to all of their primates, the question arouses: Is it possible to design a feeding enrichment device for all primates? From the extensive literature research, one of the most important factors for designing an effective enrichment device is the consideration of species-specific behaviour. With the wide range of different primates in ARTIS zoo, from great apes to lesser apes to monkeys, this is not possible. Together with ARTIS and by applying the rules, a well-considered choice is made to prioritise the cognitive higher primates. Due to maintenance of the enclosures of the chimpanzees and gorillas, these animals were not a feasible option.

Therefore, the yellow cheeked gibbons and black crested macaques (Figure 3.11) were chosen to design an enrichment device for. These primate species have also strong cognitive abilities and are curious in nature, making them the ideal subjects.

Figure 3.11- Yellow cheeked gibbon and black crested macaque

# 3.6 Behavioural research

## 3.6.1 Yellow cheeked gibbon

Figure 3.12- Yellow cheeked gibbon

**The southern yellow-cheeked gibbon** (Figure 3.12), scientifically known as Nomascus gabriellae, is an endangered gibbon species native to Vietnam, Laos, and Cambodia. They belong to the family of **lesser apes**.

The gender of yellow-cheeked gibbons can easily be differentiated by the colour of their fur. Male individuals have black fur with distinctive golden cheeks. Female gibbons posses blond fur with a black part on the top of their heads.

Gibbons live in **small monogamous groups.** They are a **diurnal** and **arboreal** primate species who primarily inhabit tropical forests. Gibbons manoeuvre trough the forest canopy using brachiation[15] to forage for fruit.

Their estimated lifespan is approximately 46 years. They weigh around 7 kilograms and can get up to 60 to 80 centimetres long

Southern yellow-cheeked gibbon groups are known for their loud vocalizations, particularly in the early mornings. These songs are believed to serve various purposes, including defending resources like territories and food sources, as well as attracting potential mates (Animalia, n.d.; The Editors of Encyclopaedia Britannica, 1999).

A collage of the gibbon, its food and habitat can be seen in Figure 3.13.

---

[15] *Branchiation " specialized form of arboreal locomotion in which movement is accomplished by swinging from one hold to another by the arms" (Britannica, n.d.).*

▶ **Diet**

▶ **Foraging and moving in the canopy**

▶ **Small monogamous groups**

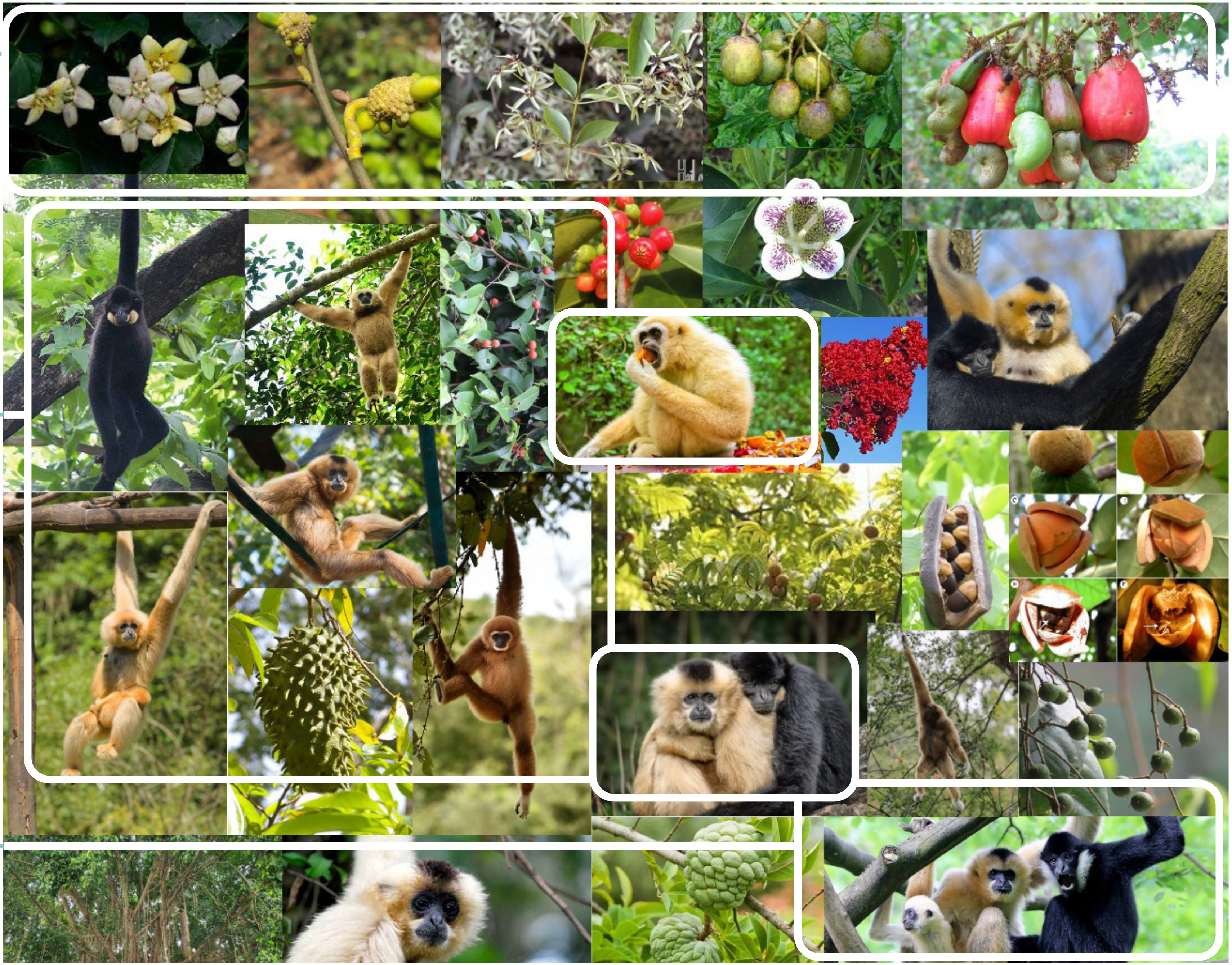


Figure 3.13- Collage food and habitat of the yellow cheeked gibbon

## 3.6.2 Black crested macaque


Figure 3.14- Black crested macaque

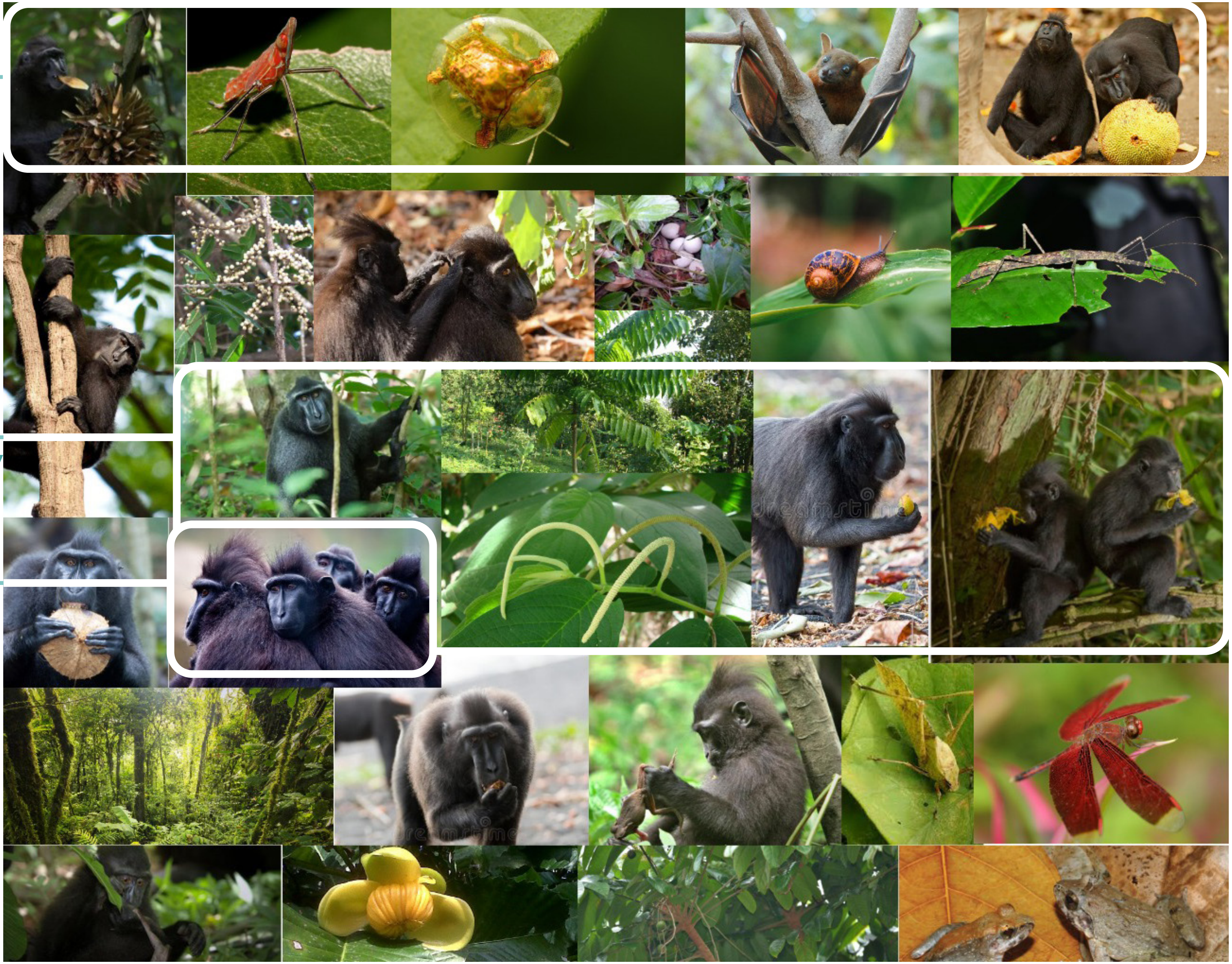
**The Black crested macaque** (Figure 3.14), scientifically known as Macaca nigra, is a critically endangered **Old World monkey** species found in Sulawesi. These macaques are characterized by their bright pink behinds.

Black crested macaques are **diurnal** creatures, with their social activities mainly occurring in the morning and rest in the afternoon. They prefer humid environments like tropical lowland and upland rainforests. The crested macaques primarily follow a **herbivorous, mostly frugivorous** diet. They also eat young leaves, stems of flowering plants and insects.

Their estimated lifespan is approximately 18 to 20 years. They weigh around 4 to 10 kilograms and can get up to 44 to 60 centimetres long.

These macaques exhibit strong territorial behaviour and form **large groups**, often consisting of 50 to 97 individuals. They have a **polygynandrous** mating system, where both males and females engage in multiple mating partnerships (Animalia, n.d.; The Editors of Encyclopaedia Britannica, 1999).

A collage of the gibbon, its food and habitat can be seen in Figure 3.15.



▶ Diet

▶ Foraging on the ground and understory

▶ Large group sizes

Figure 3.15- Collage food and habitat of the black crested macaque

## 3.6.3 Behaviour differences

A comparison analysis has been made (Appendix C) on the behaviour and cognitive abilities between these two primates. A big difference can be seen in the locomotion and foraging strategies of these primates. This can be explained by the difference in physical characteristics.

Gibbons have long arms and legs for their height, making them extremely qualified for fast locomotion trough trees. These locomotions include bipedal walking[16], quadrupedal climbing[17] and branchiating. They typically forage in trees in the high and middle canopy (Figure 3.13) and are rarely seen on the ground, as their physical characteristics makes them less suitable for these movements.

Macaques on the other hand, spent 60% of their time on the ground. Research has shown they moved and foraged significantly less when in trees. The foraging strategy of macaques is moving rapidly trough the understory, foraging briefly in small fruit trees and on insects (Figure 3.15).

These difference were also noticeable in the observational research conducted in ARTIS. The macaques were seen foraging in the grass, where they looked for insects and other food sources. The gibbons however, showed no interest in retrieving food on the ground and only foraged in the trees with the use of a feeding ball.

## 3.6.4 Behaviour differences of wild and captive populations.

To better understand the difference in behavioural profiles of the wild and captive populations of yellow-cheeked gibbons and black-crested macaques, an analysis was made based on existing data (Ching-Jong, 2022; Hai et al., 2017; Langelaar, 2021; Melfi, 2002). As can be seen in Figure 3.16 and 3.17, for both species there is a difference in behaviour profiles between the captive and wild population. Nevertheless, a Mann-Whitney U tests, revealed that there is no significant difference between the behaviour profiles of the wild and captive macaques. For the gibbons however, there was a significant difference. For this reason, the gibbon is chosen to further develop the device for.

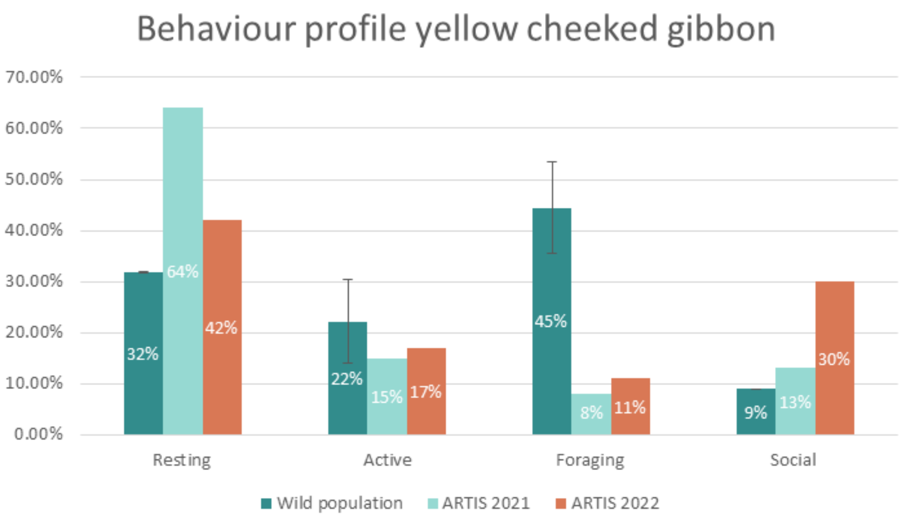


Figure3.16- Difference in behaviour profiles of the wild and captive populations of yellow cheeked gibbons (Ching-Jong, 2022; Hai et al., 2017; Langelaar, 2021).

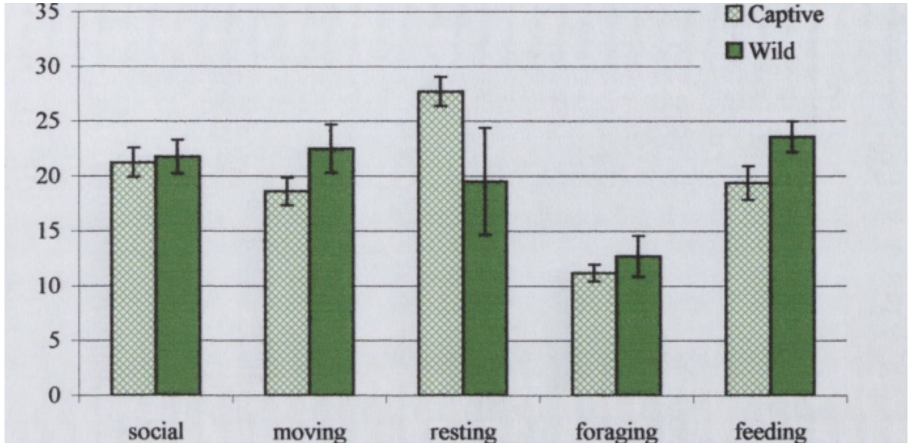


Figure 3.17- Difference in behaviour profiles of the wild and captive populations of black crested macaques (Melfi, 2002).

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[16] *Bipedal walking is walking on the back to limbs (Britannica, n.d.)*

[17] *Quadrupedal climbing is climbing with the use of the front and back limbs (Britannica, n.d.).*

## 3.7 Vision

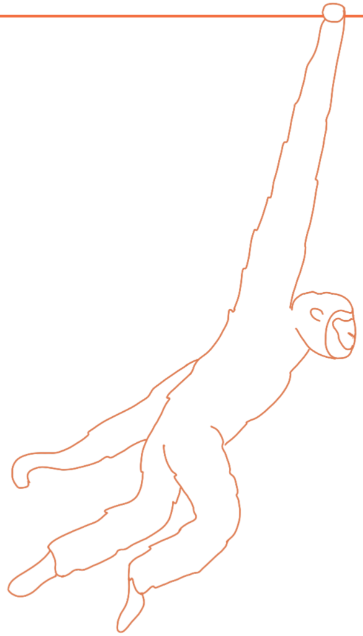
> The product should give the primates more autonomy over their feeding process while triggering the cognitive memory, decision making and problem solving abilities.

# Part B: Exploration

**In this section of the report, the ideation and conceptualization phases are presented, the main requirements are discussed and the focus points are elaborated on.**

# 4. Ideation

The insights gained from the analysis were used as inspiration for the idea generation. To begin the ideation phase a question was introduced; How to retrieve food? Based on these answers, ideas were generated. The ideas were clustered into 6 clusters, and a design direction was chosen; **A device that opens and closes inspired by an exotic fruit.** From this design direction, further exploration was conducted by creating prototypes and sketches. Based on these prototypes, a new question was formulated; How to open and close by manipulation of the user? The design direction was further defined by these explorations; **A device that opens with a peeling movement and closes automatically.**



# 4.1 First ideas

The first 'How to' question is related to the foraging behaviour: **How to retrieve food?** Several words have been written down and used to sketch simple ideas (Appendix D)

The clusters are shown in Figure 4.1 below. As can be seen, most ideas were generated in the opening and closing cluster. This cluster showed the most promising ideas.

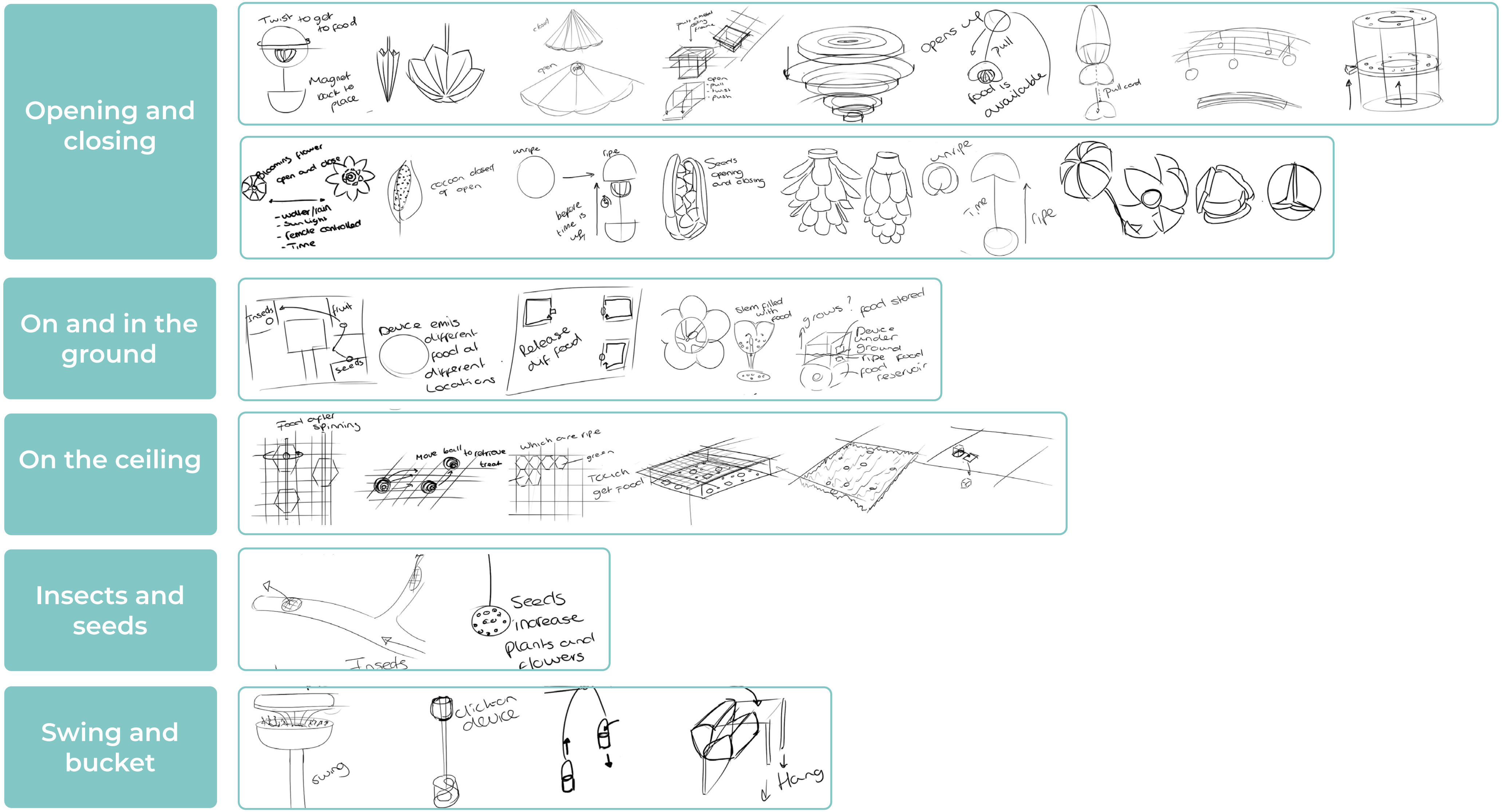


Figure 4.1- Clusters ideation

# 4.2 Design direction

Based on the wishes of the stakeholders and the formulated vision, a design direction was chosen; **A device that opens and closes inspired by an exotic fruit.**

## 4.2.1 Second clustering

The opening and closing ideas, as seen in Figure 4.1 are inspired by the exotic fruits found in the habitat of the gibbons. Since gibbons are frugivores these ideas were designed to mimic the wild foraging behaviour the most, and are therefore chosen to investigate further. When looking at the first ideas of opening and closing, two clusters could be made; movement in control of the animal and movement out of their control.

In the wild, animals are exposed to different kind of challenges. When foraging for example, gibbons have the ability to move around their habitat and choose what they want to eat. They need to make decisions beforehand to decide their travel paths. However, there are factors that are out of their control, for example when and where fruit is available.

Looking at their behaviour in captivity, this is different. The animals are not in control of when and what they are being fed. It is also impossible for them to decide to travel to get more or better food. To give the gibbon more autonomy and to stimulate their cognition abilities, the device should mimic these challenges of the wild.

As can be seen in Figure 4.2, the movements within their control are the different ways they can manipulate the device in order to retrieve the food. The movements out of their control can be either initiated by the zookeepers, time or the weather.

## 4.2.2 Second ideation

A second ideation round was conducted based on the movements in control of the gibbon. The question for the ideation was:

**How to open and close by manipulation of the user?**

The ideas can be seen in the Figure 4.3.

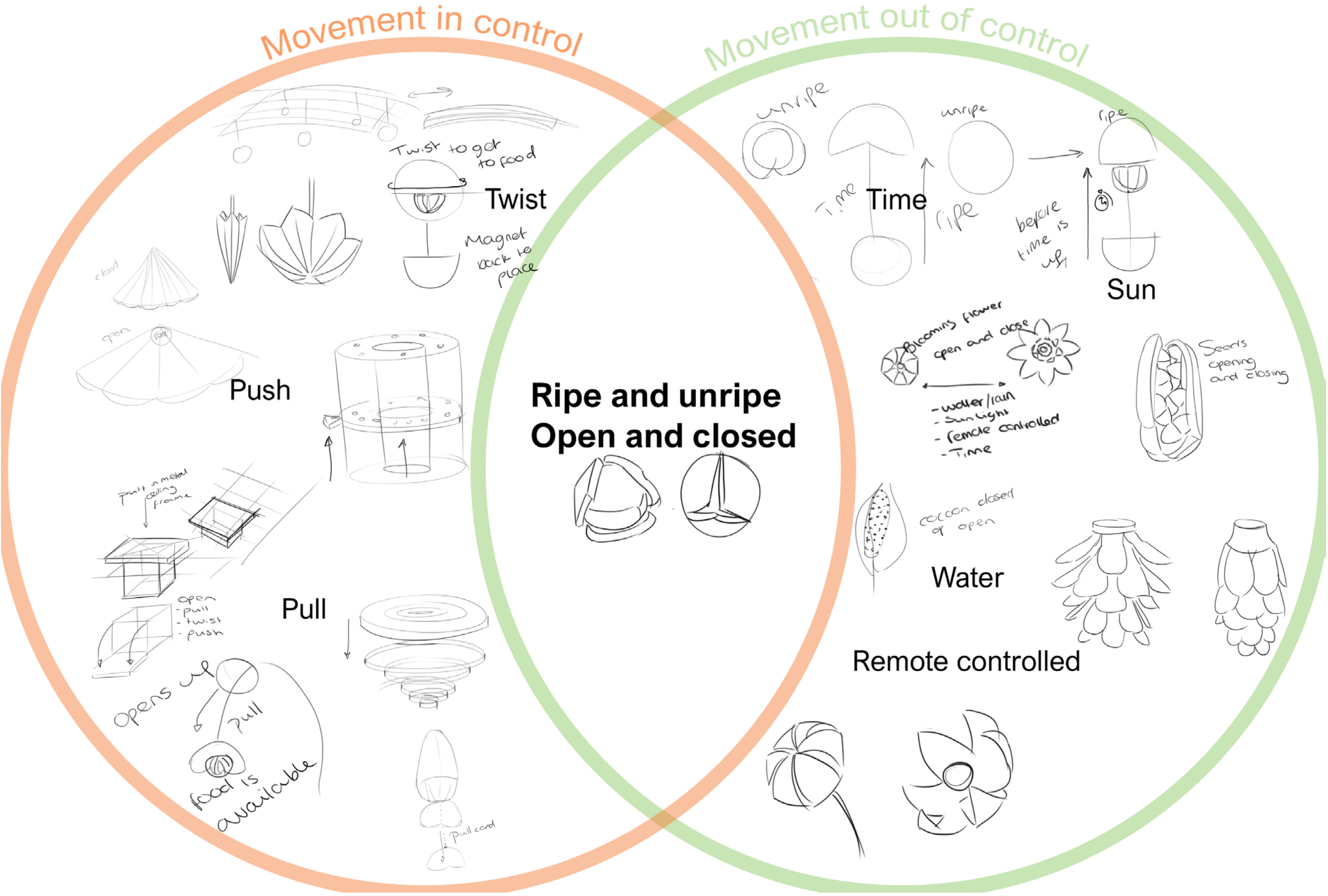


Figure 4.2- Opening and closing

# 4.3 Movements

## 4.3.1 Movements in control

The second set of ideas were categorized in rotational movement and linear movement. From the most promising ideas, simple models were made.

### ▶ Rotational movement |

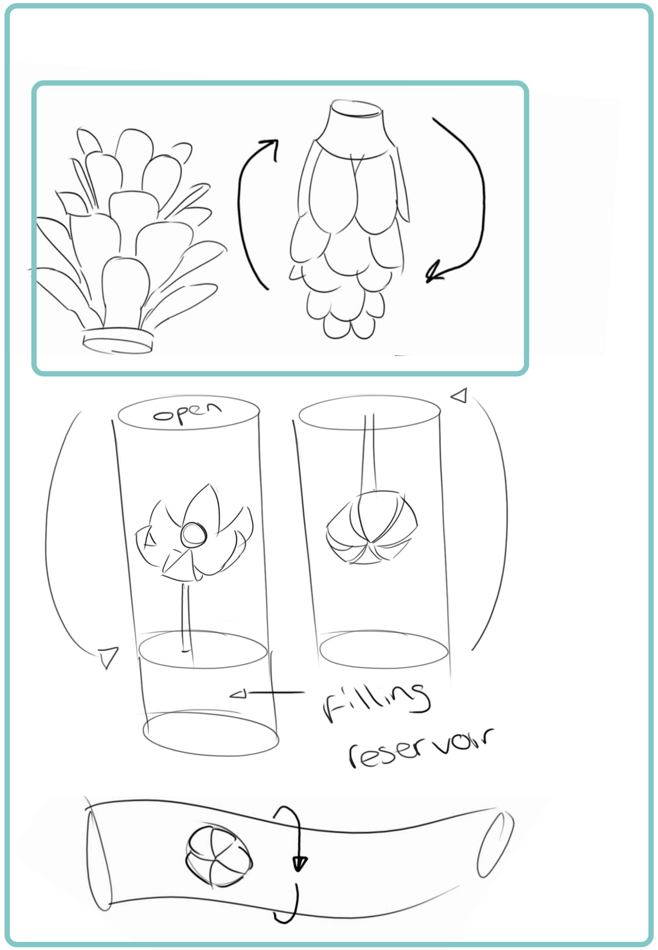


Figure 4.3- Ideas rotaional  movement

### ▶ Linear movement |

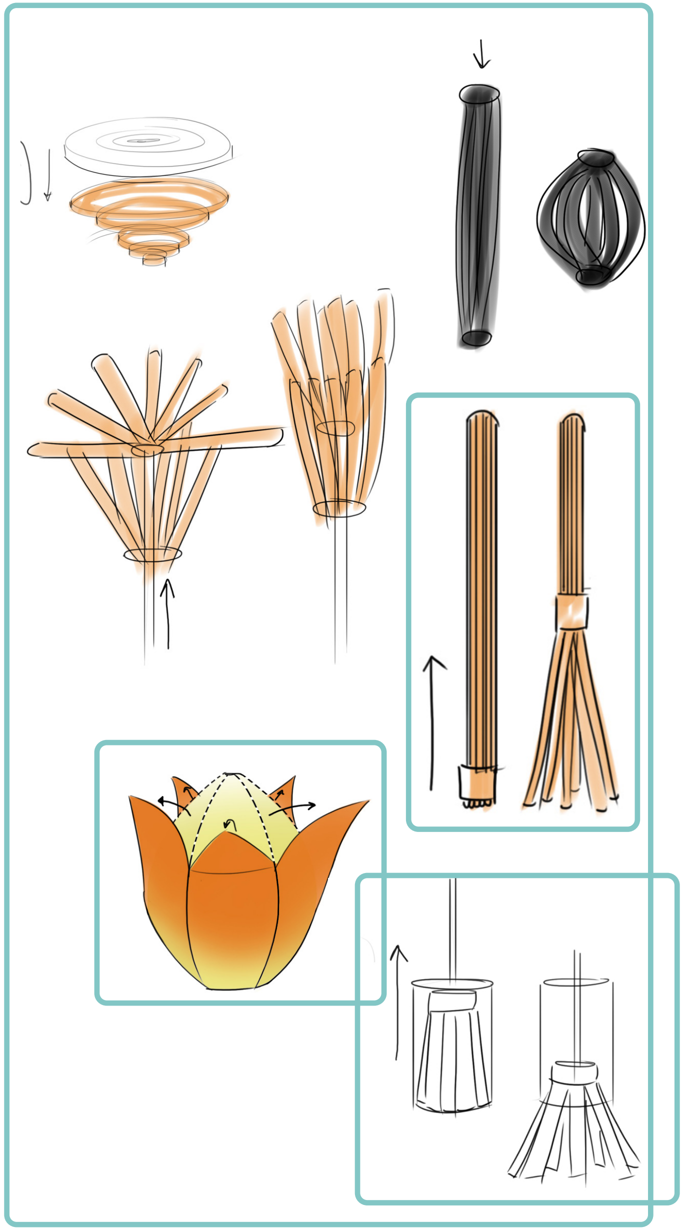


Figure 4.4-Ideas linear movement

## 4.3.2 Movements out of control

To create a device that is enriching, it is important to stimulate their cognitive abilities. Therefore, as mentioned in section 4.2, the movement out of the control of the gibbons has to be incorporated. Important for this movement is that the device can function on its own, therefore it needs to open and close automatically.

# 4.4 Prototypes

Figure 4.5-Prototypes

# 5. Conceptualisation

## 5.1 Structure of the concept

Based on the ideation phase and the chosen design direction, the structure of the device was designed (Figure 5.1).

It consists of 3 states. The first phase is the unripe state, the product is locked and can not be opened. Cues to signal to the primate that the device is unripe can be a green colour or no smell. The second state is initiated when the time interval has passed. Other parameters can for example be rain or sunlight. In the second state, the device is unlocked and can be opened by the primate. Cues for this state can be a yellow colour, smell or sound. The last state is when the gibbon interacts with the device and opens it to retrieve the food. After all the food is gone or when a certain amount of time has passed, the device goes back to the first state.

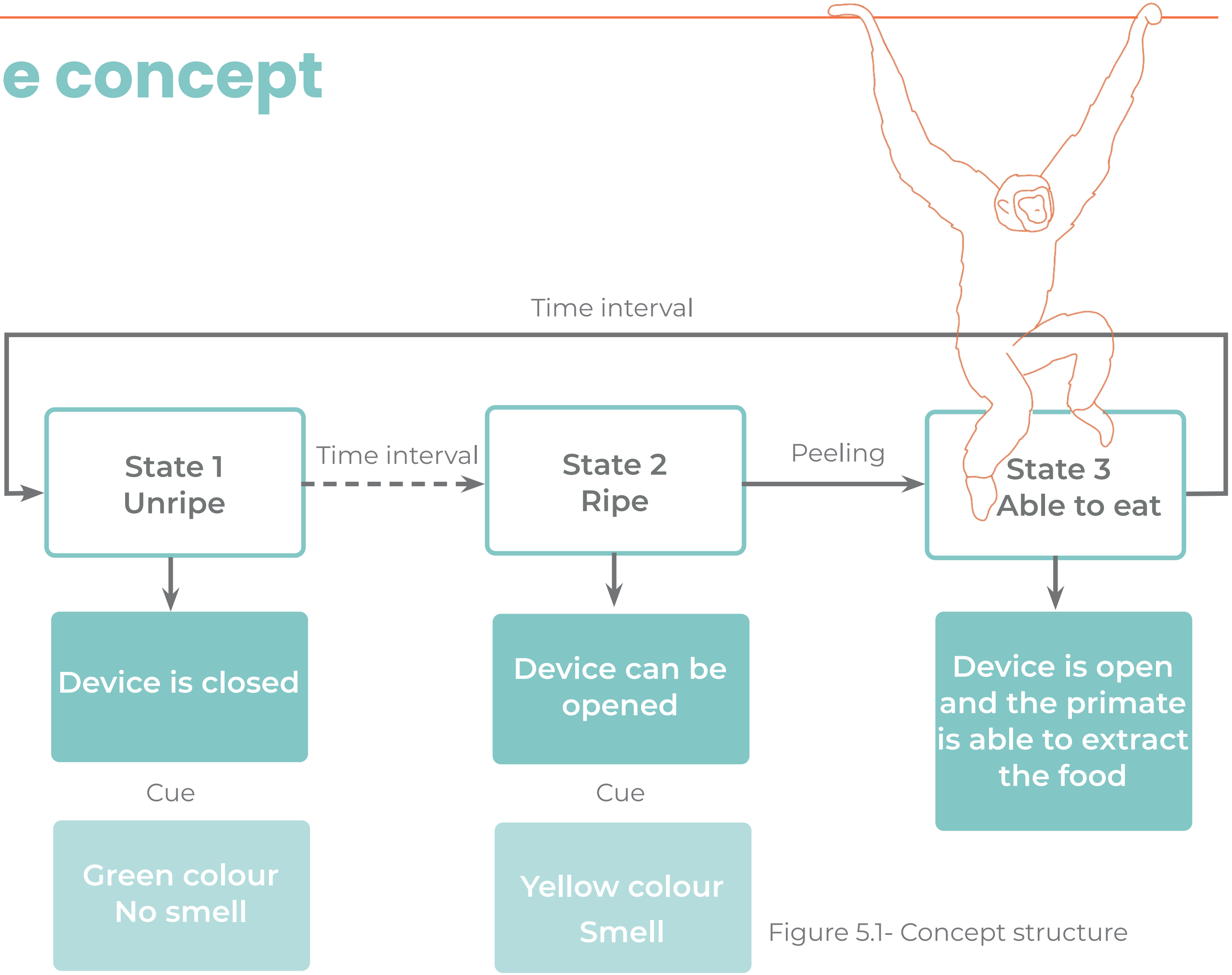


Figure 5.1- Concept structure

## 5.2 Concept direction

A concept direction was chosen based on the exploration, and supported by the sketches and prototypes. The two 'How to' questions are answered (Appendix D);

**How to retrieve the food?**

**How to open and close trough manipulation of the user?**

The concept is inspired by an exotic fruit that is peeled to retrieve the fruit. Since primates have their diet for the most part consist of fruit, this manipulating is closely related to their foraging behaviour in the wild. The device can be peeled open and the food inside can be retrieved.

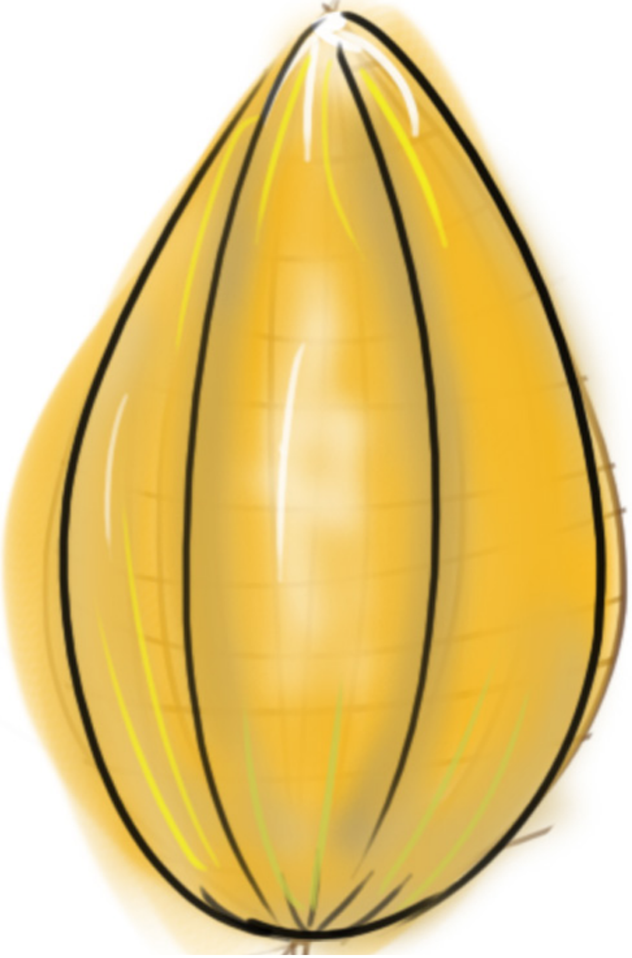


Figure 5.2- Device closed

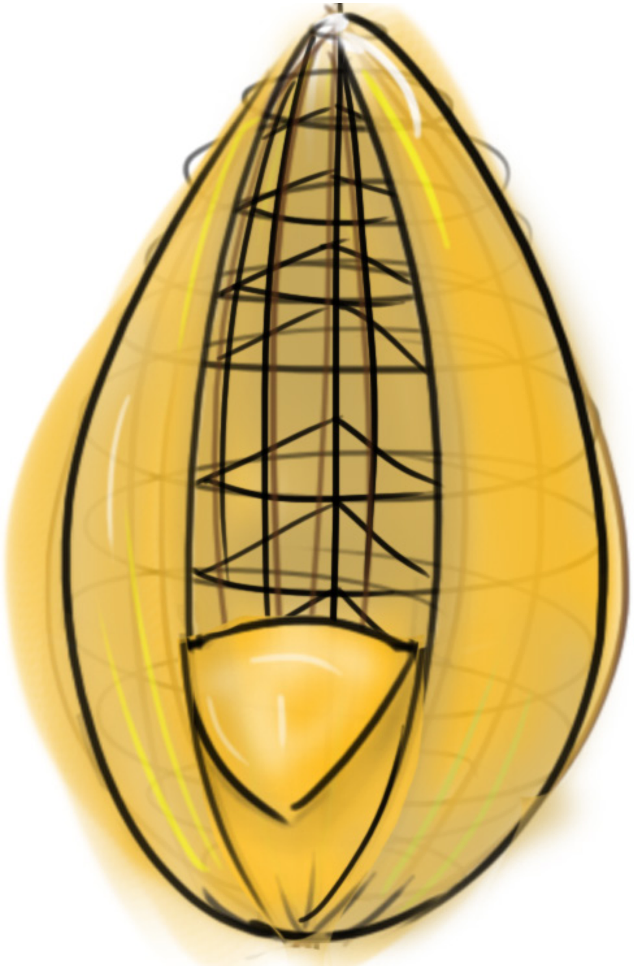


Figure 5.3- Device one petal open

Figure 5.4- Device open

# 5.3 Further exploration

From the concept direction, further exploration was conducted with a 'How to':

**How to put the food inside?**

Sketches (Figure 5.5 and Figure 5.6) and prototypes (Figure 5.7) were made to answer this question.

## 5.3.1 Sketches

### ▶ Inside the petals |

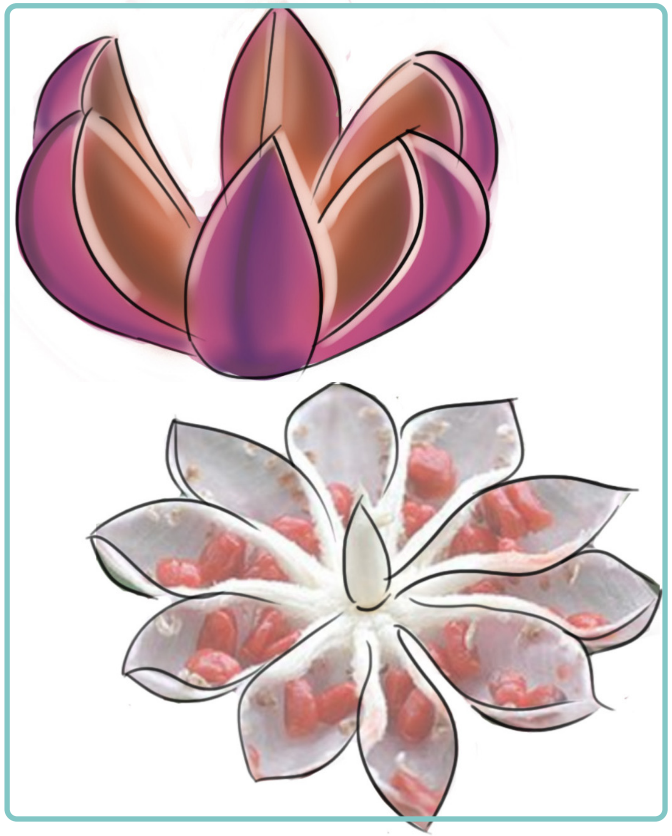


Figure 5.5- Food inside the petals

### ▶ In the inside |

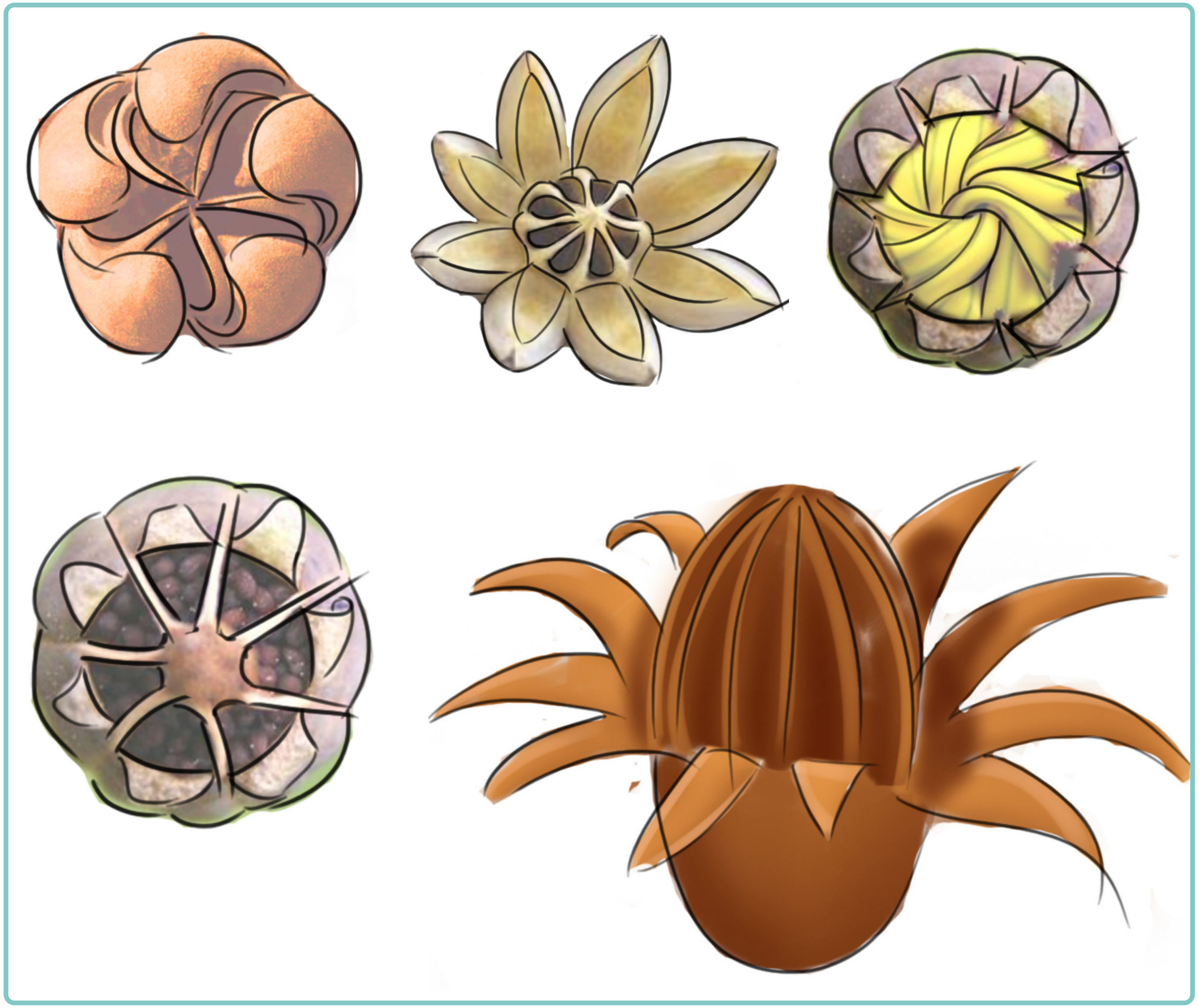


Figure 5.6- Food on the inside

### 5.3.2 Prototypes

For the opening and closing of the device, inspiration was taken from soft robotics (Appendix E). Based on the structure of these mechanisms, more prototypes were made.

Figure 5.7- Prototypes

## 5.4 Final concept

Using the exploration form the prototypes, 'How To's' and sketches, a concept drawing is made (Figure 5.8). The concept consists of ; (1) The colour change; (2) The two ways to hang the device to accommodate for the different foraging behaviour; (3) The opening and closing mechanism discovered during the prototyping; (4) The animals for whom the device is suitable for based on a meeting with head of primates from ARTIS.

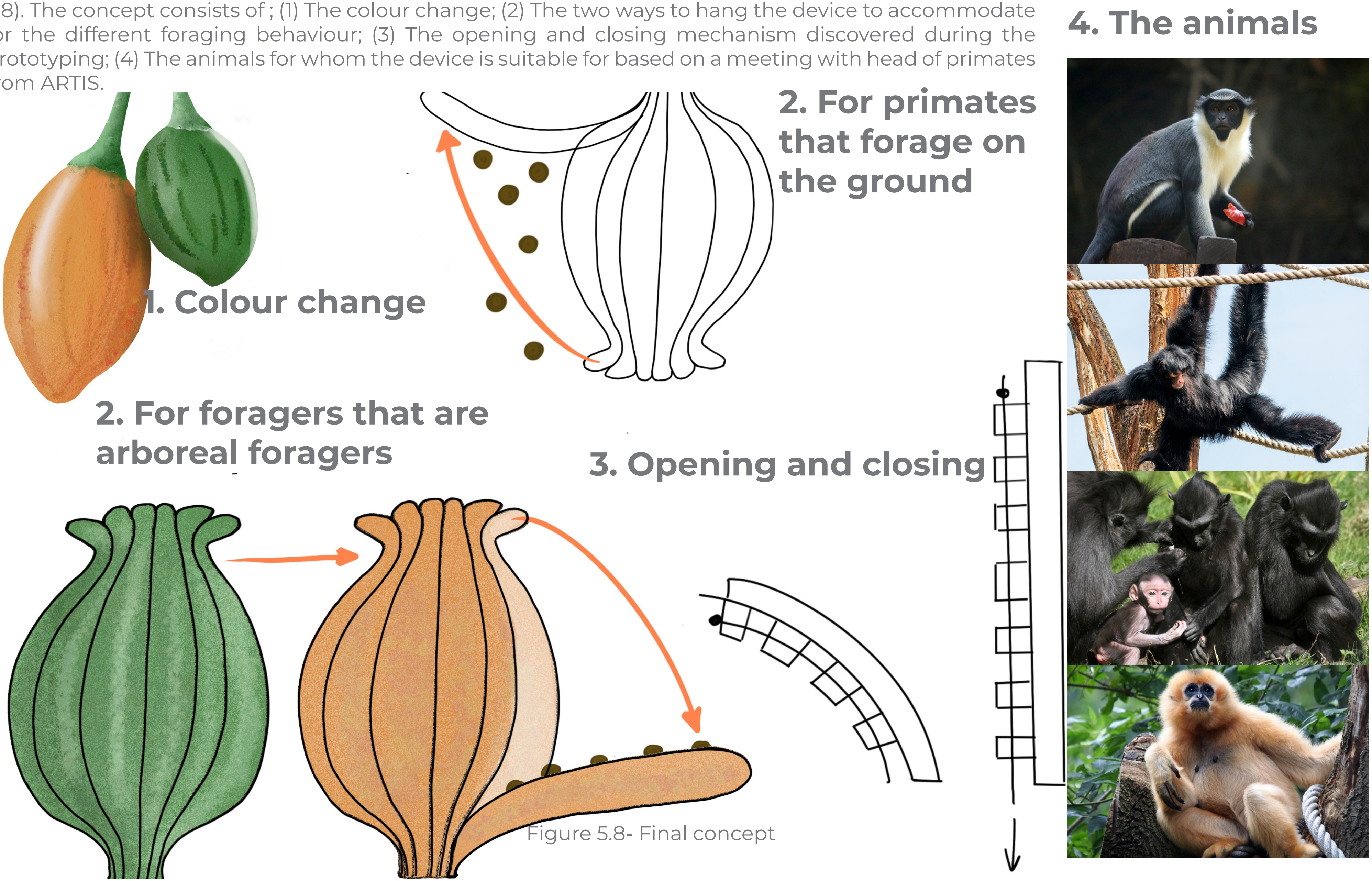
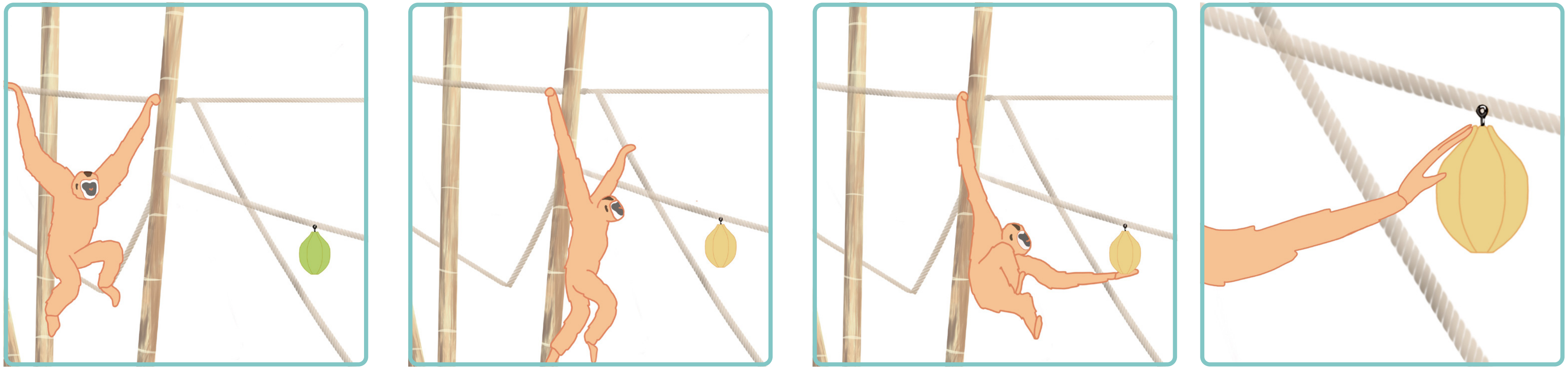


Figure 5.8- Final concept

# 5.5 Storyboard

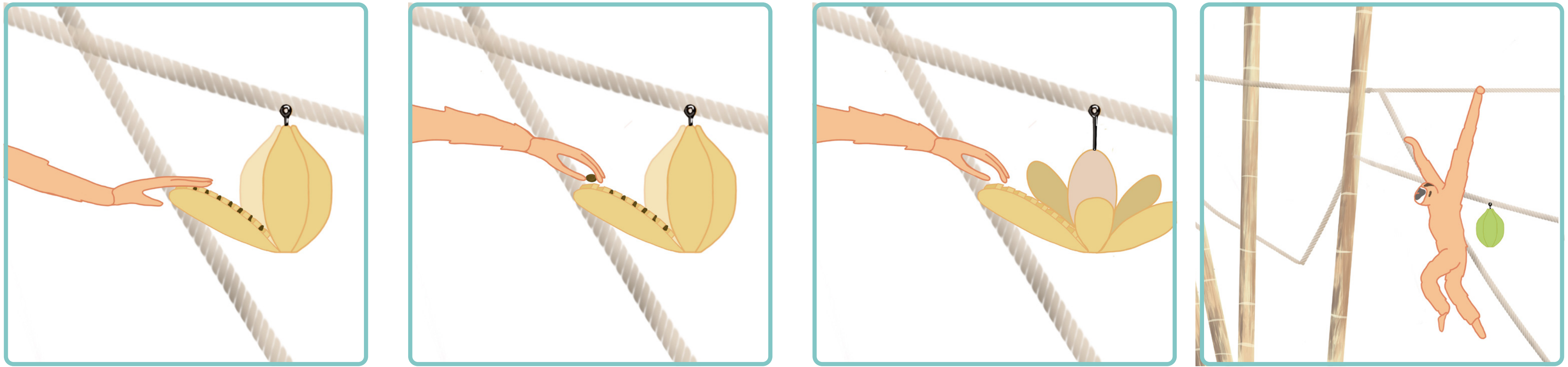


The device is green when not "ripe" and the gibbon is not interacting with it.

The device changes colour to yellow when it is "ripe". The gibbon recognises the change.

The gibbon approaches the device.

He touches the device and tries to open it.



The gibbon peels open the device and sees the food inside.

He grabs the food inside.

When all the petals are peeled and the food is gone

He leaves the device and it closes on its own and turns green again.

Figure 5.9- Storyboard

# 6. Main Requirements

Throughout the project, numerous requirements were identified. These have all been documented in the List of Requirements (LoR). The excel sheet including all the requirements can be found in Appendix A. The structure and general focus points of the list are discussed in the following section. The requirements are derived from literature research, interviews with stakeholders, observations and experiments. In the "Final design" chapter, the important requirements are further explained.

## 6.1 List structure

Table 6.1- List structure of the requirements list

| Category | Reference | Description | Priority | Source | Notes |
|---|---|---|---|---|---|
| What topic does this requirement cover<br>↓ | Reference number<br>LoR-1.1<br>LoR-1.3<br>LoR-1.3<br>↓ | What does this requirement mean<br>↓ | Is it a top requirement, demand or wish<br>↓ | Who values this requirement most?/ Who suggestes this?<br>↓ | Additional remarks<br>↓ |

## 6.2 Focus points

▶ **Usage by the primate |** To design an appropriate enrichment device for a specific animal, it is important to specify the goal of the device. For this device the goal is; promote the foraging behaviour of the primates to mimic the wild-type time budget. This reduces the time animals are inactive or resting. This is necessary as zoos want to encourage natural behaviour profiles of animals into the wild, resulting in more psychologically healthy animals.

**Related requirements:**
LoR-3.1 till LoR-3.15

▶ **Usage of the zookeeper |** To maximise the use of the device, it should be user friendly for the zookeepers. Therefore requirements are added to minimise the time needed for the filling, cleaning and installation of the device.

**Related requirements:**
LoR-3.16 till LoR-3.26

▶ **Usage of the researcher |** Besides using the device as an enrichment device, ARTIS also wants to use it for research purposes. ARTIS is collaborating with the University of Amsterdam to research the intelligence of primates, specifically, their ability to recognise time intervals. Therefore the device should be remote controlled.

**Related requirements:**
LoR-3.27 till LoR-3.28

▶ **Safety |** The safety of the design is extremely important. These requirements are applied to all the components of the design; the material, electronics, assembly and weights. The safety of the device also concerns the food safety. The material needs to be food safe and the parts have to be designed for easy cleanability. Built up of bacteria have to be avoided.

**Related requirements:**
LoR-4.1 till LoR-4.23

# Part C: Iterations

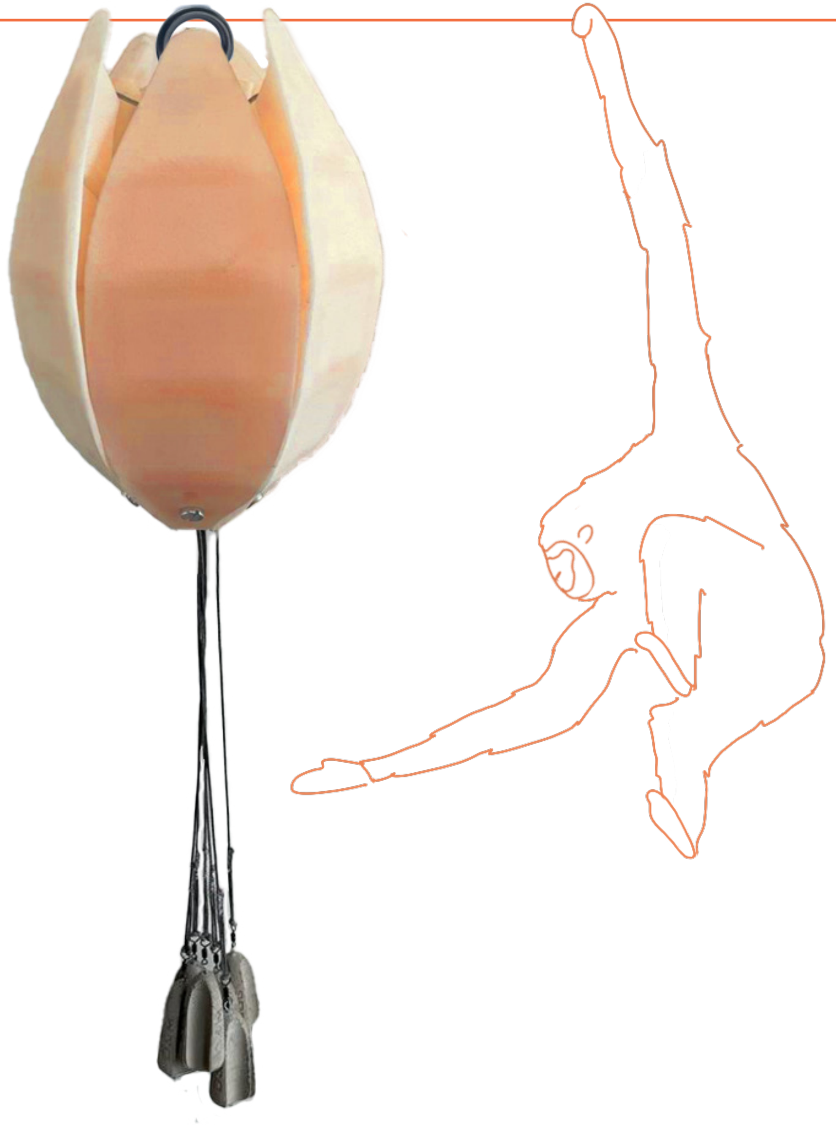
**In this section of the report, the relevant iterations and decisions of the final design are presented. The motivations behind the choices are further elaborated on.**

**Chapter**

# 7. Final Design

In the "Final design" chapter, there will be elaborated on the iterations and choices made. For the embodiment of the design, the decisions are substantiated by literature research, stakeholder interviews, experiments and user testing. These insights are used to draw up a list of requirements.

Each component of the final design and its iterations will be discussed in detail in the following sections.



# 7.1 Look and feel

Most primates are frugivores. The look and feel of the design is therefore inspired by one of the favourite fruits of a wild gibbon population, annona coriacea Mart. (Annonaceae) (Appendix E) (Melfi, 2002). This exotic fruit has an interesting ripening process. The petals expand over a period of 24 hours until the flower is fully open, displaying the pulp.

Few studies have been conducted to better understand the aesthetic and object preferences of gibbons or non-human primates in captivity. Research on the wild population however, has shown a correlation between the preferred visual characteristics of food and the sensory cues of the ripening process of fruit (Dominy, 2004).

The look and feel vision created for the object is based on these few researches and tests.

▶ **Shape |** A study in primate object preference has revealed that there is a preference of spherical objects over cuboid ones. The results show orangutans touch and manipulate spherical objects significantly longer (Ebel et al., 2020). This also corresponds with the wild behaviour preference in visual characteristic of ripe fruit.

For this reason, the shape was chosen to mimic forms found in the forest.

▶ **Colour |** Apes and Old World monkeys, have full colour vision and locate food through the use of vision and scent (Prescott, 2006). Research found that gibbons have clear preferred characteristics of food, whenever fruit is abundant in the forest, meaning they have the luxury of choice in their diet (Frechette et al., 2017). Ideal gibbon fruit has a yellow colour, a thin skin, no seeds and is large with a juicy-soft pulp. When fruit availability was high they based their choice on seed width (<21 mm), colour (yellow-orange), and fruit weight (1–5 g) (McConkey et al., 2002). Other studies revealed that colour is the most frequent determinant characteristic of fruit selection among primates. Primates prefer yellow and orange fruit as well as bright coloured once. This could be explained by colour signalling the availability of nutrients in the fruit.  (Gautier-Hion, 1990; Julliot, 1996; Leighton and Leighton, 1983; Raemaekers, 1977; Sourd and Gautier-Hion, 1986).

Contradicting to these findings in the wild, ARTIS prefers novel objects in the enclosure to blend in with the environment. This is why, when buying enrichment devices in the past, they have chosen as green or black colour. However, to increase the interest and willingness of the primate to interact with the object, the colour of the device will be a orange/ yellowish colour.

▶ **Texture |** A requirement of the device is that it has to trigger different senses, making it a multi sensory design. This is found to be one of the determining factors when evaluating the success of an enrichment device (Wells, 2009; Young, 2003). Besides their sense of smell and sight ,primates are also responsive to sensations such as touch, temperature and pressure. There is a clear preference towards soft warm materials over cold and hard ones (Ebel et al., 2020; Prescott, 2006). Observations of foraging primates suggests that fruit texture is a cue associated with the nutrition value (Dominy, 2004). This indicates their should be a preference in texture in objects. However, no research can be found to support this claim.

▶ **Size |** The size of the device and the consisting parts, were modelled based on the size and shape of the hands of gibbons. A comparison of human and gibbon hands can be seen in Figure 7.1 below with the product besides it.

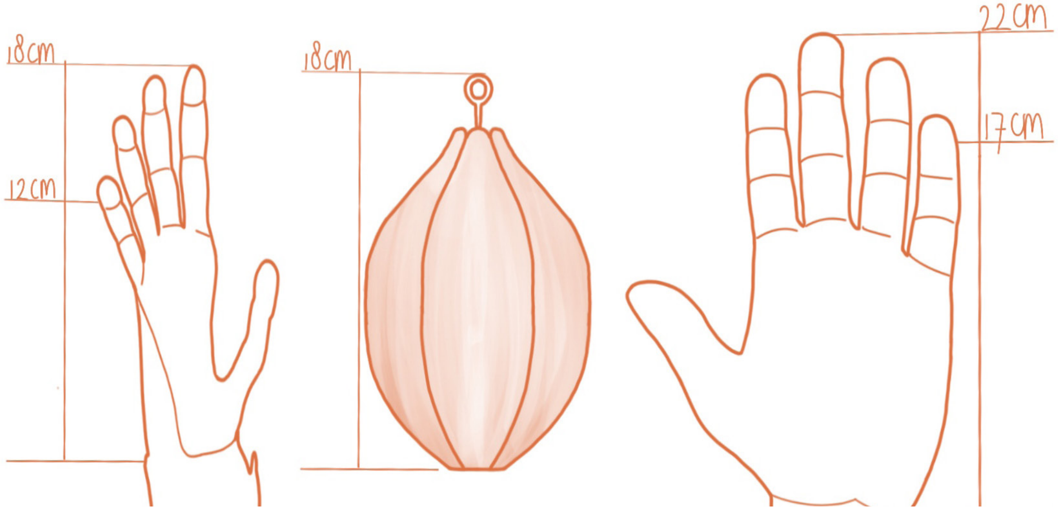
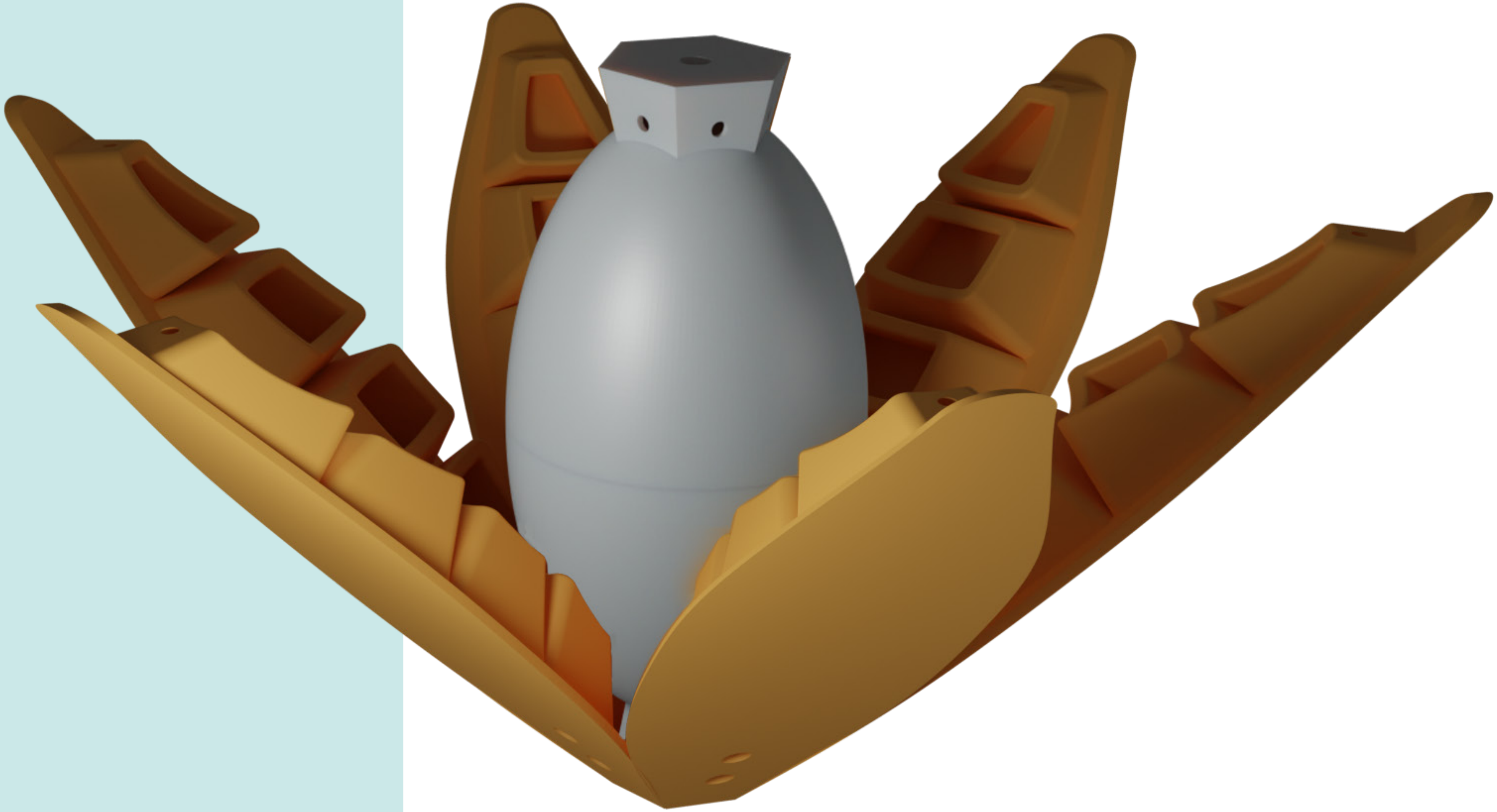


Figure 7.1 - Size comparison

# Petals



## 7.2 Petal design

The outside of the device consists of 6 petals. Every petal contains a peel and 5 ribs. The function of the peel is to close of the device, while the ribs give structure to the petal and contain the food inside.

While exploring shapes and materialization of the petals, several requirements were taken into consideration. The most important requirements can be seen in the table below.

Table 7.1 - Important requirements

| N. | Demand and wish | Requirement |
|---|---|---|
| LoR-4.12 | The product should have rounded edges | |
| LoR-4.13 | The animal's digits, limbs or other bodily appendages can not become trapped inside any part of the device | |
| LoR-4.14 | If the device breaks , it should not break into sharp fragments | |
| LoR-4.17 | The device or any part of it can not be swallowed | The connections should not be able to break at the maximum strength of the gibbon |
| LoR-4.1 | The material must be tough | Minimum tensile strength of 10 MPa |
| LoR-4.2 | The material should not be toxic | |
| LoR-4.3 | The material must be food safe | The material must be food contact safe |
| LoR-4.4 | The material must be cleaning-chemical proof | The material must have a excellent sterilizability (ethylene oxide) |
| LoR-4.5 | The material should not break when the maximum strength of the gibbon is applied by either hands or teeth | Minimum yield strength of 10 MPa |
| LoR-4.6 | The material should not break when it drops on the floor of a height of 5 meter | Minimum fracture toughness of 0.1 MPa.m^0.5 |
| LoR-4.7 | The material must be elastic | Maximum Youngs modulus 0.1 GPa |
| LoR-4.8 | The material must be waterproof | The materials must have excellent resistance to both fresh and salt water |
| LoR-4.9 | The material must be UV resistant | The material must have good UV radiation resistance |
| LoR-4.10 | The material must be light | The material should have a density between 500 and 2000 kg/m^3 |
| LoR-4.11 | The material must not catch fire easily | The material must either be self-extinguishing or non-flammable |

### 7.2.1 Materialization

Initially, the prototype was made of two materials because of the function of the different parts, a flexible material for the outside peel and a hard material for the inside ribs. However, due to legislations (Animal and plant health inspection service, 2023) and the requirements LoR-4.14 and LoR-4.5, the ribs should not be able to break of easily. An alternative solution was therefore explored, where both the peel and ribs were made of the same material. In this manner, no glue or attachment options were needed, reducing the risk of breaking. Thus, increasing the strength and durability of the device. The initial requirements were changed into measurable ones which are used in the material analysis.

In Figure 7.2 and 7.3, the charts of the materials that passed the selection stages are shown. The Young's modulus versus the Yield strength and the tensile strength versus the fracture can be seen.

The materials that passed the stages are two types of Fluoroelastomers (rubber), two types of silicones and TPU.

As can be seen, TPU scores the best in tensile strength, yield strength and price (Figure 7.4). It also scores the same on fracture toughness as the average of the silicon. To make a decision on the material, the production processes were also investigated.

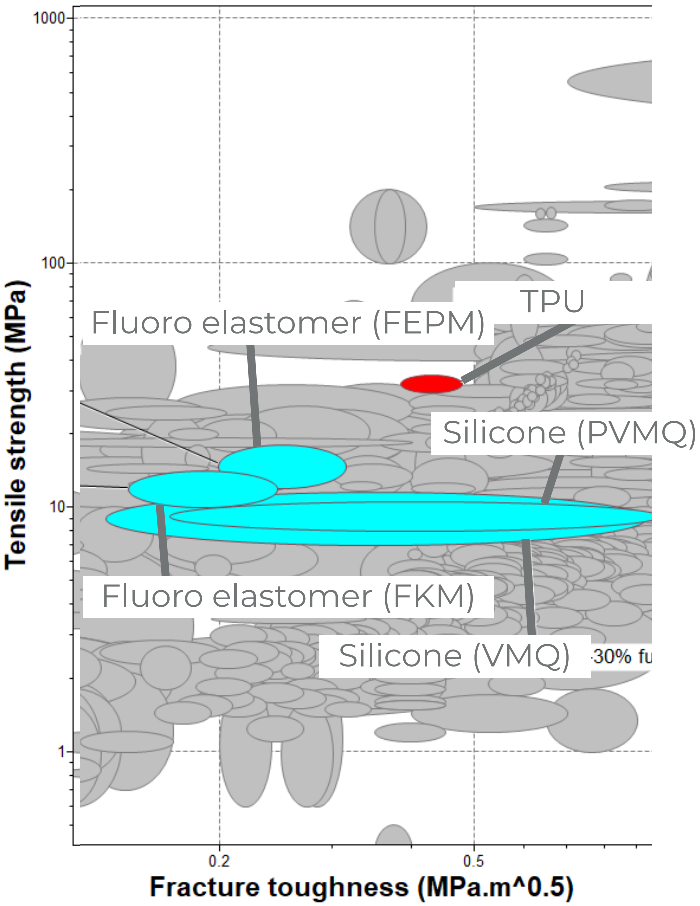


Figure 7.2- Fracture toughness vs tensile strength

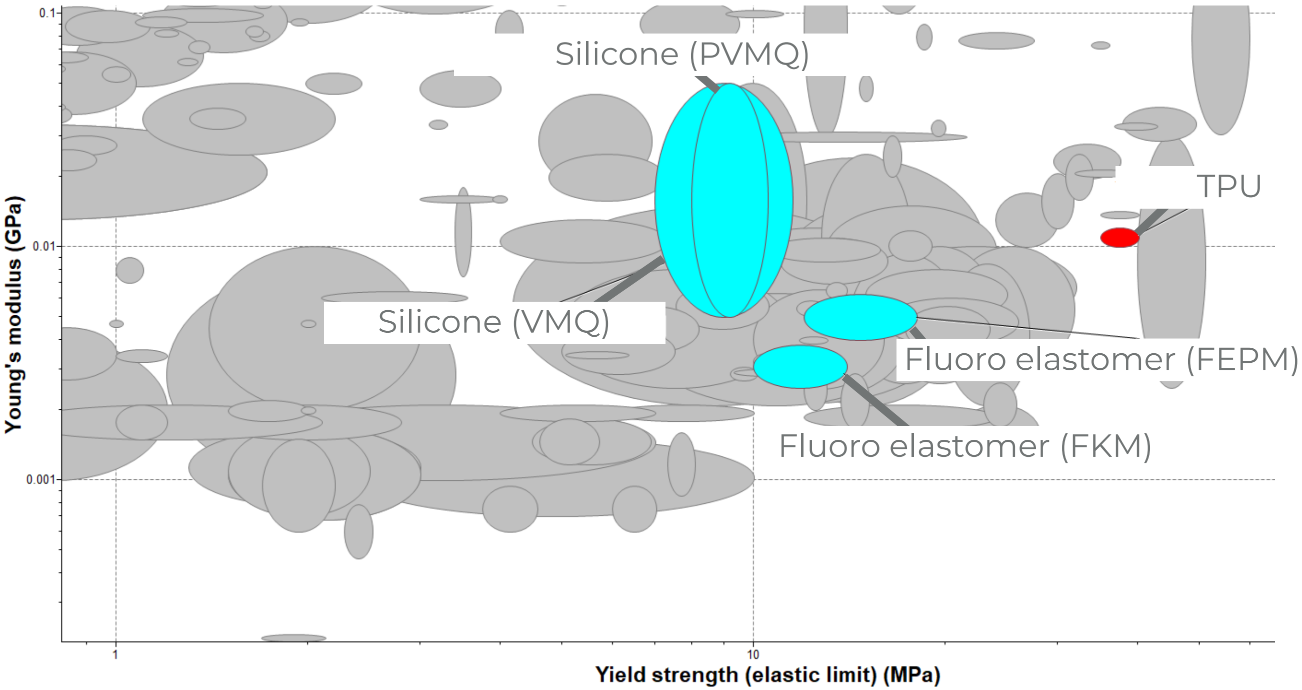


Figure 7.3- Young's modulus vs yield strength

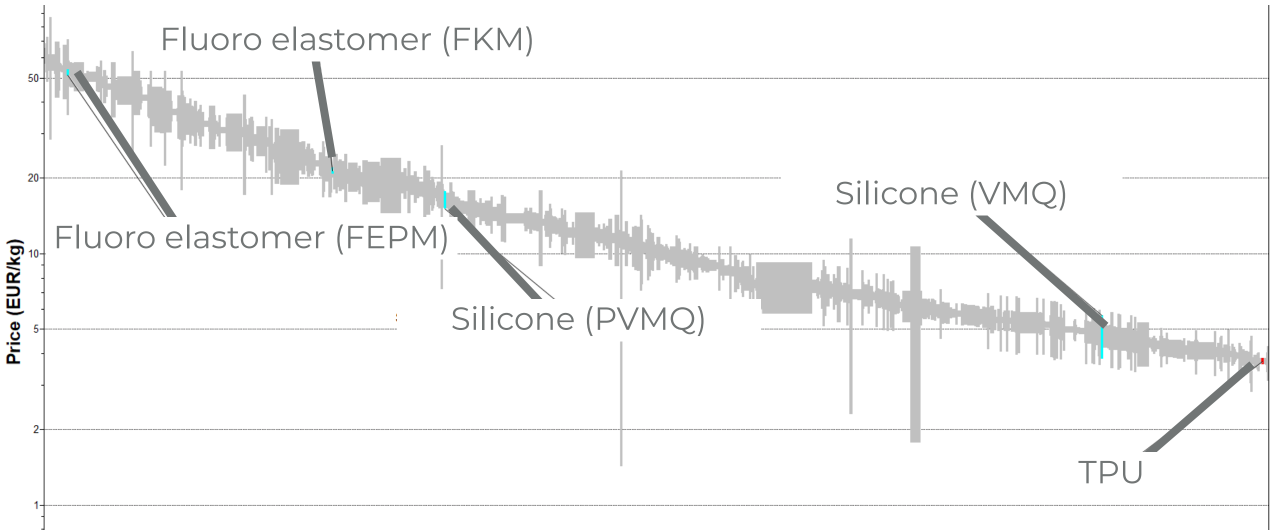


Figure 7.4- Price comparison

## 7.2.2 Manufacturing

For the material choice, the different manufacturing processes of the materials used in the analysis were investigated.

Figure 7.5- O-rings from Fluoroelastomer (Vilton, n.d.)

Fluoroelastomer is a rubber that is mostly used in commercial products such as O-rings (Figure 7.5), wearables, fuel hoses and space applications. The material is suitable for injection moulding and extrusion (CES, n.d.). It is typically selected because of the high temperature and chemical resistance. The material however, can not be used for rapid prototyping methods and is highly expensive (Vilton, n.d.).

Therefore the material is not used for the device.

Figure 7.6- Food bowls and spoons made from silicone (Bronca, 2021).

Silicone is a rubber that is used for a wide range of different products. Seals and hoses are made from this material but it is also commonly used for food (Figure 7.6) and medical applications (CES, n.d.). The material is suitable for injection moulding and extrusion. Since recently, it is also possible to 3d print silicone using stereolithography (SLA 3d printing). SLA uses an ultraviolet laser to harden resin into the proper shape. This creates fast and easy fabrications of silicone parts (Formlabs, n.d.).

Another method for rapid prototyping of silicon parts is moulding. A mould can be made using 3D printing and silicone can be poured into this mould.

However, due to the complexity of the petal part and the negative draft angles, the mould would become too complex. Also, with no access to a SLA 3D printer, silicone is not the ideal material and will therefore not be used for prototyping the design.

Figure 7.7- Flexibility of TPU made with FDM (3D people, n.d.)

Thermoplastic polyurethanes (TPU) (Figure 7.7) is a flexible rubber-like material that can be processed using injection moulding, extrusion and blow moulding (CES, n.d.). For rapid prototyping this material is suitable for using fused deposition modelling (FDM) also know as 3D printing with filament. TPU however, can also be printed with selective laser sintering (SLS). SLS is a production method that uses powder and a laser to melt the material and fuse it into a solid 3D product. This printing method is ideal for more functional applications, such as low volume production of end-use products. It allows for low cost, strong and durable parts. It also has a higher form freedom compared to FDM (Formlabs, n.d.).

For the prototyping phase, TPU was used with a FDM printer. For the final product however, the parts were ordered by an external company that has SLS printers available. The parts have also been vapour-polished and coated with epoxy to make the material food-safe.

### 7.2.3 Petal iterations

Figure 7.8- Initial design

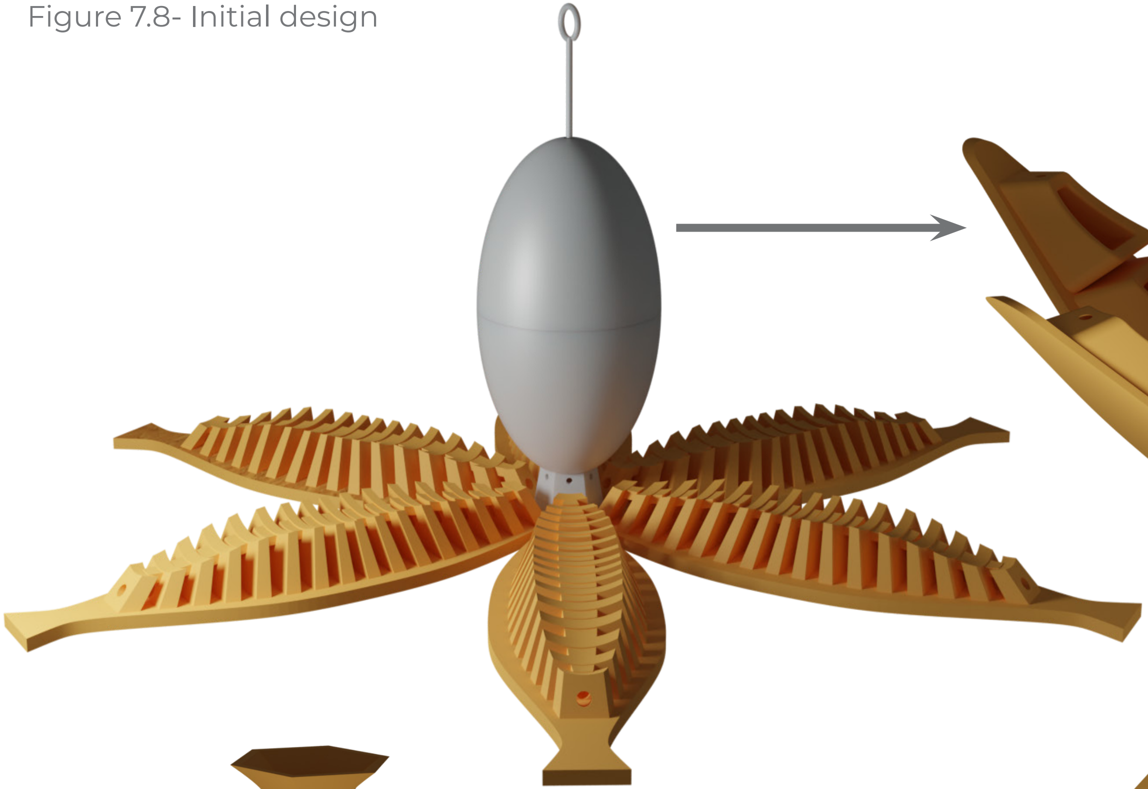
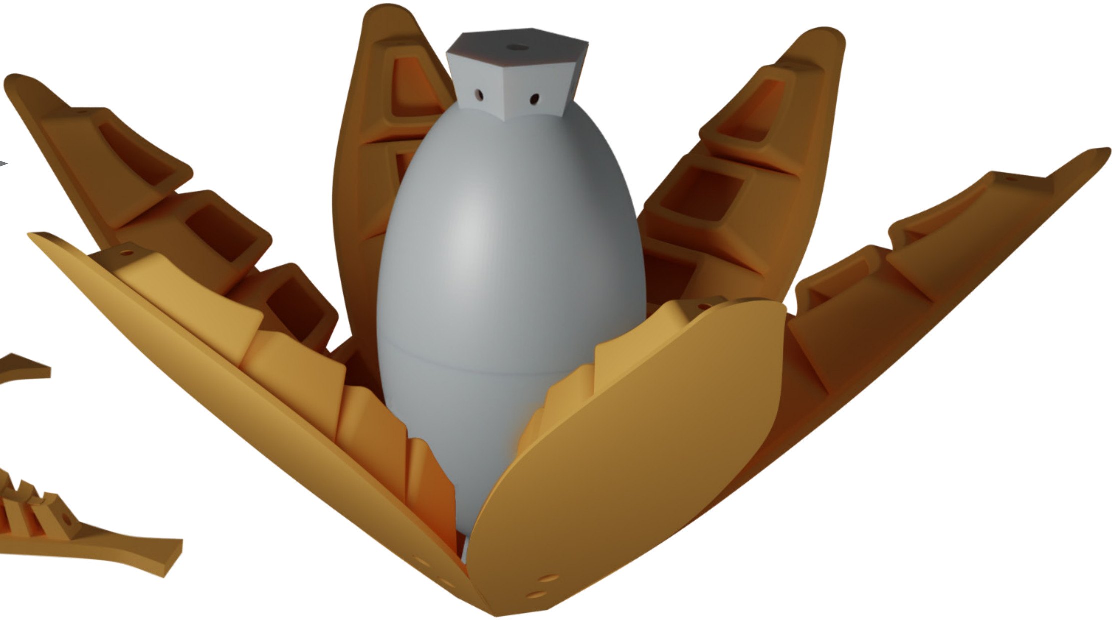


Figure 7.10- Final design



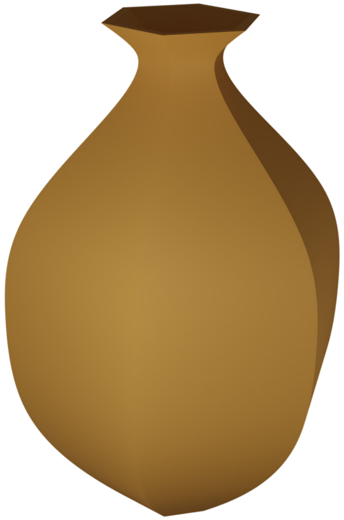


Figure 7.9- Initial shape outside

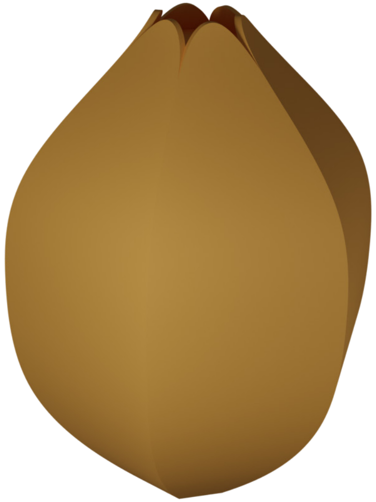


Figure 7.11- Final shape outside

## 7.2.3 Petal iterations

To create the design from one material, changes were made to the initial design. The initial design was based on the prototypes from section 5.3.2 and can be seen in Figure 7.8 , 7.9 and 7.12a.

Based on insights gained from a TPU expert, the 3D model was redesigned. The ribs were simplified and enlarged to 3D print them in TPU. Additionally, the small ribs were impractical to fill with food, hard to clean and fragile.

Altering the setting of the 3D printer to print the design from TPU was quite challenging (Figure 7.12b). To quickly conduct a user test with the gibbons, a change was made to the design. The interaction to be tested was the opening of the device and retrieving of the food. Therefore, new models were made to answer the following question: How can the PLA material still behave as a flexible material? Two directions were investigated, 'print in place hinges' (Figure 7.12d) and 'cuttings' (Figure 7.12c). Both were tested to withstand the forces applied to the petal while being used. The cutting design was strong ehough when bending to the inside. Yet, it easily broke in the other direction. The design with the print in place hinges however, remained intact when force was applied in both directions. For that reason, the print in place hinges were used for the model. This model was tested with the gibbons.

After researching TPU 3D printing, changes to the setting were made, resulting in the first TPU petal (Figure 7.12e). This petal was tested in the product setting and iterations were made.

The shape of the petals was designed to help the gibbon grab the petal and open it. The top of the peel therefore sticks out a bit (Figure 7.9). However, user testing without this feature showed no need for this grabbing piece. It was therefore removed in the following iteration (Figure 7.12f).

The design of the petal from Figure 7.13h was printed in TPU using a SLS printer as a test for the final design (Figure 7.12g).

The print was tougher than the original FDM print, making it harder to bend. Also, a detail of interest was the intersection of the ribs on the peel. These were the weak spots in the design and broke first when force was applied. Therefore the ribs were redesigned to create more space between the ribs, making them stronger (Figure 7.12h).

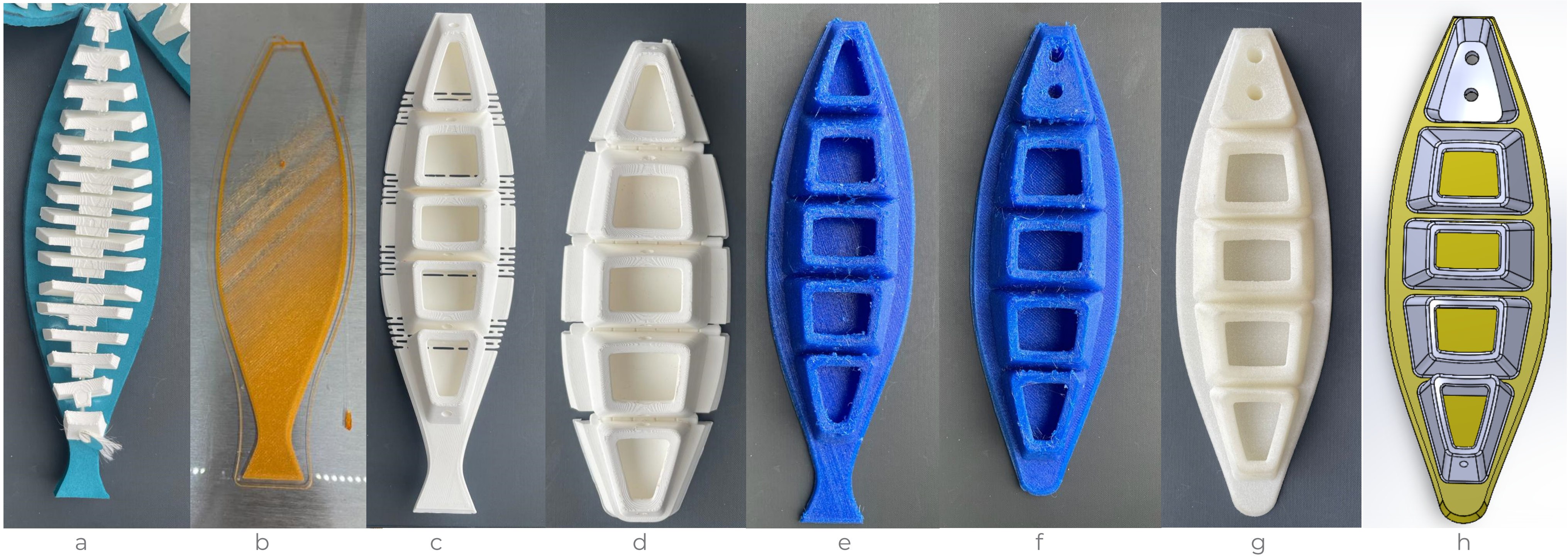


Figure 7.12 Petal iterations

### 7.2.4 Assembling iterations

For attaching the petals to the housing, several prototyping iterations were made. Initially, the petals would all be printed as an entire piece and attached from the base to the housing. Due to the dimensions of the 3d printer however, this was not possible.

First, different hinges were explored. Both print in place hinges (Figure 7.14) and separate pin hinges (Figure 7.13) were designed. However, due to the small area available, the hinges were extremely weak and broke off easily.

To reduce the risk of breaking, the hinges were replaced by a bolt and nut system (Figure 7.15). This gave more strength to the design but made it harder to remove the petals for cleaning, as attaching the nut was challenging.

The requirement of fast disassembly is of great importance for the usability and cleanability of the device. The system was redesigned using heat set inserts to put the bold in place, requiring no extra nuts (Figure 7.16).


Figure 7.13- Pin Hinges

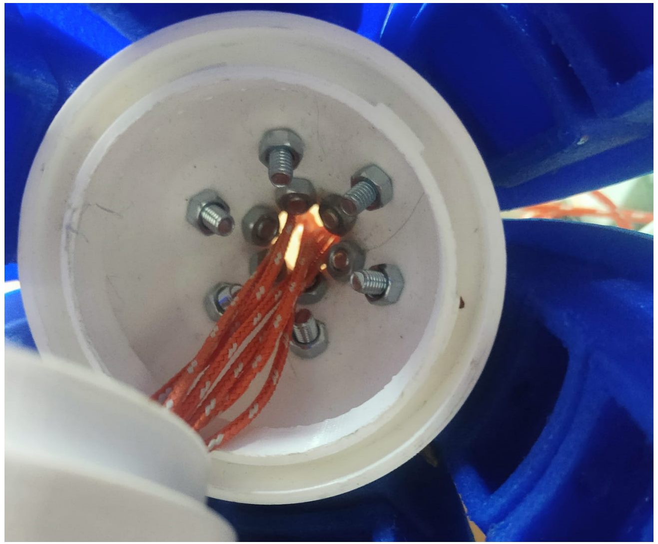


Figure 7.15- Bolt and nut system

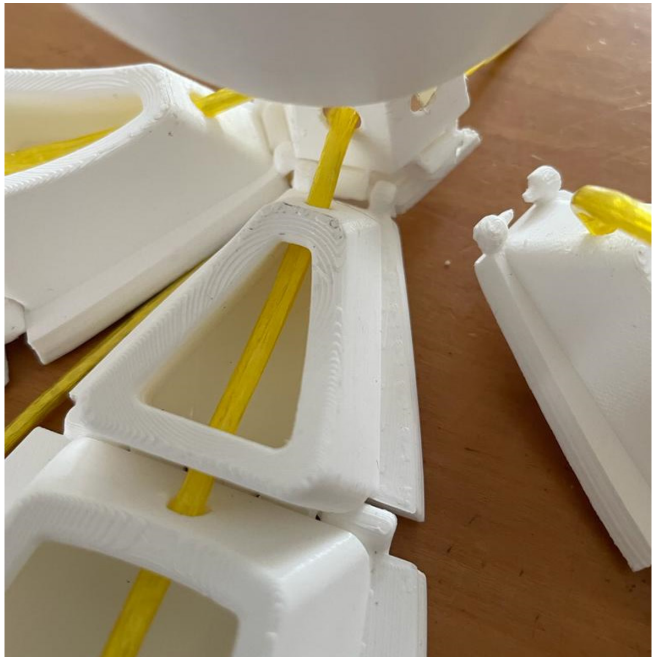


Figure 7.14- Print in place hinges

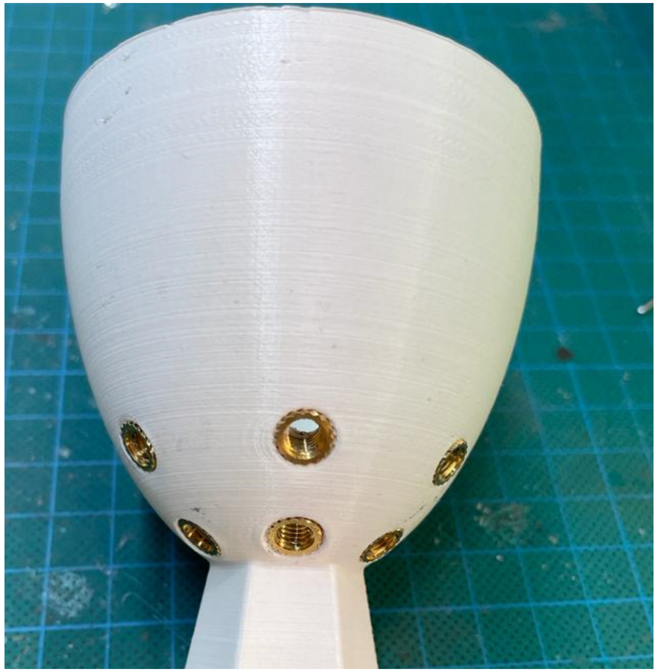
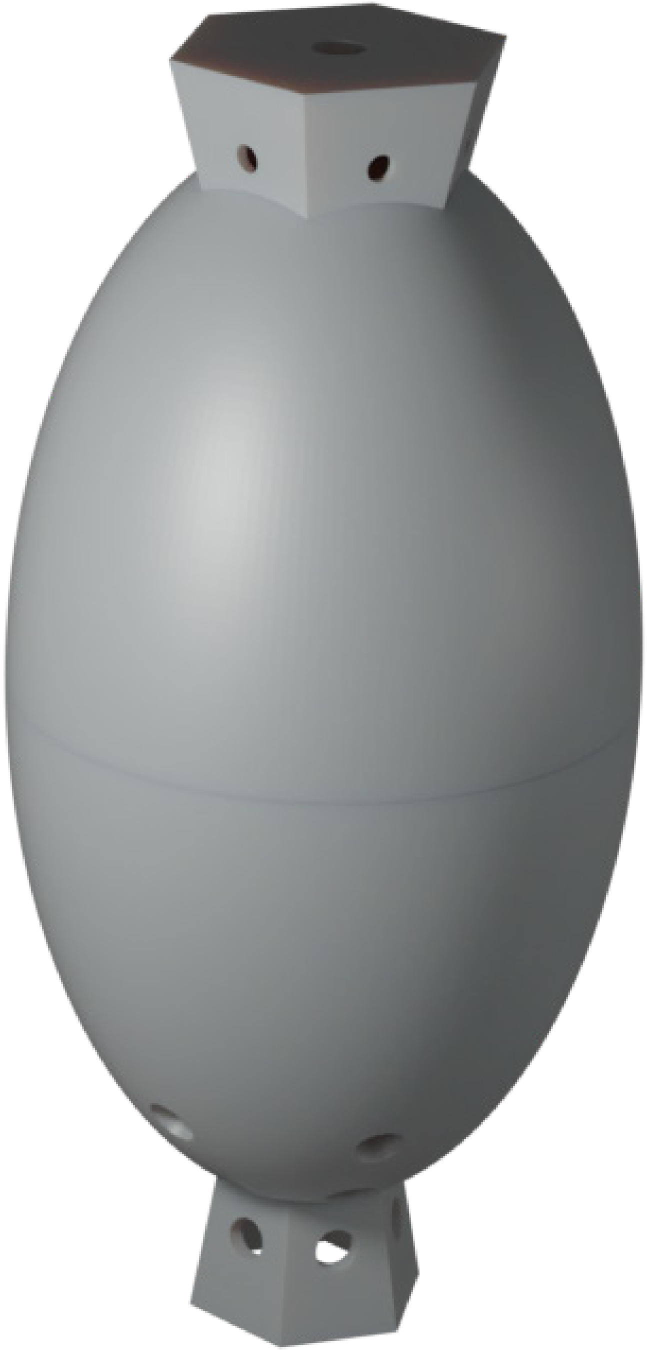


Figure 7.16- Heat set inserts

# Housing



## 7.3 Housing design

The housing of the device is shaped as a ellipsoid with at the bottom and top a drafted hexagon. These shapes function as a guideline for the outside petals to shape around.

In addition, it houses all the electronics of the device. To have easy access to the electronics, the shape disassembles into two parts. Iterations were made to meet the formulated requirements.

The most important requirements are;

Table 7.2 - Important requirements

| N. | Demand and wish |
|---|---|
| LoR-3.20 | The device should be easy to take apart |
| LoR-4.16 | The device can not be dismantled by the animal |
| LoR-4.17 | The device or any part of it can not be swallowed |
| LoR-4.18 | The animal should not become entangled in the device in any way |
| LoR-4.20 | The device must be able to carry the weight of a fully grown male gibbon (8 kg) |
| LoR-4.21 | The animal should not have access to the electronics |
| LoR-4.23 | The hanging bolt should not be loosened by rotation of the device |
| LoR-4.24 | The housing should be watertight |

### 7.3.1 Materialization

For the materialization of the housing, PLA was chosen. Using the method Additive manufacturing, also known as 3D printing, allowed for strong, durable and dimensionally stable parts. To increase the safety of the device and to minimise the chance of breaking, the device should hold the maximum weight of the gibbons. Therefore the choice was made to have the eyebolt made of stainless steel with a maximum workload of 20 kilograms.

### 7.3.2 Assembling iterations

The housing was first designed using a lip and groove for the assembly of the two parts (Figure 7.17). However, with the possible amount of force pulling the product down, this method was not strong enough. This was tested by hanging weights on the bottom piece of the housing. The housing failed at 800 grams.

To create a stronger connection, research was done into different assembly methods. This was however more difficult than expected, due to the contradicting requirements: LoR-3.20 and LoR-4.16. The second connection method tested was a bayonet closure. First the bayonet was designed with a minimal margin between the two parts, which made it impossible to close (Figure 7.18) This was later adjusted in the third version of the housing (Figure 7.19).

The housing now, could withstand the maximum weight pulling the device down. However it was easy to unlock through rotation. For this reason, a lock was added within the bayonet, to make sure the two parts would need more rotational force to be released (Figure 7.20).

Figure 7.18- No margin housing design

Figure 7.19- Test housing design

Figure 7.17- Lip and groove

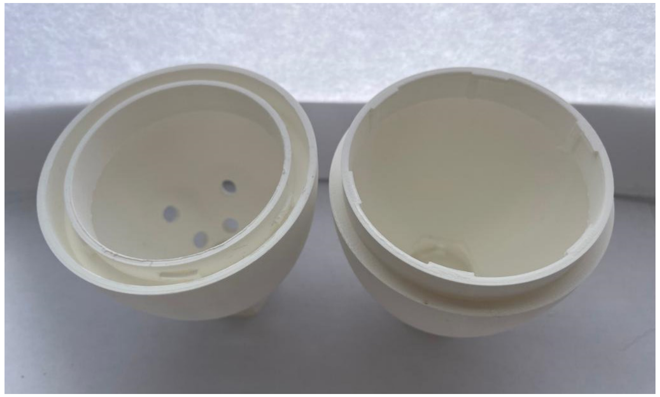


Figure 7.20- Final housing design

### 7.3.3 Hanger iterations

The hanging mechanism is the feature that allows for easy installation. Currently, the zoo keepers at ARTIS zoo use carbines to install enrichment devices to the enclosure. Pulley systems and rings were already present to easily secure the device. The hanging mechanism of the device was therefore adapted to make use of the current fastening systems. As mentioned in the materialization, a stainless steel eyebolt was used for this.

As can be seen in Figure 7.21 and 7.23, the top first had a spherical shape. However, this created a weaker link. To ensure even distribution of the force onto the inside, iterations were made. The shape was changed to be flat from the inside to allow the bolt to screw entirely against the inside.

Furthermore, the shape of the top part was changed to make the closing of the pedals go more smoothly (Figure 7.24). This was also necessary because the rotation motor and eyebolt would otherwise intersect with each other.

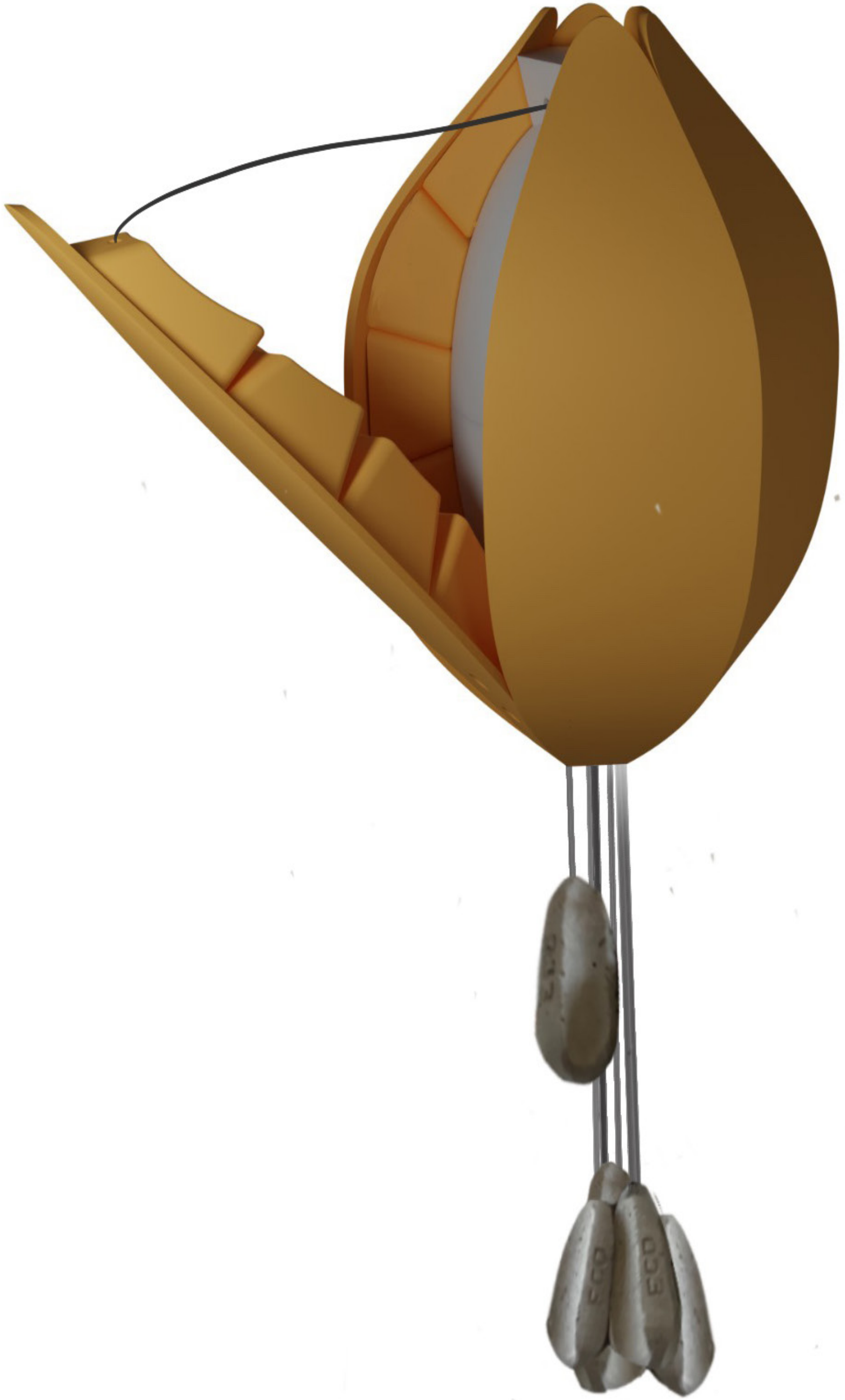
Figure 7.21- Render old housing design

Figure 7.22- Render new housing design

Figure 7.23- Initial hanger design

Figure 7.24- Final hanger design

# Closing



## 7.4 Closing and locking design

The closing and locking mechanism has two functions. First, the device has to close automatically when no force is applied. Secondly, the device should be able to lock and unlock when requested by the zookeeper. This mechanism is therefore divided into two components; the closing and locking mechanisms. Iterations were done to meet the formulated requirements.

The most important requirements are;

Table 7.3 - Important requirements

| N. | Demand and wish |
|---|---|
| LoR-3.12 | The device should close automatically when no force is applied. |
| LoR-3.13 | The gibbon should be able to open the leaves with a minimum force. |
| LoR-3.14 | The leaves should be able to open separately from each other |
| LoR-3.15 | When the device is locked, the gibbon should not be able to open the leaves with maximum force |
| LoR-3.23 | The device should be programmed to lock and unlock through the use of an app |
| LoR-3.28 | The device should be able to lock in between time intervals |
| LoR-5.2 | Electronics should be a few as possible |

## 7.4.1 Closing mechanism

For the interaction of the device, it is important that the gibbon has to be actively engaged with the product. Therefore, it should take effort to open the leaves and retrieve the food award. The task should be challenging yet not impossible.

A system using weight and gravity to close the leaves was chosen. Other options such as winding up the rope and springs was shortly looked into. However, opening the leaves separately would not be possible or it would increase the amount of electronics needed, which is not preferred.

### 7.4.1.1 Closing iterations

The amount of weight and the force applied to the leaves were carefully chosen to achieve the desired interaction. Initially, the rope would run through the ribs of the leaves. However, due to limited dimensions of the arm and due to high surface resistance, closing the device took too much weight, 880 grams. Experiments with positioning of the rope and the amount of weight were conducted using the equation:

Torque = arm * force = arm * force *sin(angle)

Table 7.4- Experiment results

| Experiment setup | Amount of weight with PLA | Amount of weight with TPU |
|---|---|---|
| Baseline (Figure 7.25) | 880 grams | 650 grams |
| Increasing distance of the arm (Figure 7.26) | 470 grams | 350 grams |
| Decreasing angle and resistance (Figure 7.27) | 80 grams | 80 grams |

As can be seen in Table 7.4, the lowest amount of weight was achieved by decreasing the angle and surface resistance and by changing the material to TPU. The test set-ups can be seen in Figure 7.28 and 7.29.

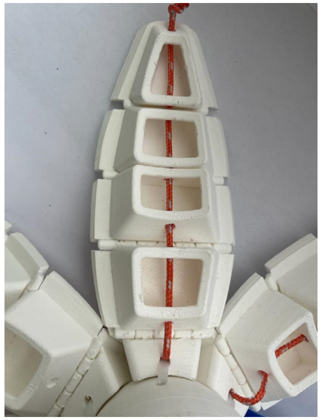


Figure 7.25- Baseline

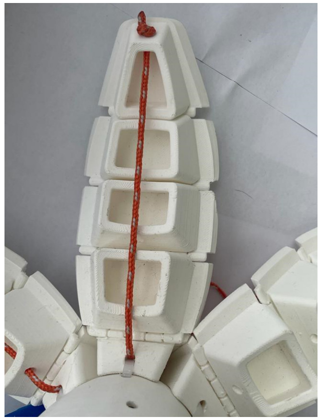


Figure 7.26 - Increasing arm

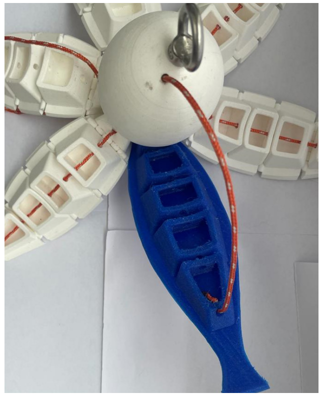


Figure 7.27- Decreasing angle and resistance


Figure 7.28- Test setup baseline


Figure 7.29- Test setup decreasing angle and resistance

### 7.4.1.2 Assembling iterations

Considering the need for fast disassembly to clean the device, special attention is given to the attachment of the rope to the weights and petals. In the PLA prototype, the fixed attachment of the rope to the petal meant that disassembling the petals required detaching all weights and ropes from the petals, making the cleaning process inconvenient. Reassembling necessitated repeating these steps. Recognizing this impracticality and time-consuming nature, iterations were introduced.

The attachment of the weights now employs a simple loop passing through the eye and around the weight. This modification significantly expedites disassembly, allowing for easier weight changes when needed.

Figure 7.30- Weights and attachment

## 7.4.2 Locking mechanism design

To use the device as a research device and allow the gibbons to interact with the device after work hours, the device should be able to lock and unlock at chosen moments. An actuator is needed that can be controlled remotely. Since there should be as few electronics as possible, one actuator should be used to lock all the separate leaves.

### 7.4.2.1 Locking iterations

First, a system was designed using a rotation motor with a vane and eyes (Figure 7.31). However, while conducting experiments it was noticeable that the petals would not always close-off perfectly. This method would leave no room for errors. A different method was therefore investigated, allowing for a bigger margin.

The second locking method of the device locks the ropes in place by trapping the rope (Figure 7.32). In this manner, even when the petals do not fully close, the device is still able to lock itself.

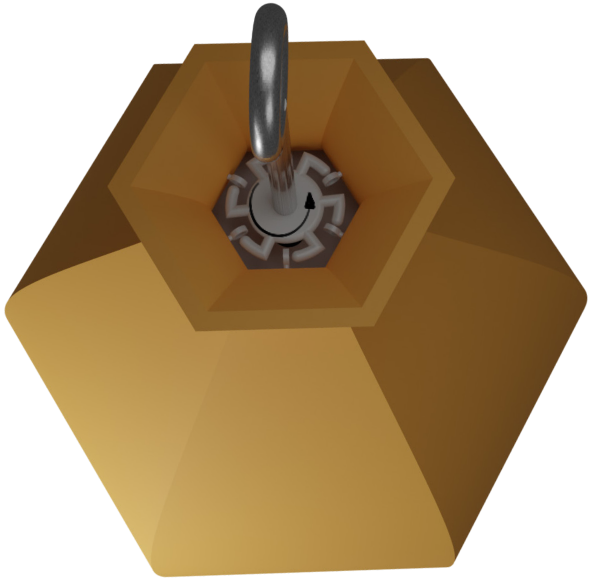


Figure 7.31- Old locking system

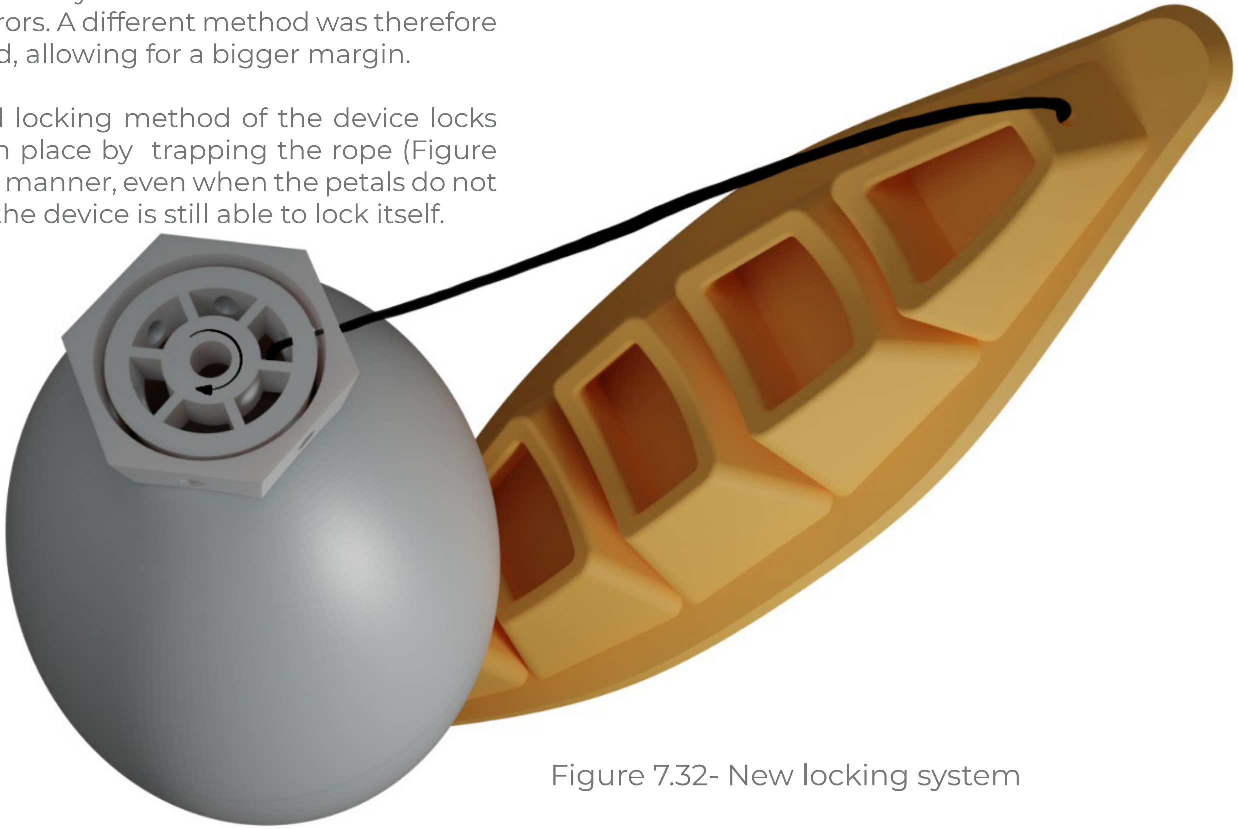


Figure 7.32- New locking system

## 7.5 Electronics

The function of the electronics is to remotely lock and unlock the device's petals through a dedicated application. The key requirements (Table 7.5) include the following;

Table 7.5-Important requirements

| N. | Demand and wish |
|---|---|
| LoR-3.16 | The product should be portable |
| LoR-3.22 | The product should be able to connect to a smartphone |
| LoR-3.23 | The device should be programmed to lock and unlock trough the use of an app |
| LoR 3.28 | The device should be able to lock in between time intervals |
| LoR-4.21 | The animal should not have access to the electronics |
| LoR-4.22 | The electronics should be properly earthed and insulated |
| LoR-5.2 | Electronics should be a few as possible |

### 7.5.1 Components

The electronic components are shown in Table 7.6 and Figure 7.33

Table 7.6- Electronical components

| Parts | Qty. | Designator | Manufacturer part |
|---|---|---|---|
| PCB | 1 | | - |
| Socket | 1 | CN1 | B5B-XH-A-(LF)(SN) |
| Stepper motor | 1 | CN1 | 28BYJ-48 |
| Motor driver | 1 | U2 | ULN2003AN |
| Capacitor 100nF | 2 | C2,C3 | CC1H104ZC1PD3F5P30MF |
| Capacitor 100uF | 1 | C1 | 10uf 25 v 5*11 ***(16V)*** |
| Jack plug male | 1 | | - |
| 12V power supply | 1 | | |
| WEMOS board | 1 | U1 | Wemos_D1_mini_Pro4 |
| Jack plug | 1 | DC1 | DC005-2.0MM |
| Voltage Regulator | 1 | U8 | L7805ABV |

**The PCB;** The Printed Circuit Board used is a PCB designed for an automatic cat feeder (Kilic, 2022). Using the production file, the PCB was manufactured by Eurocircuit. The components were manually assembled unto the PCB, following the assembly schematic (Appendix H).

**A stepper motor;** This was selected for its precision, crucial for the device's accurate movement.

**WEMOS D1;** The Arduino board used, is a WEMOS D1 mini WIFI board. The mobile application communicates with the uploaded code (Appendix H) on the board to control the stepper motor's rotation.

**12V power supply;** A 12-volt battery serves as the power supply. This was chosen because of the requirement LoR-3.16.

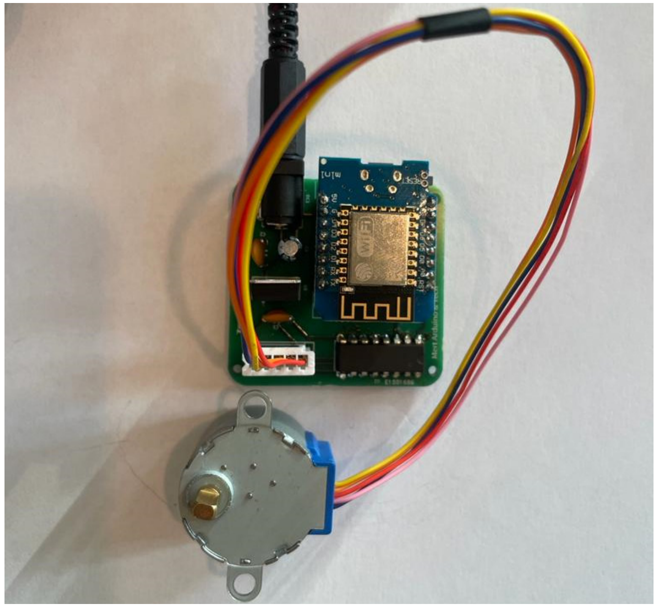


Figure 7.33- Electronics assembly

### 7.5.2 Application

The application is designed with the user-friendly MIT App Inventor, a simple drag-and-drop method for easy application development. The app's structure (Figure 7.34) includes two clickable images and a text line featuring the IP address. To establish a connection with the Arduino board, the user needs to input the IP address into the application. Once filled in, clicking the left button initiates the motor rotation for unlocking, while the button on the right locks the device again.

Apeel

Enter the IP address

192.168.0.0

Figure 7. 34- Application

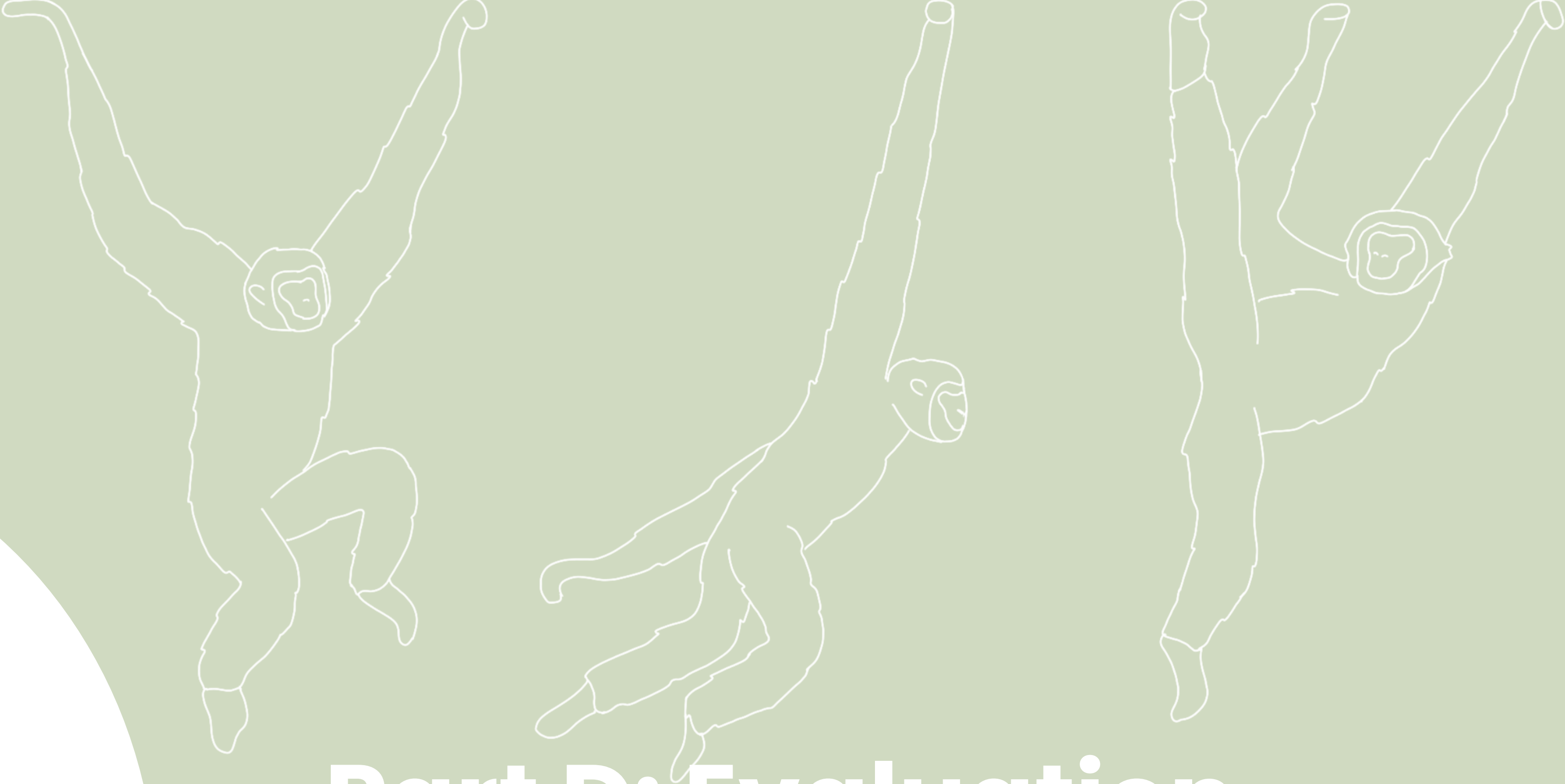
## 7.6 Cost price

The cost price of the device (Figure 7.35) is €256,56. The biggest investments for this device are the SLS printed petals and the electronics. This amount would increase when the device is assembled at a different company.

Table 7.7- Cost price

| **Parts** | **Qty.** | **Costs** | **Total** |
|---|---|---|---|
| SLS printed petal | 6 | € 26,18 | € 157,05 |
| Housing | 1 | € 8,50 | € 8,50 |
| Eyebolt | 1 | € 1,02 | € 1.02 |
| Weights | 6 | € 1,60 | € 9,60 |
| Swivel | 6 | € 0,04 | € 0,24 |
| Heat set insert | 14 | € 0,25 | € 3,50 |
| Dyneema rope | 6 | € 2,50 | € 15,00 |
| Bolt | 14 | € 0,82 | € 11,48 |
| PCB | 1 | € 20,0 | € 10,0 |
| Stepper motor | 1 | € 3,85 | € 3,85 |
| Motor driver | 1 | € 5,50 | € 5,50 |
| Capacitor 100nF | 2 | € 0,44 | € 0,88 |
| Capacitor 100uF | 1 | € 0,44 | € 0,44 |
| Jack plug male | 1 | € 0,50 | € 0,50 |
| 12V power supply | 1 | € 20,90 | € 20,90 |
| WeMos D1 mini | 1 | € 5,95 | € 5,95 |
| Jack plug | 1 | € 1,75 | € 1,75 |
| Voltage Regulator | 1 | € 0,40 | € 0,40 |
| **TOTAL** | | | **€ 256,56** |

Figure 7.35- Final prototype



# Part D: Evaluation

In this section of the report, the device is evaluated by user testing and conclusions are made accordingly. Advice for further embodiment is given. The client can use the insights to keep iterating and testing for the final design.

**Chapter**

# 8. User testing and conclusions

## 8.1 First user testing

Two user tests were conducted with the gibbons at Artis Zoo. The first test involved the PLA prototype (Figure 8.1), aiming to observe the interaction between the gibbons and the device. The research question was: **Can the gibbons understand that the petals can be opened to obtain a food reward?**

### 8.1.1 Key observations

Key observations from the test include:

▶ **Immediate interest |** Both the gibbons displayed immediate interest in the device (figure 8.2), showcasing curiosity towards new objects in the enclosure. They immediately approached the location where the device was present.

▶ **Initial scepticism |** Initially, the gibbons approached the device with a bit of scepticism. They preferred opening the device with additional objects, such as a rope. Subsequently, as they grasped the mechanics, the gibbons transitioned to using their hands to manipulate the device. However, upon the petals opening, their response was to pull back without further exploration.

▶ **Indifference to the food given |**The gibbons showed no interest in the food inside. Additionally, they displayed no interest in the same food that was placed on the ground to lure them to the device. This behaviour could be attributed to the fact that they had recently consumed the same food for breakfast and were no longer hungry.

From the insights of the observations, several conclusions were drawn and potential adjustments emerged.

Figure 8.1- First user test setup

Figure 8.2- Interaction with the device

### 8.1.2 Conclusions and iterations

1. **The gibbons demonstrated an understanding of how to open the different petals but had not yet grasped the concept of the food reward.**

2. The device proved intriguing enough to overcome their initial scepticism.

3. They exhibited improved understanding in the following interactions, changing their initial manipulation of the device upon further interaction.

4. The device's relative easy way of opening led to swift interactions, resulting in less exploration.

5. The provided food failed to adequately capture their interest.

**Iterative adjustments** implemented included:

1. Increasing the difficulty to open the device by adding **more weights** to the design. This modification ensured that the petal **automatically closes** in the absence of applied force, requiring two sets of hands for the interaction.

2. Improvement of the food's appeal to stimulate greater interest.

## 8.2 Second user testing

The second user test was conducted with the TPU prototype (figure 8.3). This test was a three day observational research. The research question remained the same.

Figure 8.3- Second user test setup

Figure 8.4- Lee interacting with the device while Ray is observing.

Figure 8.5- Lee and Ray interacting together with the device

### 8.2.1 Key observations

Key observations from this second test include:

▶ **Device placement |** Initially, the device was placed in an area of the enclosure with a low ceiling, near the ground for easy observation. However, throughout the morning, the gibbons showed no interest in interacting with it. In the afternoon, the device was relocated to a different spot with a higher ceiling, further from the ground, leading to immediate interaction from the gibbons. This placement was also chosen the following days.

▶ **Obtaining food reward |** The older gibbon, Lee, was the first to approach the device and comprehend the interaction. However, even after changing the food, there was limited interest in retrieving it.

Only after adding grapes, did the food reward become enticing enough for Lee to retrieve it. For three consecutive days, the device was filled both mornings and afternoons with food. Following the initial introduction day with the grapes, the gibbons directly approached the device, retrieving the food stored inside, even when there were no grapes present.

▶ **"Copyape" |** The younger gibbon, Ray, exhibited less interaction with the device. However, he closely observed Lee's interactions and copied him after a while (Figure 8.4).

▶ **Collaboration |** Over time, both gibbons engaged with the device collaboratively. Lee opened the petals, while Ray retrieved the food reward from the ribs (Figure 8.5).

▶ **Use of the hands and feet |** The anticipated interaction involved the use of both hands to open the petal. However, the gibbon utilized a variety of combinations, involving both hands and feet, to interact with the device.

▶ **Weights |** The device occasionally did not close entirely due to the weights interfering with each other.

▶ **Sturdiness |** The device remained intact when the gibbons hung with their collective weight from it. However, when Lee sat on the device, it likely caused a twisting motion, leading to the separation of the top housing

### 8.2.2 Conclusions and iterations

The key insights from these observations provided several conclusions and suggested potential adjustments.

**1. The gibbons comprehended the process of opening the device to obtain a food reward.**

2. The gibbons displayed reluctance to engage with the device when the placement was to close to the ground.

3. The type of food mattered less after the first food retrieval.

4. The device fostered improved interaction between the gibbons, promoting teamwork during food retrieval.

**Iterative changes** based on these observations and conclusions include:

1. **Modification of the weights** to a more spherical shape to prevent interference with each other.

2. The **attachment between the two parts** of the housing were made to be stronger.

# 9. Recommendations

▶ **Materialisation and production |** To materialize the design, TPU was chosen for its flexibility and suitability for 3D printing, allowing for swift prototyping with numerous iterations. However, achieving food safety with 3D printing poses challenges due to the production process, even when using food-safe materials. To address this, an epoxy coating was introduced in the final product to ensure complete food safety.

For a more efficient production process and further embodiment of the design, injection moulding would be a superior method. Food-grade silicon, available in various colours and hardness levels, is a suitable material based on the material analysis.

To optimize the part for injection moulding, modifications are required, particularly in the petal design. The current negative draft angle of the ribs poses challenges in creating a straightforward mould for the petal and requires adjustments for improved manufacturability.

The housing can also be efficiently manufactured through injection moulding, offering the opportunity to replace the current heat-set insert with an insert moulding. Changing the material and production process enables faster manufacturing of the device, but makes the device less suitable for small quantities, consequently increasing the overall cost.

▶ **Look and feel |** The design draws inspiration from an exotic fruit and decisions are made based on limited research on object preferences of captive primates. However, further refinement of the design's aesthetics can be achieved through user testing. For instance, while the current texture is smooth, experimenting with the different textures, shapes and colours with primates may reveal a preference for a more textured surface, a different colour, or even an alternative shape.

▶ **Other research parameters |** In addition to utilizing the time parameter to research the abilities of primates to understand time perception, other factors can be considered. In the wild, primates comprehend the correlation between the accelerated ripening of a fruit and environmental factors like temperature and UV radiation. These elements can serve as parameters to enhance and further stimulate cognitive abilities. For instance, the device could unlock only after accumulating a specific amount of sunlight days or perhaps exclusively open during rainfall. This device opens possibilities for various additional research, enriching the experiences of primates by providing diverse stimuli.

▶ **Electronics |** For the electronics, a lot of advancements can still be made. Given the limited expertise in this area, it wasn't the primary focus during the design phase. Consequently, the current app functionality is basic, allowing manual device operation by touching a button when connected to the same WiFi network. To improve the design further, it is recommended to collaborate with students who specialize in hardware and software. This could lead to the incorporation of additional features, including pre-programmed time intervals and the inclusion of various parameters such as UV radiation. Achieving this would necessitate the development of a comprehensive database. Moreover, enabling connection via bluetooth instead of WiFi and adding an on and off switch is advised.

# Part E: Additions

This part of the report consists of the sources and appendices.

**Chapters**

# 10. Sources

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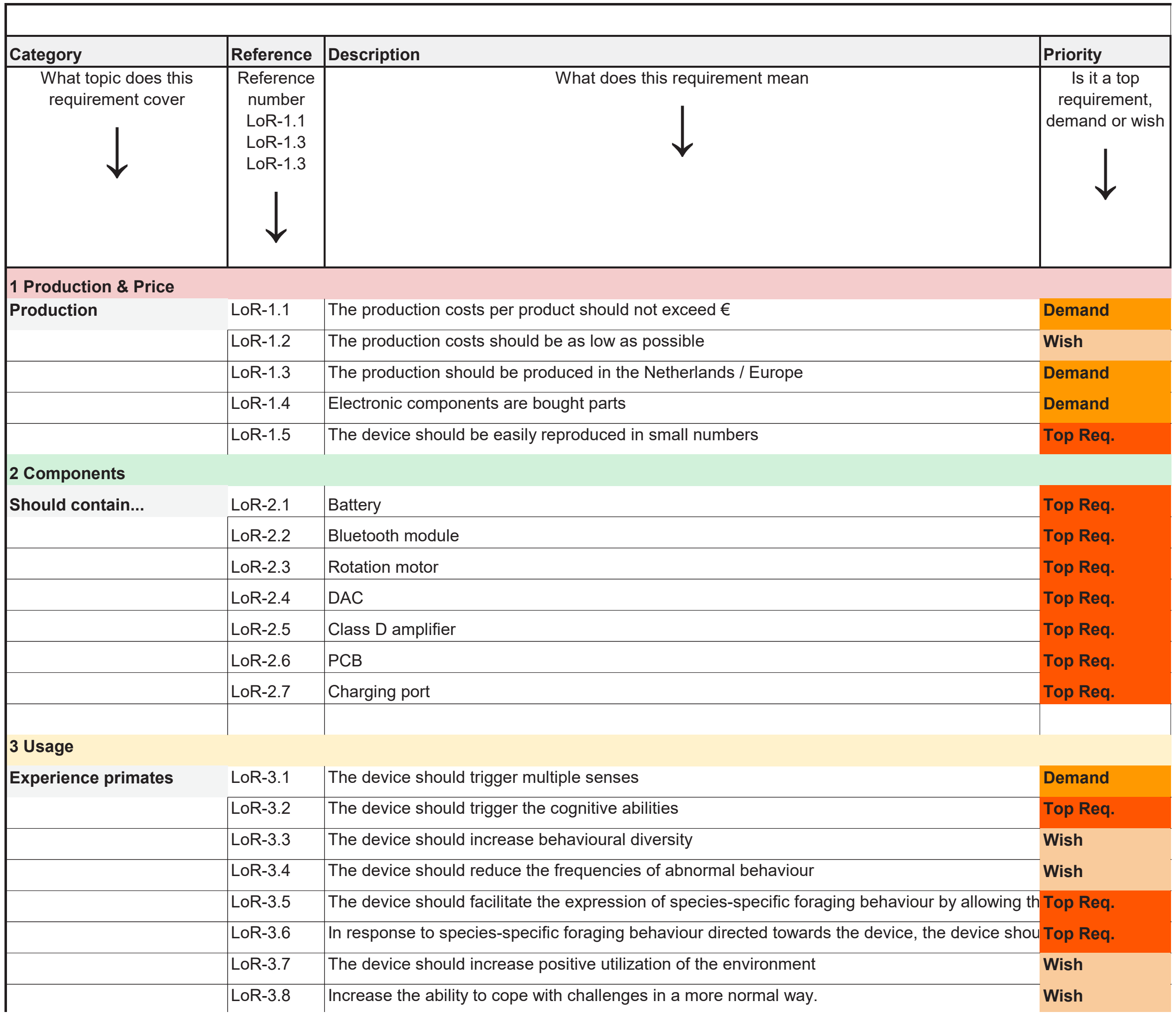
# 11. Appendix

## Appendix A: List of requirements



| Category | Reference | Description | Priority |
|---|---|---|---|
| What topic does this requirement cover<br>↓ | Reference number<br>LoR-1.1<br>LoR-1.3<br>LoR-1.3<br>↓ | What does this requirement mean<br>↓ | Is it a top requirement, demand or wish<br>↓ |
| **1 Production & Price** | | | |
| **Production** | LoR-1.1 | The production costs per product should not exceed € | **Demand** |
| | LoR-1.2 | The production costs should be as low as possible | **Wish** |
| | LoR-1.3 | The production should be produced in the Netherlands / Europe | **Demand** |
| | LoR-1.4 | Electronic components are bought parts | **Demand** |
| | LoR-1.5 | The device should be easily reproduced in small numbers | **Top Req.** |
| **2 Components** | | | |
| **Should contain...** | LoR-2.1 | Battery | **Top Req.** |
| | LoR-2.2 | Bluetooth module | **Top Req.** |
| | LoR-2.3 | Rotation motor | **Top Req.** |
| | LoR-2.4 | DAC | **Top Req.** |
| | LoR-2.5 | Class D amplifier | **Top Req.** |
| | LoR-2.6 | PCB | **Top Req.** |
| | LoR-2.7 | Charging port | **Top Req.** |
| | | | |
| **3 Usage** | | | |
| **Experience primates** | LoR-3.1 | The device should trigger multiple senses | **Demand** |
| | LoR-3.2 | The device should trigger the cognitive abilities | **Top Req.** |
| | LoR-3.3 | The device should increase behavioural diversity | **Wish** |
| | LoR-3.4 | The device should reduce the frequencies of abnormal behaviour | **Wish** |
| | LoR-3.5 | The device should facilitate the expression of species-specific foraging behaviour by allowing th | **Top Req.** |
| | LoR-3.6 | In response to species-specific foraging behaviour directed towards the device, the device shou | **Top Req.** |
| | LoR-3.7 | The device should increase positive utilization of the environment | **Wish** |
| | LoR-3.8 | Increase the ability to cope with challenges in a more normal way. | **Wish** |

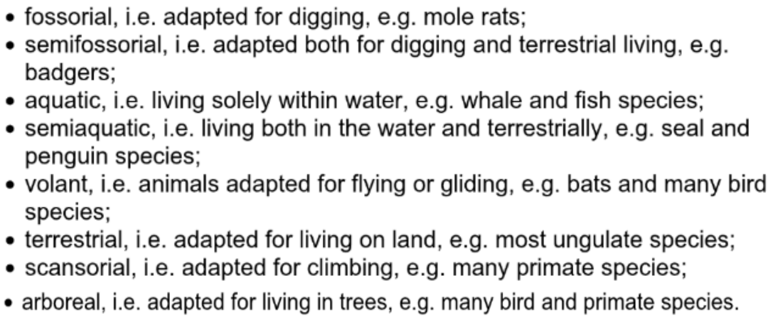
| | | | |
|---|---|---|---|
| | LoR-3.9 | The animal should be given a choice to participate | **Top Req.** |
| | LoR-3.10 | The device has to have high cost to encourage decision making. | **Demand** |
| | LoR-3.11 | The usage should be straight-forward/intuitive | **Wish** |
| | LoR-3.12 | The device should close automatically when no force is applied. | **Top Req.** |
| | LoR-3.13 | The gibbon should be able to open the leaves with a minimum force of…….. | **Top Req.** |
| | LoR-3.14 | The leaves should be able to be opened separately from each other | **Top Req.** |
| | LoR-3.15 | When the device is locked, the gibbon should not be able to open the leaves with maximum forc | **Top Req.** |
| **Experience zookeeper** | LoR-3.16 | The product should be easy to operate | **Wish** |
| | LoR-3.17 | The device should be refilled after every use | **Top Req.** |
| | LoR-3.18 | The device should be easy to install | **Top Req.** |
| | LoR-3.19 | The device should be easy and quick to turn on / to be made usage ready | **Top Req.** |
| | LoR-3.20 | The device should be easy to take apart | **Top Req.** |
| | LoR-3.21 | The device should be easy to clean and quick to fill | **Top Req.** |
| | LoR-3.22 | The product should be able to connect to a smartphone through Bluetooth | **Demand** |
| | LoR-3.23 | The device should be programmed to lock and unlock trough the use of an app | **Top Req.** |
| | LoR 3.24 | The battery should last at least 6 hours | **Wish** |
| | LoR-3.25 | The device should be portable | **Top Req.** |
| | LoR-3.26 | The device should be remotely controlled. | **Top Req.** |
| **Experience researcher** | LoR-3.27 | Time intervals should be tested with the device without other variables | **Wish** |
| | LoR 3.28 | The device should be able to lock in between time intervals | **Top Req.** |
| **4 Safety** | | | |
| **Safety material** | LoR-4.1 | The material must be tough | **Top Req.** |
| | LoR-4.2 | The material should not be toxic | **Top Req.** |
| | LoR-4.3 | The material must be food safe | **Top Req.** |
| | LoR-4.4 | The material must be cleaning-chemical proof | **Top Req.** |
| | LoR-4.5 | The material should not break when the maximum strength of the gibbon is applied by either ha | **Demand** |
| | LoR-4.6 | The material should not break when it drops on the floor of a height of 5 meter | **Demand** |
| | LoR-4.7 | The material must be elastic | **Top Req.** |
| | LoR-4.8 | The material must be waterproof | **Top Req.** |
| | LoR-4.9 | The material must be UV resistant | **Top Req.** |
| | LoR-4.10 | The material must be light | **Demand** |
| | LoR-4.11 | The material must not catch fire easily | **Top Req.** |
| **Safety usage** | LoR-4.12 | The product should have rounded edges | **Demand** |
| | LoR-4.13 | The animal’s digits, limbs or other bodily appendages can not become trapped inside any part of the device | **Top Req.** |
| | LoR-4.19 | The device must be attached to the enclosure to avoid throwing the device | **Top Req.** |
| | LoR-4.14 | if the device breaks, it should not break into sharp fragments | |
| | LoR 4.20 | The device must be able to carry the weight of a fully grown male gibbon (8 kg) | **Top Req.** |
| | LoR-4.16 | The device can not be dismantled by the animal | |
| | LoR-4.21 | The animal should not have access to the electronics | **Top Req.** |
| | LoR-4.17 | The device or any part of it can not be swallowed | |
| | LoR-4.22 | The electronics should be properly earthed and insulated | **Top Req.** |
| | LoR-4.23 | The hanging bolt should not be loosened by rotation of the device | **Top Req.** |
| | LoR-4.24 | The housing should be watertight | |
| **5 End of life** | | | |
| | LoR-5.1 | The product lifespan should be at least 2 years | **Demand** |
| | LoR-5.2 | Their should be as few electronics as possible | **Demand** |

# Appendix B: Enrichment

▶ **Housing|** The housing of an animal refers to the environment in which an animal is living. The environment can be separated into two parts, the actual enclosure and the surrounding outside environment. Both should be considered when designing an enriching housing for an animal. Understanding the primary substrate (the surface on which an animal lives) of an animal is crucial for designing the enclosures. This allows for optimisation of usable 3D space. Creating species-specific requirements for the spaces is essential for allowing them to display their natural behaviour as resting, locomotion and foraging (Maple & Perdue, 2012). The list of Eisenberg (1981) can be used as a guide line. Other considerations important are the barriers, lighting, quality of air, water and soil.

▶ **Structural|** Structural enrichments refers to semi-permanent changes made to the animals' environment. These changes improve the quality of space and life for the animals when the changes are species and goal specific. Examples of furniture for specific behaviour can be found in the Figure 3.2.

▶ **Toys|** This type of enrichment involves providing objects to play with that are physically stimulating to the animal. Initially, toys and novel objects can trigger avoidance. However, animals more used to new objects are immediately curious and will explore further. The difference between toys and novel objects is, with toys animals learn and remember the particular function while novel objects are always a new interaction. When implemented effectively, toys can reduce fear and stress, help develop coordination and provide the animal with a sense of control (Maple & Perdue, 2012).



- fossorial, i.e. adapted for digging, e.g. mole rats;
- semifossorial, i.e. adapted both for digging and terrestrial living, e.g. badgers;
- aquatic, i.e. living solely within water, e.g. whale and fish species;
- semiaquatic, i.e. living both in the water and terrestrially, e.g. seal and penguin species;
- volant, i.e. animals adapted for flying or gliding, e.g. bats and many bird species;
- terrestrial, i.e. adapted for living on land, e.g. most ungulate species;
- scansorial, i.e. adapted for climbing, e.g. many primate species;
- arboreal, i.e. adapted for living in trees, e.g. many bird and primate species.

Substrate categories

| **Behaviour** | **Example Furniture** |
|---|---|
| Avoiding predators | Vegetation, climbing frames, perches, hide boxes, visual barriers |
| Birthing | Dens, nest boxes, plants |
| Cognition | Puzzle feeders |
| Comfort | Scratching posts, showers, wallows |
| Drinking | Ponds, water moats, nipple drinkers |
| Eliminative | Litter trays |
| Exploration | Toys, novel objects |
| Finding food | Foraging devices, foraging boards, feeders, bowls, plants |
| Learning | Puzzle feeders, toys, novel objects |
| Locomotion | Climbing frames, perches, vegetation, hunting enrichment, foraging enrichment, swimming pools |
| Marking | Wooden posts, plants, general furniture |
| Play | Toys, novel objects, plants |
| Shelter | Nest boxes, dens, man-made shelters, plants, grottos, tunnels |
| Sleep | Platforms, shelves, nest boxes, beds |
| Social avoidance | Hide boxes, climbing frames, visual barriers |
| Social interaction | Resting platforms, climbing frames, toys, novel objects, puzzle feeders, grooming boards |
| Thermal regulation | Shelters, hot rocks |
| Vigilance | Platforms, plants, climbing frames |

Furniture examples for specific behaviour

▶ **Animal-animal|** For many species, social living offers more benefits than just finding food and avoiding predators. It represents a major source of stimulation. The social interactions of species provide a continuous stream of mental stimulation that cannot be fully replicated through any form of environmental enrichment (Humphrey, 1976). Nevertheless, creating the right social environment is essential for stimulating social animal species (Young, 2003). In a zoo, social enrichment may involve adding or removing members from group when appropriate. However, this can sometimes lead to unnecessary aggression or might not be feasible if animals need to be separated for reasons such as prevention of breeding (Maple & Perdue, 2012).

In cases where animals cannot be housed together, there are alternative methods to stimulate natural social behaviour more effective than simple isolation (Young, 2003). Howdy doors for example seen in figure to the right, can facilitate visual, olfactory, and auditory contact between individuals that need to be kept apart. Additionally, options like mirrors or videos featuring other animals can help broaden the social context (Maple & Perdue, 2012). Nevertheless, none of these techniques can fully replicate the entire range of species-specific social behaviour (Young, 2003).

▶ **Human-animal|** Interacting positively with humans can enhance the social environment for captive primates, as documented by various studies (Bayne et al., 1993; Bloomsmith et al., 1997; Baker, 1997). However, it's important to note that such interaction should not replace conspecific (same species) social interactions.

Human-animal interaction in captive settings is most frequently observed in interactions between caregivers and animals. These interactions involve a wide range of activities. Hosey and Melfi (2012) conducted a survey involving 130 zoo professionals to assess the strength of their relationships with zoo animals. The results indicated that human-animal bonds were prevalent among keepers, scientists, and others working in zoos. Respondents believed that these bonds contributed to the well-being of the animals and provided job satisfaction to the caretakers. Bayne et al. (1993) also demonstrated that just six minutes of human contact per week significantly reduced abnormal behaviour in rhesus macaques.

Another type of interaction that is currently more common in zoos is the animal-researcher interaction. This interaction can vary from direct, hands-on training to participation in research projects to more indirect involvement, such as behavioural observation. Even in cases of observational research, the presence of the researcher can provide stimulation to the animal, even without direct contact (Maple & Perdue, 2012). This type of interaction can also be seen in ARTIS zoo, where Students of the University of Amsterdam are observing animals cognitive abilities. For most animals, behaviour suggests these interactions spark curiosity and engagement.

Lastly, interaction between animals and humans occurs when animals are on exhibit for zoo visitors. The influence of zoo visitors on animals can be either enriching or potentially distressing. It is essential for zoo staff to monitor animal behaviour during such human-animal interactions to ensure they remain enriching and not stressful (Maple & Perdue, 2012). Research found that visitors can sometimes be a source of stress for zoo animals (Fernandez et al., 2008). Species like Cottontop tamarins (Saguinus Oedipus), Diana monkeys (Cercopithecus Diana), and ringtailed lemurs (L. catta) have exhibited increased aggression and decreased grooming activity in the presence of visitors (Maple & Perdue, 2012).

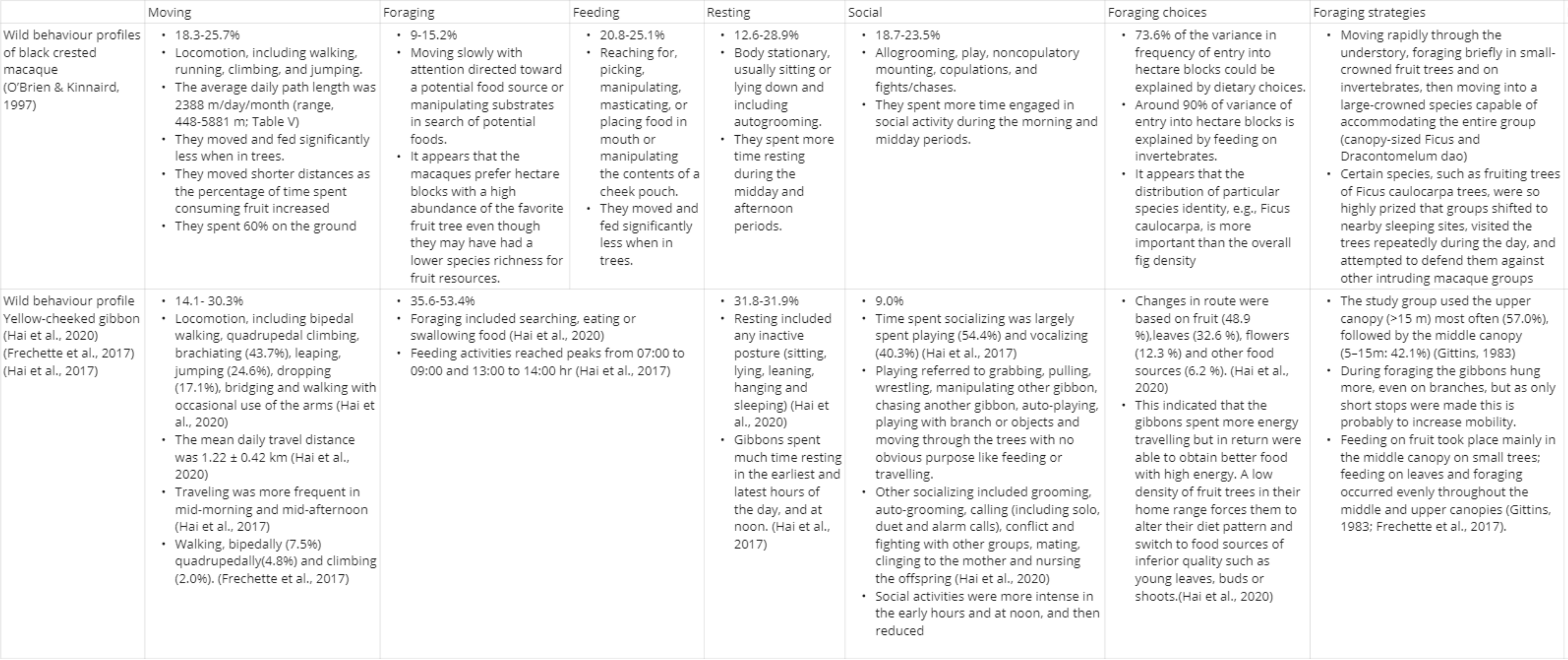
Howdy doors (Lemm, 2021)

**Table 8.1** Mammalian feeding categories.

| Feeding Category | Behavioural characteristics |
|---|---|
| Piscivore and squid eater (fish eaters, e.g. seals, penguins, etc.) | Normally, prey is chased in the water until captured when it is often swallowed whole and while the animal is submerged. |
| Carnivore (meat eaters, e.g. felids, raptors etc.) | Two methods of hunting exist:<br>(1) the prey species is chased across the terrain (e.g. dogs) or sky (e.g. raptors).<br>(2) the prey species is ambushed, typically by a solitary animal (e.g. leopard).<br>Type 1 hunting may involve long chases (e.g. hunting dogs) or short sprints by the predator (e.g. cheetah). Within a given species all types of hunting behaviour may be used, e.g. polar bears. Type 1 may also involve group hunting (e.g. killer whales) that relies upon group co-operation (e.g. wolves). |
| Nectarivore (nectar eaters, e.g. humming birds) | The animal moves between patches of flowers, where it feeds usually using a specialised tongue. The animal may have a highly developed spatial memory and the ability to use UV-light to determine on which flowers to forage. |
| Gummivore (gum eaters, e.g. common marmosets) | The animal moves between trees where it gouges holes in the bark, normally using specialised dentition. |
| Crustacivore and molluscivore (crustacean and mollusc eater, e.g. walrus) | The animal dives to the bottom of the sea and usually feels for the food using its whiskers, food is then dug up using either fins or mouth. |
| Myrmecophage (anteaters, e.g. giant anteater) | The animal moves between insect nests which, typically, it breaks open with a claw and then feeds using a long, sticky tongue. Often, these species feed from a nest for only a short period of time and their foraging behaviour could be characterised as harvesting. |
| Aerial insectivore (flying insect eater, e.g. bats, swallows and swifts) | The animal normally waits until it locates a swarm of insects and then chases them in the air. |
| Foliage-gleaning insectivore (insect eater, e.g. bushbabies) | The animal may either chase the insects through vegetation or wait until the insects come close and then leap to capture them. |
| Insectivore – omnivore (e.g. marmosets and tamarins) | Insects or vegetable food are found by moving between patches of vegetation. |
| Frugivore – omnivore (e.g. Old World primates) | Fruit or vegetable food are found by moving between patches of vegetation. |
| Frugivore – granivore (e.g. yellow-eyed juncos) | Seeds are either collected when they have fallen to the ground or collected directly from the plant. Normally, the animal moves between vegetation to find food. |
| Frugivore – herbivore (e.g. ungulates) | Food, usually grasses, is cropped from the ground by grazing. |
| Herbivore – browser (e.g. goats) | The animal uses specialised dentition to access as much of the plant material as is available. |
| Herbivore – grazer (e.g. cattle) | Typically, the animal pulls the plant material out of the ground using its tongue and then masticates it. |
| Planktonivore – nektonivore (plankton and small fish eater, e.g. baleen whales) | The animal filters water through its specialised (baleen) jaw plates to extract plankton, krill and small, shoaling fish. |
| Sanguivore (blood eater, e.g. vampire bat) | The animal hunts for other animals at night and once encountered, it removes a small quantity of blood using a painless bite. |

# Appendix C: Behavioural differences

Behaviour differences between yellow cheeked gibbon and black crested macaque



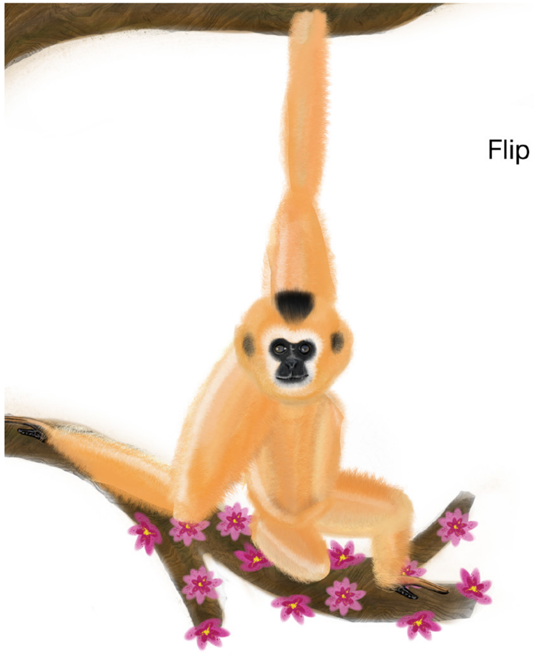
| | Moving | Foraging | Feeding | Resting | Social | Foraging choices | Foraging strategies |
|---|---|---|---|---|---|---|---|
| Wild behaviour profiles of black crested macaque (O'Brien & Kinnaird, 1997) | • 18.3-25.7%<br>• Locomotion, including walking, running, climbing, and jumping.<br>• The average daily path length was 2388 m/day/month (range, 448-5881 m; Table V)<br>• They moved and fed significantly less when in trees.<br>• They moved shorter distances as the percentage of time spent consuming fruit increased<br>• They spent 60% on the ground | • 9-15.2%<br>• Moving slowly with attention directed toward a potential food source or manipulating substrates in search of potential foods.<br>• It appears that the macaques prefer hectare blocks with a high abundance of the favorite fruit tree even though they may have had a lower species richness for fruit resources. | • 20.8-25.1%<br>• Reaching for, picking, manipulating, masticating, or placing food in mouth or manipulating the contents of a cheek pouch.<br>• They moved and fed significantly less when in trees. | • 12.6-28.9%<br>• Body stationary, usually sitting or lying down and including autogrooming.<br>• They spent more time resting during the midday and afternoon periods. | • 18.7-23.5%<br>• Allogrooming, play, noncopulatory mounting, copulations, and fights/chases.<br>• They spent more time engaged in social activity during the morning and midday periods. | • 73.6% of the variance in frequency of entry into hectare blocks could be explained by dietary choices.<br>• Around 90% of variance of entry into hectare blocks is explained by feeding on invertebrates.<br>• It appears that the distribution of particular species identity, e.g., Ficus caulocarpa, is more important than the overall fig density | • Moving rapidly through the understory, foraging briefly in small-crowned fruit trees and on invertebrates, then moving into a large-crowned species capable of accommodating the entire group (canopy-sized Ficus and Dracontomelum dao)<br>• Certain species, such as fruiting trees of Ficus caulocarpa trees, were so highly prized that groups shifted to nearby sleeping sites, visited the trees repeatedly during the day, and attempted to defend them against other intruding macaque groups |
| Wild behaviour profile Yellow-cheeked gibbon (Hai et al., 2020) (Frechette et al., 2017) (Hai et al., 2017) | • 14.1- 30.3%<br>• Locomotion, including bipedal walking, quadrupedal climbing, brachiating (43.7%), leaping, jumping (24.6%), dropping (17.1%), bridging and walking with occasional use of the arms (Hai et al., 2020)<br>• The mean daily travel distance was 1.22 ± 0.42 km (Hai et al., 2020)<br>• Traveling was more frequent in mid-morning and mid-afternoon (Hai et al., 2017)<br>• Walking, bipedally (7.5%) quadrupedally(4.8%) and climbing (2.0%). (Frechette et al., 2017) | • 35.6-53.4%<br>• Foraging included searching, eating or swallowing food (Hai et al., 2020)<br>• Feeding activities reached peaks from 07:00 to 09:00 and 13:00 to 14:00 hr (Hai et al., 2017) | | • 31.8-31.9%<br>• Resting included any inactive posture (sitting, lying, leaning, hanging and sleeping) (Hai et al., 2020)<br>• Gibbons spent much time resting in the earliest and latest hours of the day, and at noon. (Hai et al., 2017) | • 9.0%<br>• Time spent socializing was largely spent playing (54.4%) and vocalizing (40.3%) (Hai et al., 2017)<br>• Playing referred to grabbing, pulling, wrestling, manipulating other gibbon, chasing another gibbon, auto-playing, playing with branch or objects and moving through the trees with no obvious purpose like feeding or travelling.<br>• Other socializing included grooming, auto-grooming, calling (including solo, duet and alarm calls), conflict and fighting with other groups, mating, clinging to the mother and nursing the offspring (Hai et al., 2020)<br>• Social activities were more intense in the early hours and at noon, and then reduced | • Changes in route were based on fruit (48.9 %),leaves (32.6 %), flowers (12.3 %) and other food sources (6.2 %). (Hai et al., 2020)<br>• This indicated that the gibbons spent more energy travelling but in return were able to obtain better food with high energy. A low density of fruit trees in their home range forces them to alter their diet pattern and switch to food sources of inferior quality such as young leaves, buds or shoots.(Hai et al., 2020) | • The study group used the upper canopy (>15 m) most often (57.0%), followed by the middle canopy (5–15m: 42.1%) (Gittins, 1983)<br>• During foraging the gibbons hung more, even on branches, but as only short stops were made this is probably to increase mobility.<br>• Feeding on fruit took place mainly in the middle canopy on small trees; feeding on leaves and foraging occurred evenly throughout the middle and upper canopies (Gittins, 1983; Frechette et al., 2017). |

| Diet | Diet influence | Seasons | Sex difference |
|---|---|---|---|
| • Fruits (60.0-70.7%)<br>• Invertebrates (26.9-37.3%)<br>• Unripe seeds, leaf, flowers, pith, terminal shoots, herbs, grass seeds, and fungus (2.4-2.7%) | • Macaques fed longer and foraged less as the proportion of time spent feeding on fruit in the diet increased, and they socialized more as the proportion of invertebrate prey in the diet increased | • A major difference between Sulawesi macaques and other cercopithecines is the absence of seasonal variation in activity budgets despite a seasonally fluctuating environment. | • Adult males moved and rested more but fed, foraged and socialized less than adult females did<br>• Adult females were the second most active in social behavior; most of the their social interactions were directed toward other adult females and small juveniles<br>• Large juveniles moved more, fed and foraged more, and rested more than small juveniles did.<br>• Small juveniles spent the most time in social behavior and the least time foraging or resting. |
| • During the study period, a total 69 plant species in 35 families consumed by gibbons was recorded.<br>• Fruits (43.3%)<br>• Leaves (38.4%),<br>• Flowers (11.6%)<br>• Other plant parts (6%).<br>• Insects and bird eggs (0.5%) (Hai et al., 2017) | • Gibbons spent more time traveling and less time feeding when more of their diet consisted of fruit, whereas they spent less time traveling and more time feeding when more of their diet consisted of leaves. (Hai et al., 2017) | • Gibbons showed distinct seasonality in behavioural patterns in response to precipitation. The group was highly frugivorous but had a seasonal dependence on leaves and flowers.<br>• Dietary shifts coincided with changes in rainfall, which were likely indicative of fruitavailability (Frechette et al., 2017) | |

| ognitive ibilities | Where Spatial memory | What (is where) | synchrony strategy |
|---|---|---|---|
| ll lacaques wild an aptive) | Animals who found a piece of artificially introduced akebi fruit seemed to put more weight on reliable, established information about past multiple finds than on the location of one recent find in deciding where to search, as if their memory evoked a search 'routine' for this recurrent seasonal fruit. In contrast, animals who found chocolate seemed to put more weight on the location of a single recent find than on past finds of native plant foods. Taken together, the observations suggest detailed knowledge of the feeding environment, attentiveness to novel ecological details and considerable flexibility in organizing an effective search routine (Menzel, 1991). | Menzel's study revealed macaques first search location is linked to the preferred food if two types of food are presented at different locations (1991). | |
| ll gibbons captive and ild) | The gibbon also approached more often the food locations in the kiwi than in the control condition ($T$=0, $p <$ 0.001, $N$=13). Note, however, that the result is based on visiting a single food location (10) during the experiment. In summary, most of the orangutans and the gibbon female approached the food locations more often in the kiwi than in the control condition, suggesting that the discovery of kiwi fruits in one location caused them to go to and inspect other locations where they had found kiwi fruits previously. Thus, the results of the first experiment supported the hypothesis that orangutans and gibbons remember the location of previously discovered food (Scheumann & Call, 2006). | It confirmed the hypothesis that these gibbons indeed use information about the where and what while foraging. In summary, the results of experiment 2 supported the findings of experiment 1 in which subjects remembered the location of food sources. Further, we found that the orangutans and the gibbon remembered not only a food location but also its contents. Finally, the results ruled out the possible explanation that subjects visited more locations in test sessions because they had encountered food in the same sessions and that put them in a foraging mode.(Scheumann & Call, 2006). | The first fruit encounter in the beginning of a fruiting season triggered Javan gibbons to increase visiting frequency to other trees of the same species—and even to empty trees. However, Javan gibbons increased visit rates to preferred fruit species regardless of synchrony levels. Our results suggest that Javan gibbons have general knowledge of synchronous characteristics of fruit trees, and that they are able to use the first fruit encounter as a cue of the start of a fruiting season. Nevertheless, we found no support for gibbons' use of different synchrony levels of fruit species in their foraging decisions. Javan gibbons at our study site did not differentiate their visit rates to highly synchronous versus asynchronous fruit species. ghly synchronous versus asynchronous fruit species. One possible explanation as to why Javan gibbons do not use different synchrony levels of preferred fruit species may lie in their relatively small home ranges (Jang et al., 2021) |

| Vision in fruit selection | Rippeness |  | Object play | Tool use | Gaze following |
|---|---|---|---|---|---|
| Leaf colour and size were examined as potential visual cues for food selection, whereas toughness mirrored fibre content, the inverse of food quality. As leaves matured, they changed colour and toughened. Leaf lightness and yellowness were strongly negatively correlated with toughness, but variation in both the red-green axis of the CIE Lab colour space and leaf size were not. Leaves selected as food by the macaques were distinguished by being very light, yellow to slightly green. We argue that leaf colour is an important indicator of the nutritive value of leaves.<br>Trichromatic vision is an important advantage in finding those palatable leaves that are dappled red (Lucas et al., 1998). | More specifically, their behaviour suggested extrapolation of search from experimentally introduced akebi fruit to at least four independent attributes of naturally occurring akebi: the visual appearance of akebi fruit, the visual appearance of akebi vines per se, the general habitat or height level containing the plants, and possibly the exact locations containing akebi in the past. In addition, their behaviour suggested long-term memory and the ability to learn the location of a new food site from one experience (Menzel, 1991) |  |  | Two of the three troops of long-tailed macaques found on the island were observed using axe-shaped stones to crack rock oysters, detached gastropods (Malaivijitnond et al., 2007)<br>Captive group of pigtailed macaques was given the opportunity to use a rod to reach otherwise unavailable food. Initial solution by one group member resulted from trial and error but subsequent solutions by others were accelerated by three types of observation learning: social facilitation, stimulus enhancement, and imitative copying. (Beck, 1976) | gaze following is modulated by the strong affiliative relationships between informants and subjects. Friends did not react more often to the informant's gaze cue than nonfriends, yet subjects tested with friends were quicker to react, regardless of the nature of the gaze cues provided by the informant. Moreover, our results suggest that this effect of friendship seems to be independent of social status and kin relationships. (Micheletta & Waller, 2012) |
| Ideal gibbon fruit were yellow, large, with a juicy-soft pulp, thin skin and available in large crops. Gibbons ultimately sought seedless fruit, but when seeds were present they selected fruit with a single, well-protected seed. Selection was strongest when fruit were abundant in the forest and was based on seed width (<21 mm), color (yellow-orange), and fruit weight (1–5 g).<br>Gibbons overselected strongly for yellow-orange fruits, underselected red fruits, and did not eat black fruits. They ate green fruits in accordance with their abundance. Color is most frequent determinant of fruit selection by primates. Raemaekers (1977) also found that both siamang and lar gibbons prefer orange and yellow fruits (44 and 35% of diet, respectively), and Leighton and Leighton (1983), Sourd and Gautier-Hion (1986), Gautier-Hion (1990), and Julliot (1996) found that primates select brightly colored fruit, and reject dull ones. Color may signal the relative availability of nutrients in the fruit (Gautier-Hion, 1990). At Barito Ulu, red fruit tended to be associated with fruit traits favored by birds (McConkey, 1999), and the underselection of red may reflect this association of traits. |  | These results suggest that while gibbons may strategize to maximize benefits in a competitive food task, they often allowed their partners to obtain better rewards. Our results highlight the importance of social tolerance and motivation as drivers promoting cooperation in these species. (Sánchez-Amaro et al., 2021)<br>gibbons may perform better in competitive settings compared to neutral ones.<br>(Sánchez-Amaro et al., 2021) | Our observations with gibbons show that they play in various ways with new objects, however with great individual differences. (Fedor et al., 2008) | There are very few observations about the tool using of gibbons. Gibbons drop branches on intruders and sometimes they roll up leaves to sponge up liquids in the wild (Tingpalong, Watson, Whitmire, Chapple, & Marshall, 1981). Rumbaugh (1970) observed a gibbon using a cloth as a sponge and a rope to make a swing in captivity.<br>Their causal understanding of three factors, the rake, the reward and a trap into which the reward could fall and be lost, was moderately better than that of chimpanzees, Pan troglodytes, and capuchins, Cebus spp., on a similar task (Cunningham et al., 2006)<br>In the first experiment, hoolocks learned to pull a rake to obtain an out-of-reach food item. One of the 4 subjects succeeded in the task on the second try, which suggests that he did not use trial-and-error learning but mentally represented the action and the outcome beforehand. (Fedor et al., 2008) | -there has been extensive research on the abilities of gibbons to follow the gaze of others to discover an unseen object. Researchers have found that gibbons are able to shif their gaze in response to an experimenter gaze shif but it remains unclear whether gibbons are taking the perspective of the experimenter into account, including her mental states (Fedor etal., 2008) |

# Appendix D: 'How To's'



HMW
Retrieve the food

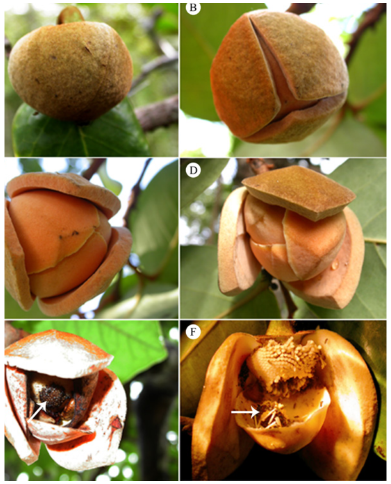
Break
Dig
Swing
Rotate
Flip
Touch
Grab
Peel
Together
Push
Stick
Mouth
Pull
Twist
Roll
Openup
Turn
Move
Shake
Wait

HMW
Return to default

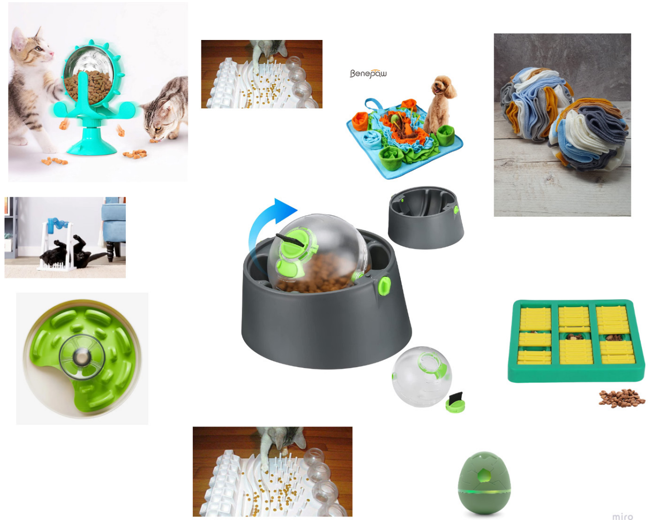
Origami
Electronics
Magnets
Rotate
Water
Move
Timer
Tabwire
String
Pull and release
Spring
Twist
Turn

# Appendix E: Inspiration

## Annona coriacea Mart. (Annonaceae)

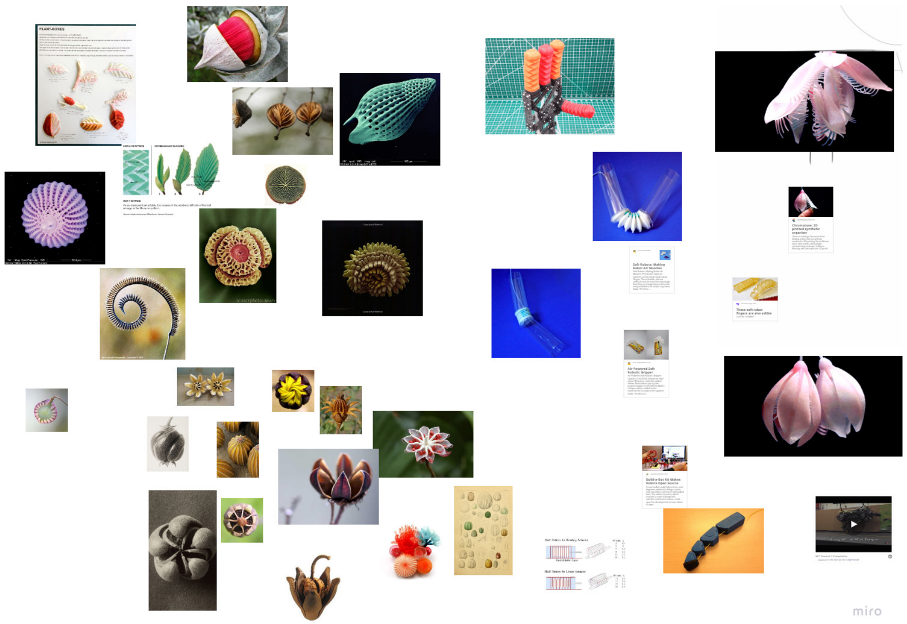


## Other foraging devices



## Enclosures

## Soft robotics

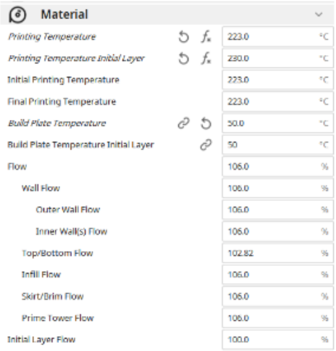


## Automatic feeders

# Appendix F: TPU printing setting

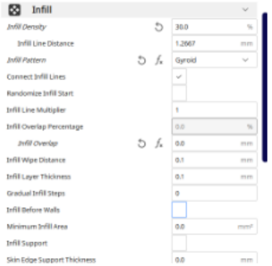
**Quality**

| | |
|---|---|
| Layer Height | 0.1 mm |
| Initial Layer Height | 0.27 mm |
| Line Width | 0.38 mm |
| Wall Line Width | 0.38 mm |
| Outer Wall Line Width | 0.38 mm |
| Inner Wall(s) Line Width | 0.38 mm |
| Top/Bottom Line Width | 0.47 mm |
| Infill Line Width | 0.38 mm |
| Skirt/Brim Line Width | 0.38 mm |
| Initial Layer Line Width | 120.0 % |



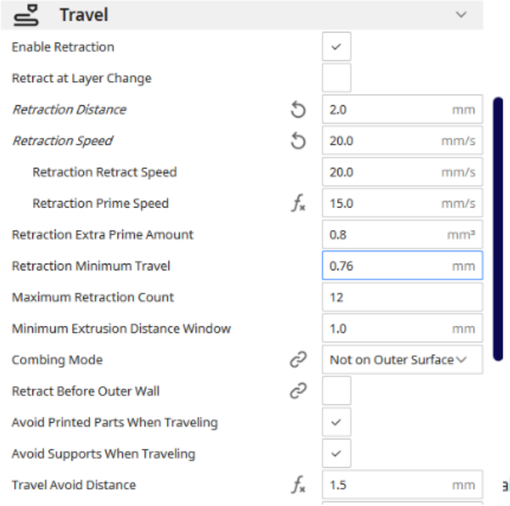
**Material**

| | |
|---|---|
| *Printing Temperature* | 223.0 °C |
| *Printing Temperature Initial Layer* | 230.0 °C |
| Initial Printing Temperature | 223.0 °C |
| Final Printing Temperature | 223.0 °C |
| *Build Plate Temperature* | 50.0 °C |
| Build Plate Temperature Initial Layer | 50 °C |
| Flow | 106.0 % |
| Wall Flow | 106.0 % |
| Outer Wall Flow | 106.0 % |
| Inner Wall(s) Flow | 106.0 % |
| Top/Bottom Flow | 102.82 % |
| Infill Flow | 106.0 % |
| Skirt/Brim Flow | 106.0 % |
| Prime Tower Flow | 106.0 % |
| Initial Layer Flow | 100.0 % |



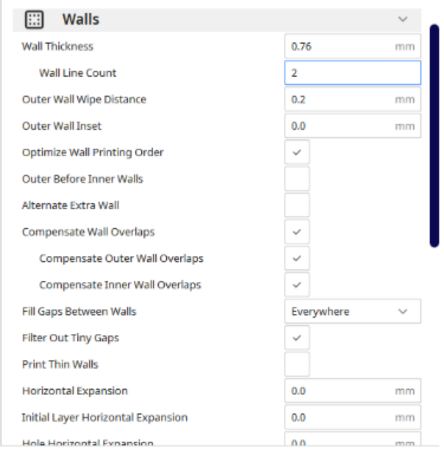
**Infill**

| | |
|---|---|
| *Infill Density* | 30.0 % |
| Infill Line Distance | 1.2667 mm |
| *Infill Pattern* | Gyroid |
| Connect Infill Lines | ☑ |
| Randomize Infill Start | ☐ |
| Infill Line Multiplier | 1 |
| Infill Overlap Percentage | 0.0 % |
| *Infill Overlap* | 0.0 mm |
| Infill Wipe Distance | 0.1 mm |
| Infill Layer Thickness | 0.1 mm |
| Gradual Infill Steps | 0 |
| Infill Before Walls | ☐ |
| Minimum Infill Area | 0.0 mm² |
| Infill Support | ☐ |
| Skin Edge Support Thickness | 0.0 mm |



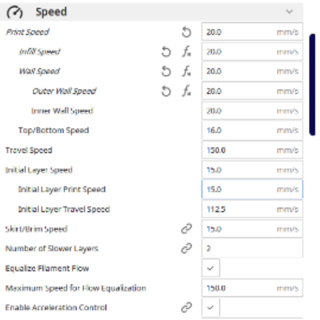
**Travel**

| | |
|---|---|
| Enable Retraction | ☑ |
| Retract at Layer Change | ☐ |
| *Retraction Distance* | 2.0 mm |
| *Retraction Speed* | 20.0 mm/s |
| Retraction Retract Speed | 20.0 mm/s |
| Retraction Prime Speed | 15.0 mm/s |
| Retraction Extra Prime Amount | 0.8 mm³ |
| Retraction Minimum Travel | 0.76 mm |
| Maximum Retraction Count | 12 |
| Minimum Extrusion Distance Window | 1.0 mm |
| Combing Mode | Not on Outer Surface |
| Retract Before Outer Wall | ☐ |
| Avoid Printed Parts When Traveling | ☑ |
| Avoid Supports When Traveling | ☑ |
| Travel Avoid Distance | 1.5 mm |



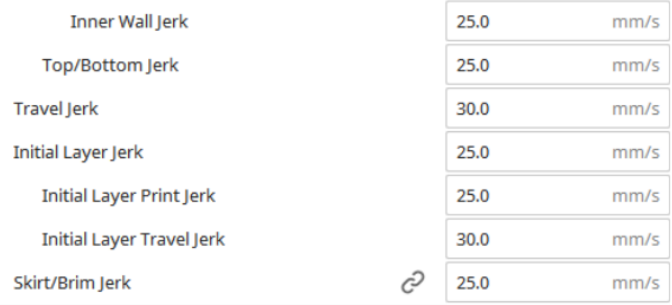
**Walls**

| | |
|---|---|
| Wall Thickness | 0.76 mm |
| Wall Line Count | 2 |
| Outer Wall Wipe Distance | 0.2 mm |
| Outer Wall Inset | 0.0 mm |
| Optimize Wall Printing Order | ☑ |
| Outer Before Inner Walls | ☐ |
| Alternate Extra Wall | ☐ |
| Compensate Wall Overlaps | ☑ |
| Compensate Outer Wall Overlaps | ☑ |
| Compensate Inner Wall Overlaps | ☑ |
| Fill Gaps Between Walls | Everywhere |
| Filter Out Tiny Gaps | ☑ |
| Print Thin Walls | ☐ |
| Horizontal Expansion | 0.0 mm |
| Initial Layer Horizontal Expansion | 0.0 mm |
| Hole Horizontal Expansion | 0.0 mm |

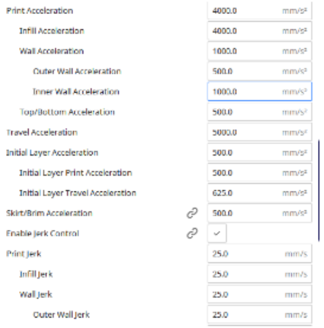


**Speed**

| | |
|---|---|
| *Print Speed* | 20.0 mm/s |
| *Infill Speed* | 20.0 mm/s |
| *Wall Speed* | 20.0 mm/s |
| *Outer Wall Speed* | 20.0 mm/s |
| Inner Wall Speed | 20.0 mm/s |
| Top/Bottom Speed | 16.0 mm/s |
| Travel Speed | 150.0 mm/s |
| Initial Layer Speed | 15.0 mm/s |
| Initial Layer Print Speed | 15.0 mm/s |
| Initial Layer Travel Speed | 112.5 mm/s |
| Skirt/Brim Speed | 15.0 mm/s |
| Number of Slower Layers | 2 |
| Equalize Filament Flow | ☑ |
| Maximum Speed for Flow Equalization | 150.0 mm/s |
| Enable Acceleration Control | ☑ |



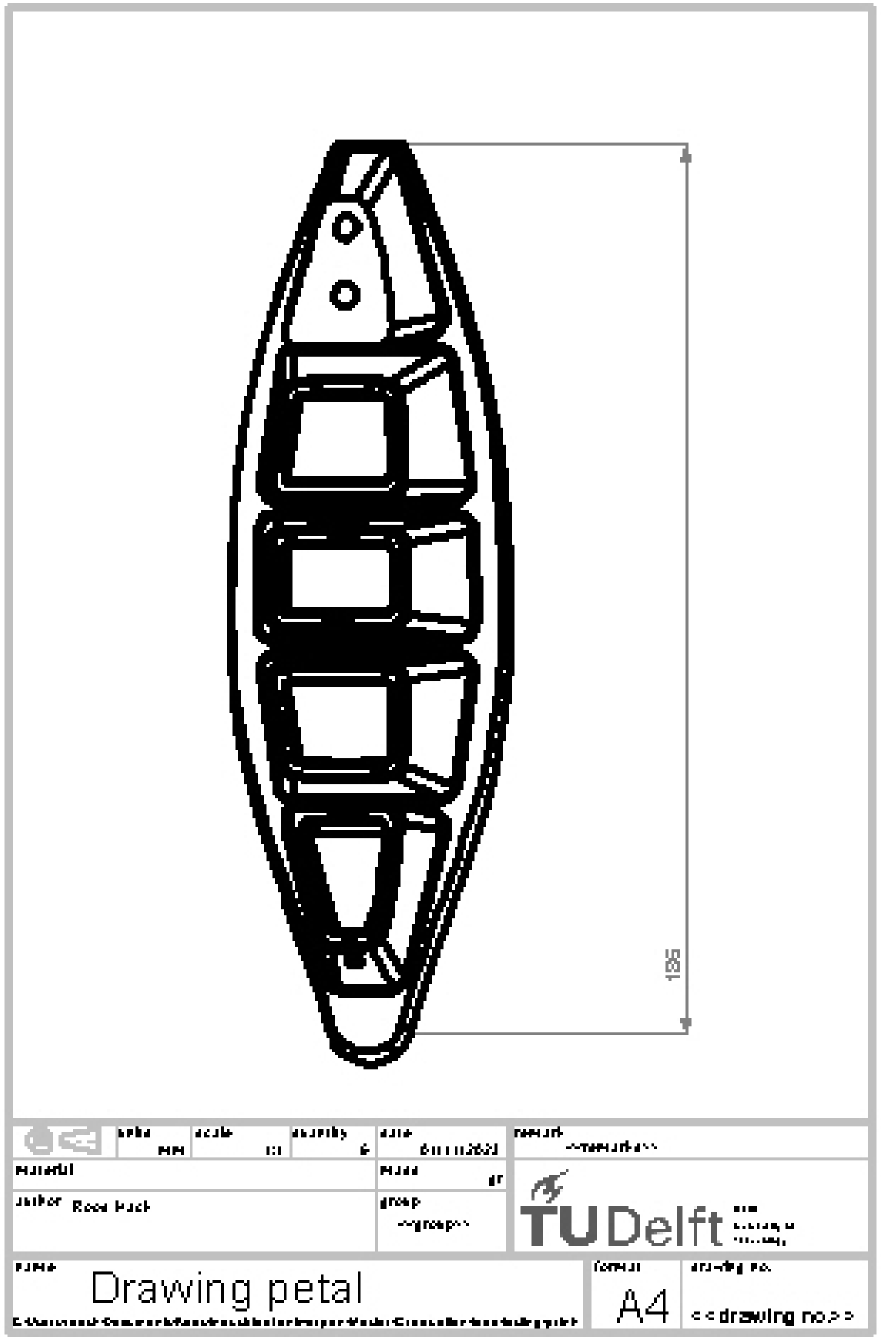
| | |
|---|---|
| | 25.0 mm/s |
| all Jerk | 25.0 mm/s |
| Inner Wall Jerk | 25.0 mm/s |
| Top/Bottom Jerk | 25.0 mm/s |
| Travel Jerk | 30.0 mm/s |
| Initial Layer Jerk | 25.0 mm/s |
| Initial Layer Print Jerk | 25.0 mm/s |
| Initial Layer Travel Jerk | 30.0 mm/s |
| Skirt/Brim Jerk | 25.0 mm/s |

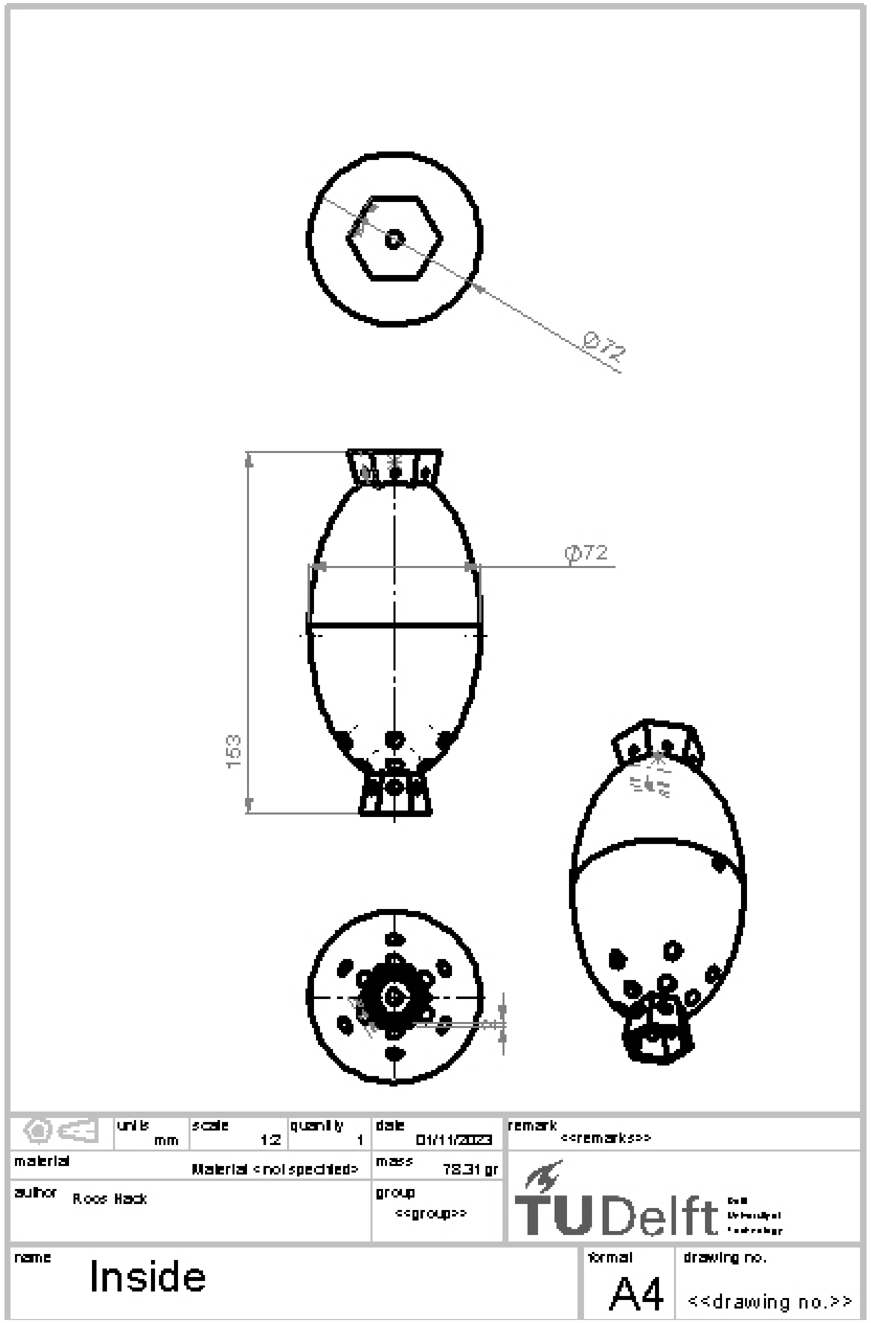


| | |
|---|---|
| Print Acceleration | 4000.0 mm/s² |
| Infill Acceleration | 4000.0 mm/s² |
| Wall Acceleration | 1000.0 mm/s² |
| Outer Wall Acceleration | 500.0 mm/s² |
| Inner Wall Acceleration | 1000.0 mm/s² |
| Top/Bottom Acceleration | 500.0 mm/s² |
| Travel Acceleration | 5000.0 mm/s² |
| Initial Layer Acceleration | 500.0 mm/s² |
| Initial Layer Print Acceleration | 500.0 mm/s² |
| Initial Layer Travel Acceleration | 625.0 mm/s² |
| Skirt/Brim Acceleration | 500.0 mm/s² |
| Enable Jerk Control | ☑ |
| Print Jerk | 25.0 mm/s |
| Infill Jerk | 25.0 mm/s |
| Wall Jerk | 25.0 mm/s |
| Outer Wall Jerk | 25.0 mm/s |

miro

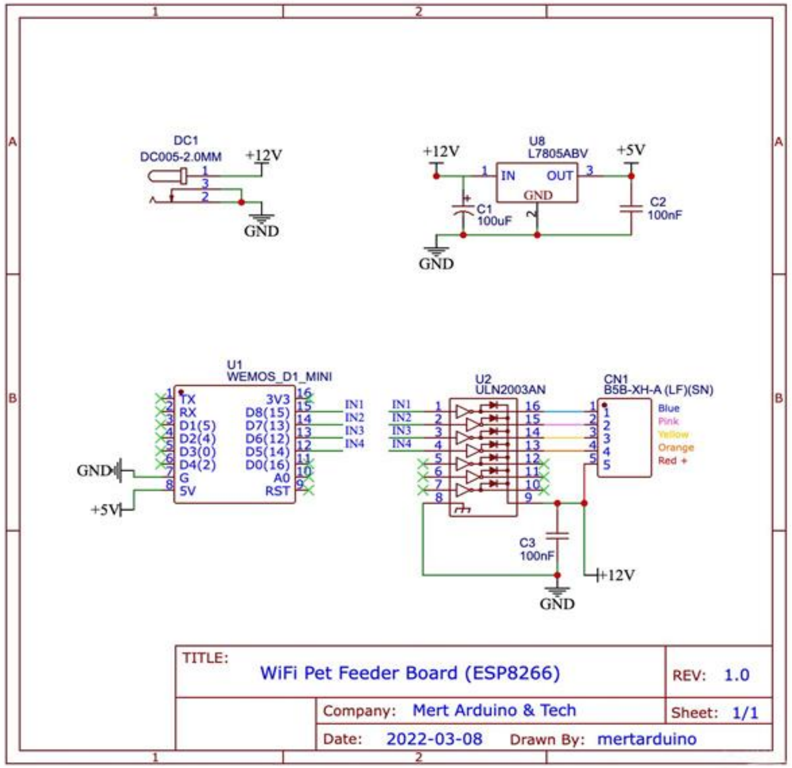
# Appendix G: Technical drawings



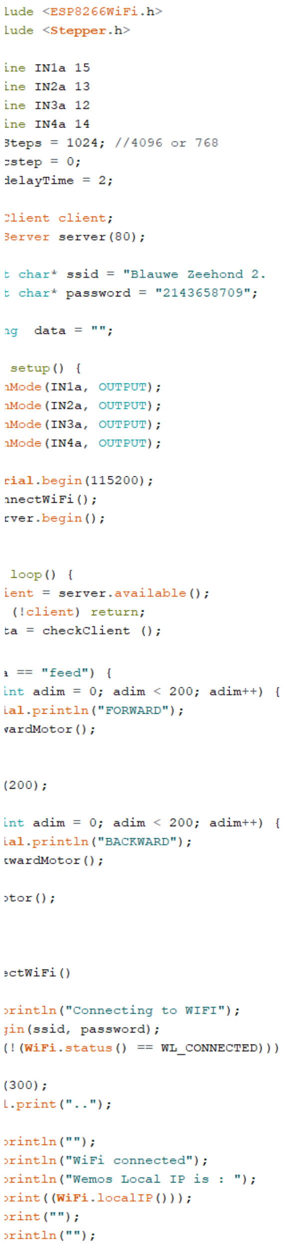


# Appendix H: Electronics

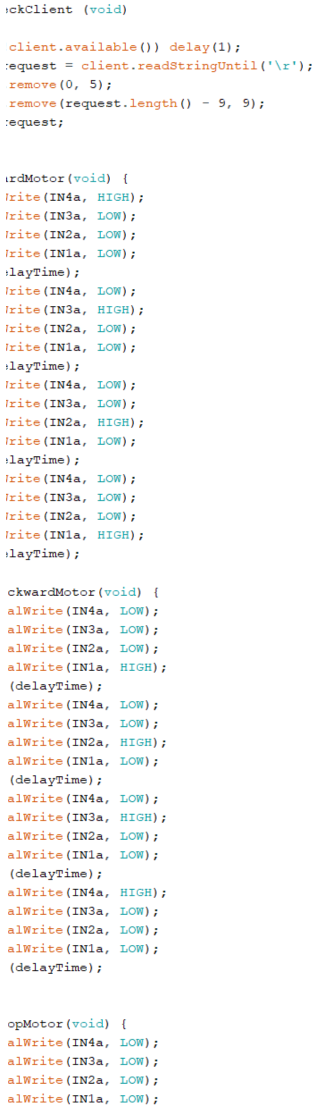
## Assembly schematic



## Source code

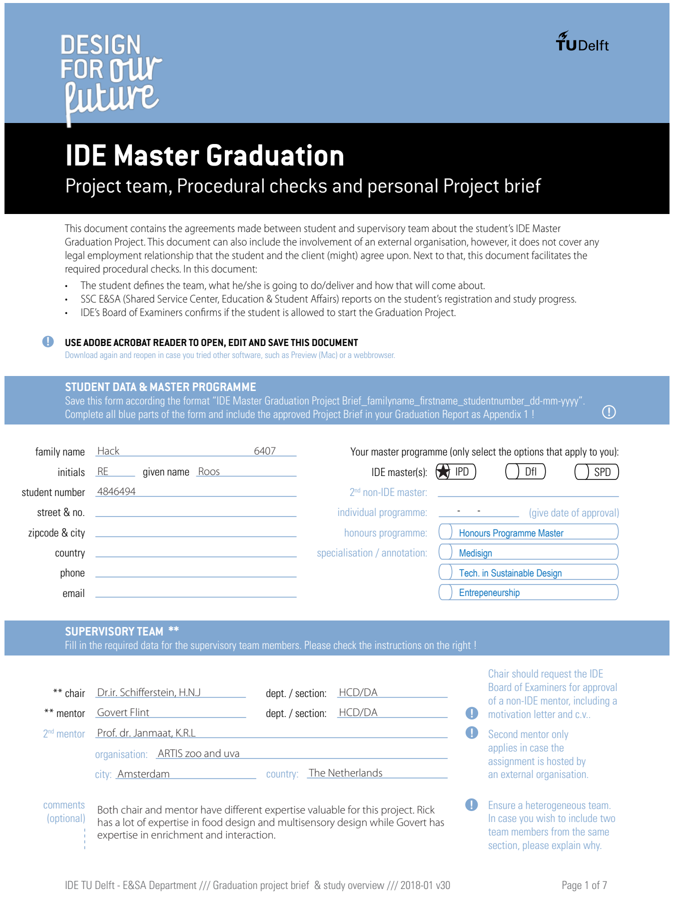


```
lude <ESP8266WiFi.h>
lude <Stepper.h>

ine IN1a 15
ine IN2a 13
ine IN3a 12
ine IN4a 14
3teps = 1024; //4096 or 768
:step = 0;
delayTime = 2;

Client client;
Server server(80);

t char* ssid = "Blauwe Zeehond 2.
t char* password = "2143658709";

ng  data = "";

 setup() {
nMode(IN1a, OUTPUT);
nMode(IN2a, OUTPUT);
nMode(IN3a, OUTPUT);
nMode(IN4a, OUTPUT);

rial.begin(115200);
nnectWiFi();
rver.begin();


 loop() {
ient = server.available();
 (!client) return;
ta = checkClient ();

a == "feed") {
int adim = 0; adim < 200; adim++) {
ial.println("FORWARD");
wardMotor();


(200);

int adim = 0; adim < 200; adim++) {
ial.println("BACKWARD");
kwardMotor();

otor();



ectWiFi()

println("Connecting to WIFI");
gin(ssid, password);
(!(WiFi.status() == WL_CONNECTED)))

(300);
l.print("..");

println("");
println("WiFi connected");
println("Wemos Local IP is : ");
print((WiFi.localIP()));
print("");
println("");
```



```
eckClient (void)

 client.available()) delay(1);
request = client.readStringUntil('\r');
 remove(0, 5);
 remove(request.length() - 9, 9);
request;


ardMotor(void) {
Write(IN4a, HIGH);
Write(IN3a, LOW);
Write(IN2a, LOW);
Write(IN1a, LOW);
elayTime);
Write(IN4a, LOW);
Write(IN3a, HIGH);
Write(IN2a, LOW);
Write(IN1a, LOW);
elayTime);
Write(IN4a, LOW);
Write(IN3a, LOW);
Write(IN2a, HIGH);
Write(IN1a, LOW);
elayTime);
Write(IN4a, LOW);
Write(IN3a, LOW);
Write(IN2a, LOW);
Write(IN1a, HIGH);
elayTime);

 ckwardMotor(void) {
 alWrite(IN4a, LOW);
 alWrite(IN3a, LOW);
 alWrite(IN2a, LOW);
 alWrite(IN1a, HIGH);
 (delayTime);
 alWrite(IN4a, LOW);
 alWrite(IN3a, LOW);
 alWrite(IN2a, HIGH);
 alWrite(IN1a, LOW);
 (delayTime);
 alWrite(IN4a, LOW);
 alWrite(IN3a, HIGH);
 alWrite(IN2a, LOW);
 alWrite(IN1a, LOW);
 (delayTime);
 alWrite(IN4a, HIGH);
 alWrite(IN3a, LOW);
 alWrite(IN2a, LOW);
 alWrite(IN1a, LOW);
 (delayTime);


 opMotor(void) {
 alWrite(IN4a, LOW);
 alWrite(IN3a, LOW);
 alWrite(IN2a, LOW);
 alWrite(IN1a, LOW);
```

# Appendix I: Project brief



DESIGN FOR our future

TU Delft

## IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

**USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT**
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

**STUDENT DATA & MASTER PROGRAMME**
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Hack 6407
initials: RE given name: Roos
student number: 4846494
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ● IPD ○ Dfl ○ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ○ Honours Programme Master
specialisation / annotation: ○ Medisign
○ Tech. in Sustainable Design
○ Entrepeneurship

**SUPERVISORY TEAM ****
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Dr.ir. Schifferstein, H.N.J dept. / section: HCD/DA
** mentor: Govert Flint dept. / section: HCD/DA
2nd mentor: Prof. dr. Janmaat, K.R.L
organisation: ARTIS zoo and uva
city: Amsterdam country: The Netherlands

comments (optional): Both chair and mentor have different expertise valuable for this project. Rick has a lot of expertise in food design and multisensory design while Govert has expertise in enrichment and interaction.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

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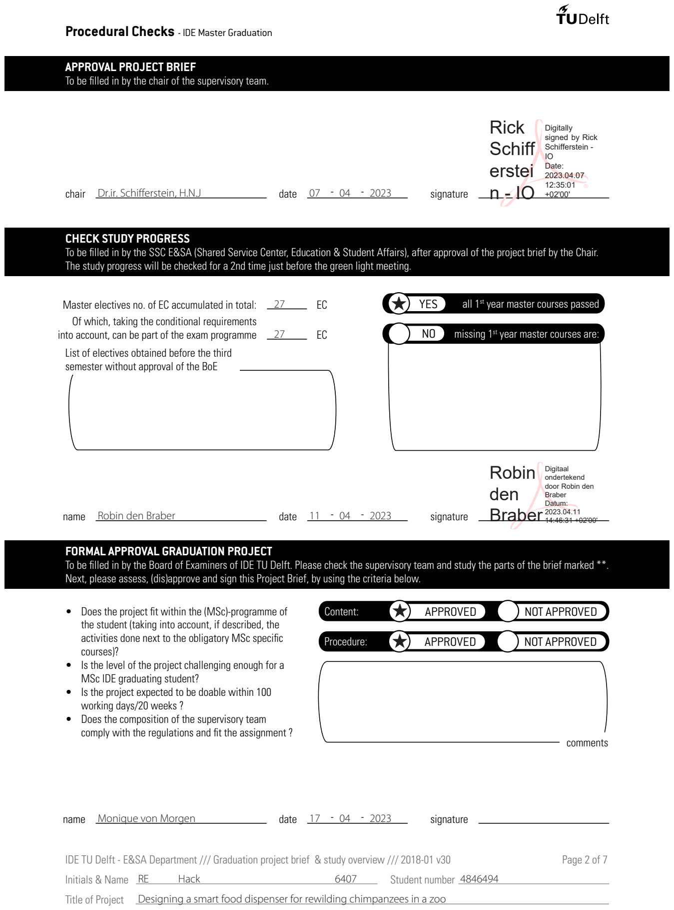

**Procedural Checks** - IDE Master Graduation

TU Delft

**APPROVAL PROJECT BRIEF**
To be filled in by the chair of the supervisory team.

chair: Dr.ir. Schifferstein, H.N.J date: 07 - 04 - 2023 signature: Rick Schifferstein - IO Digitally signed by Rick Schifferstein - IO Date: 2023.04.07 12:35:01 +02'00'

**CHECK STUDY PROGRESS**
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 27 EC
Of which, taking the conditional requirements into account, can be part of the exam programme: 27 EC
List of electives obtained before the third semester without approval of the BoE:

● YES all 1st year master courses passed
○ NO missing 1st year master courses are:

name: Robin den Braber date: 11 - 04 - 2023 signature: Robin den Braber Digitaal ondertekend door Robin den Braber Datum: 2023.04.11 14:46:31 +02'00'

**FORMAL APPROVAL GRADUATION PROJECT**
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ● APPROVED ○ NOT APPROVED
Procedure: ● APPROVED ○ NOT APPROVED

comments

name: Monique von Morgen date: 17 - 04 - 2023 signature:

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 2 of 7
Initials & Name: RE Hack 6407 Student number: 4846494
Title of Project: Designing a smart food dispenser for rewilding chimpanzees in a zoo

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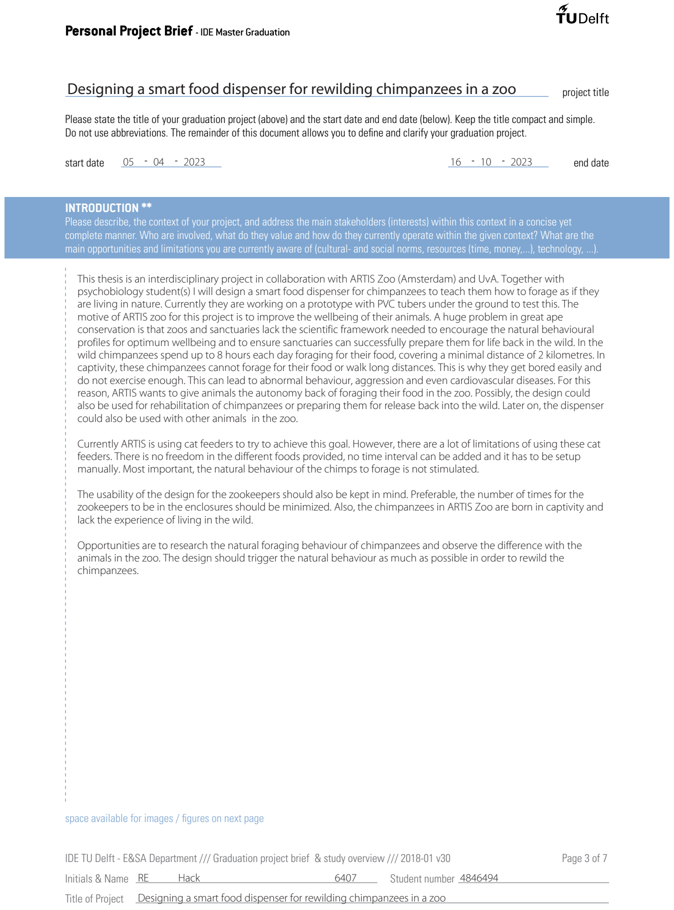


**Personal Project Brief** - IDE Master Graduation

TU Delft

project title: Designing a smart food dispenser for rewilding chimpanzees in a zoo

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date: 05 - 04 - 2023 end date: 16 - 10 - 2023

**INTRODUCTION ****
Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

This thesis is an interdisciplinary project in collaboration with ARTIS Zoo (Amsterdam) and UvA. Together with psychobiology student(s) I will design a smart food dispenser for chimpanzees to teach them how to forage as if they are living in nature. Currently they are working on a prototype with PVC tubers under the ground to test this. The motive of ARTIS zoo for this project is to improve the wellbeing of their animals. A huge problem in great ape conservation is that zoos and sanctuaries lack the scientific framework needed to encourage the natural behavioural profiles for optimum wellbeing and to ensure sanctuaries can successfully prepare them for life back in the wild. In the wild chimpanzees spend up to 8 hours each day foraging for their food, covering a minimal distance of 2 kilometres. In captivity, these chimpanzees cannot forage for their food or walk long distances. This is why they get bored easily and do not exercise enough. This can lead to abnormal behaviour, aggression and even cardiovascular diseases. For this reason, ARTIS wants to give animals the autonomy back of foraging their food in the zoo. Possibly, the design could also be used for rehabilitation of chimpanzees or preparing them for release back into the wild. Later on, the dispenser could also be used with other animals in the zoo.

Currently ARTIS is using cat feeders to try to achieve this goal. However, there are a lot of limitations of using these cat feeders. There is no freedom in the different foods provided, no time interval can be added and it has to be setup manually. Most important, the natural behaviour of the chimps to forage is not stimulated.

The usability of the design for the zookeepers should also be kept in mind. Preferable, the number of times for the zookeepers to be in the enclosures should be minimized. Also, the chimpanzees in ARTIS Zoo are born in captivity and lack the experience of living in the wild.

Opportunities are to research the natural foraging behaviour of chimpanzees and observe the difference with the animals in the zoo. The design should trigger the natural behaviour as much as possible in order to rewild the chimpanzees.

space available for images / figures on next page

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 3 of 7
Initials & Name: RE Hack 6407 Student number: 4846494
Title of Project: Designing a smart food dispenser for rewilding chimpanzees in a zoo

introduction (continued): space for images

image / figure 1: Observation of chimpanzees in ARTIS

**TO PLACE YOUR IMAGE IN THIS AREA:**

- **SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER**
- **CLICK AREA TO PLACE IMAGE / FIGURE**

**PLEASE NOTE:**

- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 2:

---

## PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The problem is: zoos lack the scientific framework needed to encourage the natural behavioural profiles needed for optimum wellbeing of their chimpanzees. Therefore, abnormal behaviour is seen in the captive chimpanzees such as aggression.

The scope of my project will be to design and prototype a feeding solution to trigger the natural foraging behaviour of chimpanzees in the wild. The design must keep in mind the physical behaviour (use of hands and tools) as well as the mental aspect of thinking about their food resources (where they can be found, when they are ripe). This can be done by replicating the mechanical challenges they experience in the wild. Keeping a healthy food diet for the chimpanzees is also important.

The challenge is to make the dispenser smart, remote controlled and from biobased materials. Every product which is placed inside an animal enclosure should be made from organic materials. The product should be designed to be enriching for the animal and must consider the anatomy of chimpanzees. Preferably, the design is scalable and chimpanzee proof in the most literal way.

The design should be a multi-sensory design. Feedback or output of smell, feel or sound can be added to trigger the multiple senses of the chimpanzee to attract and trigger the thinking process.
Knowledge of the foraging behaviour in the wild must be obtained in order to compare this to the observed behaviour of the enclosed chimpanzees.

## ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... . In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Design and prototype a feeding solution for chimpanzees to trigger the natural foraging behaviour of chimpanzees in the wild. Encouraging the natural behaviour in order to contribute to a better wellbeing for the chimpanzees.

The final delivery will be a product/prototype, a smart feeding solution. The final product has gone through numerous of redesigns which are tested and adjusted to get the optimum interaction with the chimpanzees.
In addition, a report will be written and an additional communication tool (e.g., poster or video) will be provided.

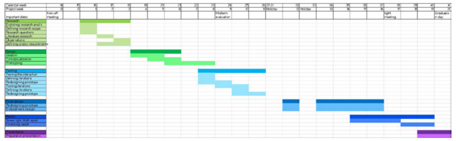
---

## PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 5 - 4 - 2023

16 - 10 - 2023 end date



For the making the planning, I used the backwards design approach. What deliverables are there? What is the desired outcome mentioned in the section above? A prototype. What is needed before producing the prototype? A design that is tested and iterated on. This design needs to be based of research.

---

## MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... . Stick to no more than five ambitions.

For my graduation project I decided for myself 3 points that were important when choosing a project. These were enough freedom, working in a small organization, and being able to make an impact with my project. Personally, I was immediately drawn to the project because of my love for animals and the ability to create a better life for the animals.

I want to prove to myself that I am able to lead my own project from research to final design and manage time well. Also important for me is to work with the stakeholders and create a vision fitting everyone, also the animals.

My personal learning ambition is to really focus on testing and iterating my design. I tend to spend most of my time perfecting my concept and usually lack the time to test and make adjustments to my design. Therefore, I already took this into account for my planning. Also, I am really interested in working with animals. Obviously, there is a huge difference between humans and, therefore, it is important to acknowledge when the methods learned can be used and when these methods needs to be adjusted. Lastly, I want to reach out to experts as much as possible to get a great understanding of the topic. This is something I often struggle with and therefore want to focus on.

## FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

**Master thesis Integrated product design**
1 November 2023
Roos Hack - 4846494
Delft university of technology
Faculty of industrial design engineering

**Graduation committee**
Chair: Dr.ir. Rick Schifferstein
Mentor: Govert Flint

**Company**
ARTIS dierentuin
Company mentor: Prof. Dr. Karline Janmaat