Adapting a mosquito trap for future deployment in African communities

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Executive Summary

In this report, two proposals are made: first is the improvement and embodiment of an innovative mosquito trap concept, and second is the proposed way forwards: the implementation, deployment and future sustainability are described.

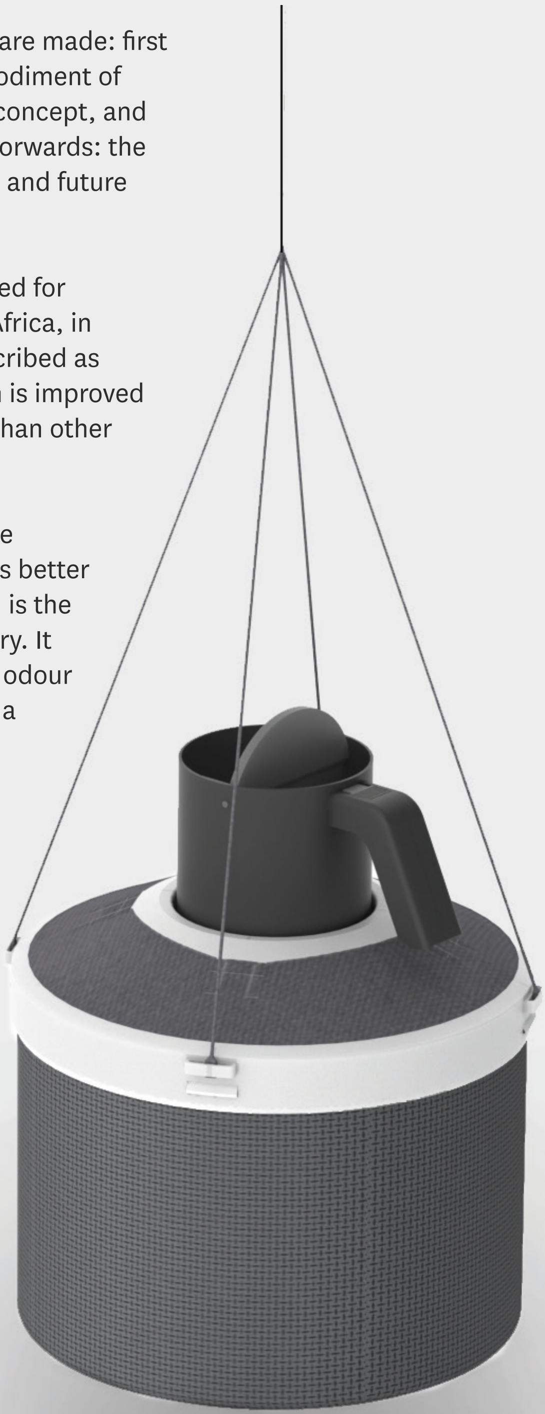
The mosquito trap is fine-tuned for deployment in sub-Saharan Africa, in conditions that could be described as extreme. The user interaction is improved and the trap is easier to use than other traps on the market.

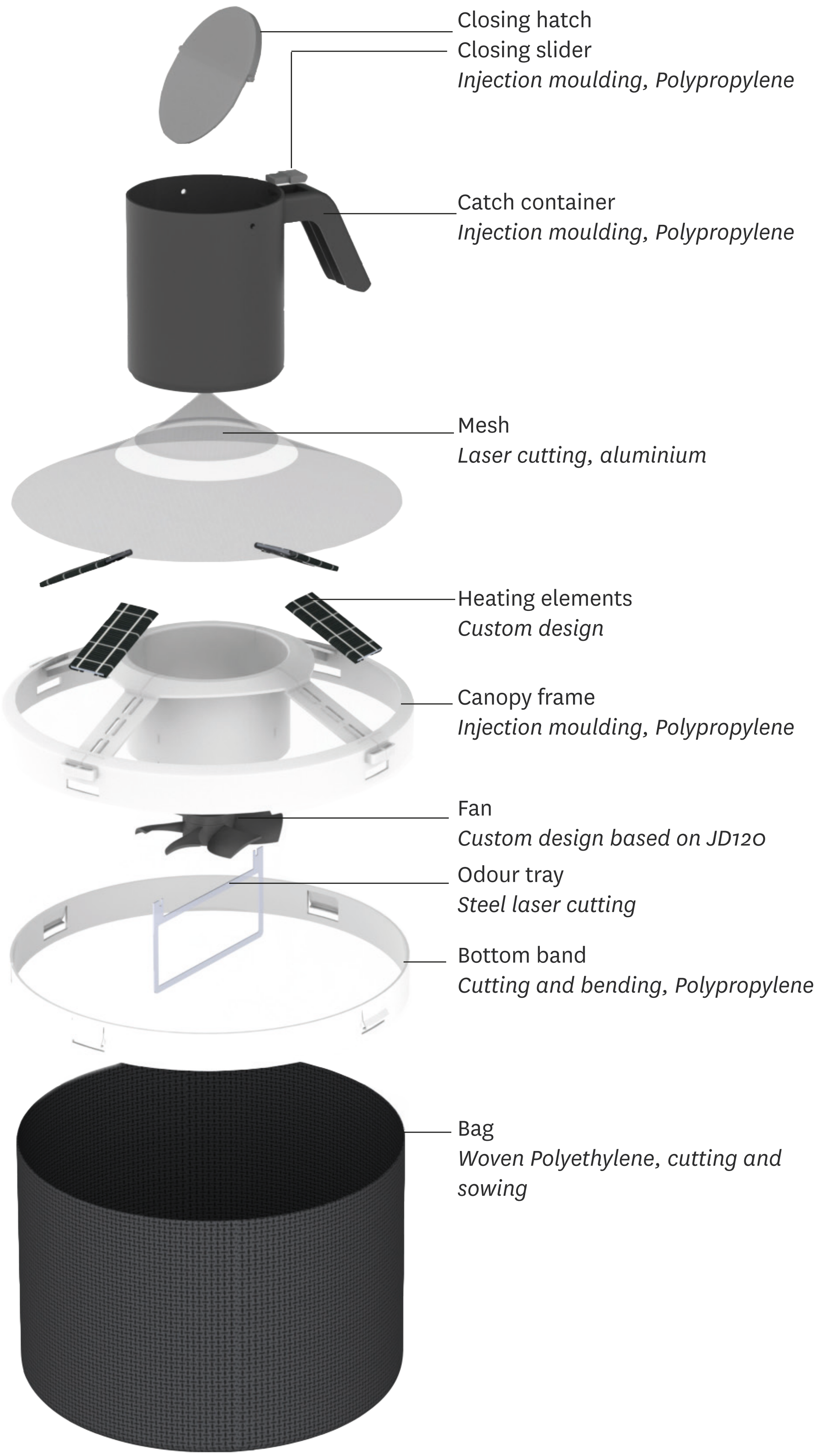
During initial experiments, the prototype performed 3X times better than the BG-Suna trap, which is the benchmark trap in the industry. It lures mosquitoes using heat, odour and colour contrast, and has a superior airflow.

At a manufacturing cost of €6,99 and proposed sales price of €24 (€76 including solar system) it is more affordable than any successfully tested system.

The implementation described in this report proposes tactical partnerships with Micro-solar companies and Biogents, the manufacturer of current traps. With these partnerships, the future sustainability of both the company and the trap implementation are a step closer.

Industry experts, scientists and local people in Africa are enthusiastic about the potential of mosquito trapping and this embodiment in the fight against malaria.



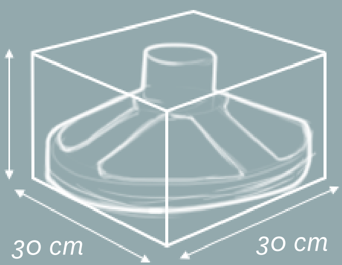


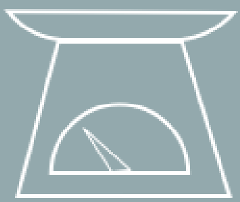
EXPLODED VIEW

On the right, the parts of the M-Tego are shown.

M-Tego II properties

	Suna	M-Tego II	
Price of trap*	€70	€24	2.9X more affordable
Price of system**	€125	€75	1.7X more affordable
Effectiveness***	100	300	at least 3.0X more effective***
Effectiveness / €	0.8	4.3	5.3X more efficient
Power consumption	3.3W	8W	Uses more power due to heating elements
Weight	1.05 Kg	0.54 Kg	1.9X lighter
Individually boxed volume	80L	18L	4.4X smaller





*Does not include solar panel or batteries. An 8AH, 12V battery is required for one night of sampling. A 20W solar panel, controller and 20AH battery are recommended for continued use. (costs approx €55)
**Includes a 20W solar panel, 20AH battery, controller and wiring.
***Estimation based on to be published lab and semi-field dual-choice data, and individual testing with earlier M-Tego prototypes. Tested on *An. gambiae s.s.*, a main vector of malaria. Suna = 100, baseline.

Foreword

This is a female mosquito of the genus *Anopheles*, the main vector of malaria: it is responsible for the death of 445,000 people annually, of which mostly children under five years old. Not even a hundred years ago, malaria was widespread in Europe and the USA.

We can, and must, beat malaria.

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Abbreviations

2- Butanone	A chemical, attractive to mosquitoes and a potential replacement for CO_2 in mosquito traps
IHI	Ifakara Health Institute, a research institute and the location of the field work
IHME	Institutes for Health Metrics and Evaluation (the research institute of the Bill and Melinda Gates foundation)
IPD	Integrated Product Design, a master programme at the TU Delft faculty of Industrial Design Engineering
IRS	Indoor Residual Spraying. The indoor spraying of chemicals such as DDT in order to reduce the amount of vectors
ITN	Insecticide Treated Net, a mosquito net used to protect people against insects and in particular mosquitoes. It is treated with an insecticide that kills mosquitoes shortly after they land on it
M-Tego (I)	M(osquito)- Trap in Swahili. M-Tego is the result of Henry Fairbairns MSc project and the starting point of this project
M-Tego II	The trap design that is a result of this graduation project.
MB5	A blend of chemicals, attractive to mosquitoes of the genus *Anopheles*, in particular *Anopheles gambiae s.s.*
MSC	Micro Solar system Company; a company leasing or selling solar home solutions in sub-Saharan Africa.
SSA	sub-Saharan Africa
SMoT	Solar powered Mosquito Trapping system. A connected mosquito trap and solar system, and usually a controller.
WHO	The World Health Organisation, a branch of the United Nations concerned with 'directing and coordinating international health within the United Nations' system.'
WUR	Wageningen University and Research

Screenhouses near Ifakara, Tanzania. Owned and operated by the IHI.

Introduction

1. Cribellier A, van Erp JA, Hiscox A, Lankheet MJ, van Leeuwen JL, Spitzen J, Muijres FT. 2018 Flight behaviour of malaria mosquitoes around odour-baited traps: capture and escape dynamics.

2. Fairbairn, H. (2018) Design of an odour baited mosquito trap for malaria prevention in Africa.

3. Konradsen et al (1997). Measuring the Economic Cost of Malaria to Households in Sri Lanka.

The department of Experimental Zoology and the laboratory of Entomology at the WUR (Wageningen University Research) are optimising an odour-based mosquito trap. The original trap is designed by Biogents and is called the BG-Suna. It was designed specifically for experiments by the WUR. The researchers in this project, Florian Muijres and Antoine Cribellier[1], focus on the flight dynamics of mosquitoes. They recently studied the flight behaviour of malaria mosquitoes around these odour-baited traps and showed that current traps are far from optimal. In fact, current traps are attractive to mosquitoes, but capture efficiency is very low: less than 4% of all approaching mosquitoes get caught and killed![1] Future iterations of the mosquito trap might have a better attract to kill ratio, but most likely won't kill all mosquitoes it attracts.

A PROMISING METHOD OF ERADICATING MALARIA

Despite the imperfections of the current traps, mosquito trapping is a promising method of reducing malaria densities.
A pilot study performed on the Rusinga island in Kenya with the Suna, saw a decline of 70% in mosquito population and a 30% drop in malaria cases. However, the trap was deployed "in combination with mosquito nets, anti-malaria drugs, and a solid social strategy" so these effects cannot be attributed to the trap alone. More importantly, after the research programme had finished, most of the traps fell into disrepair and most of the health benefits disappeared.

A PROMISING MOSQUITO TRAP CONCEPT

Through an iterative design process and lab testing, the researchers hope to improve the kill-to-attract ratio. From March through August 2018, Henry Fairbairn worked on a concept for an improved trap[2]. This trap included more short-range host cues, like passive-heated water and heated inlet pipe through a coil. The shape, colour contrast and size also varied significantly from the Suna. The resulting concept was named M-Tego, or M(osquito) trap, in Swahili. The prototypes that were build according to the concept, were designed for lab testing the new features rather than implementation in Africa.

A successful iteration of the mosquito trap has the potential to significantly reduce the population of *Anopheles* (malaria mosquito) and potentially *Aedes aegypti* (yellow fever mosquito). This should result in less cases of malaria, a healthier society and better economic circumstances. Currently 10% of annual African family income is lost due to malaria[3].

So far, the research project has been focussed on the technical principles that improve the catch rate and for lab testing purposes. The eventual production, deployment, and use of the trap, as well as key social and economic aspects of the local context, have had little attention.

FUNCTIONALITY AND CLASS OF MOSQUITO TRAP

The type of mosquito trap that was redesigned works by sucking mosquitoes in after luring them with attractive odours, heat, and/or colour contrast (figure 1). While there are other types of mosquito traps, deviating from this type of trap was not the objective of this project.

Figure 1. Working principles of an airflow-based mosquito trap with a close-range cue (heat)

1. An odour strip is suspended in the trap, luring mosquitoes from the long (10-100m) distance.

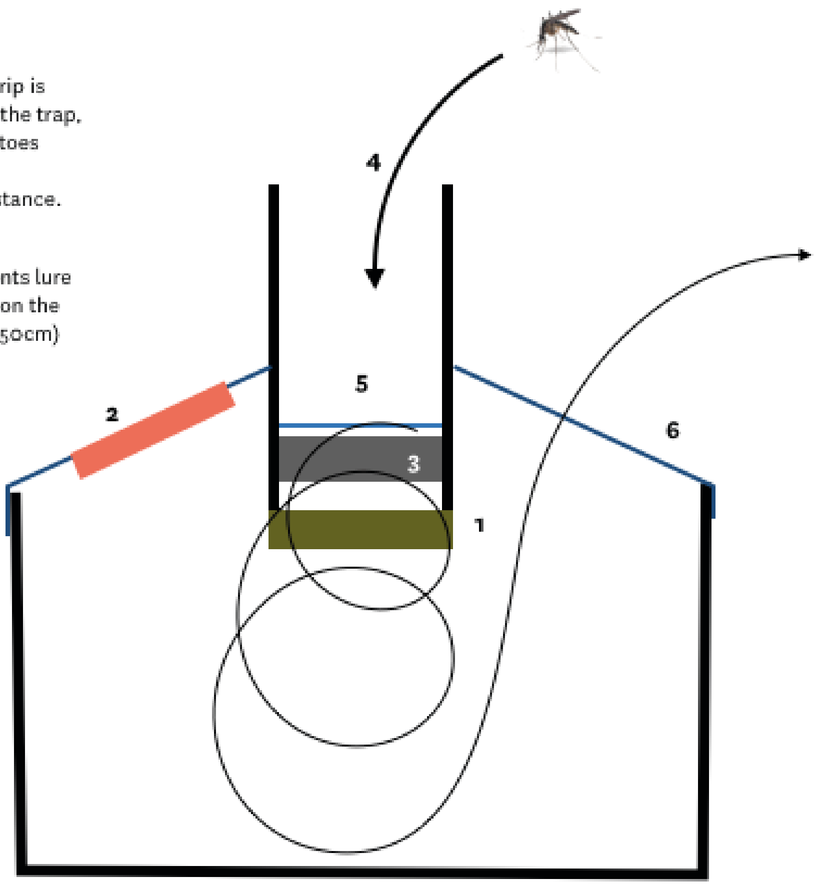
2. Heat elements lure the mosquito on the short range (<50cm)

3. A fan draws in air and mosquitoes

4. Mosquito enters the trap, being sucked in by a fan

5. Mosquitoes are captured here, unable to escape the airflow

6. The air, now scented with the odour blend, leaves the trap



M-Tego: a promising concept

4. The current use of the trap is explained further in chapter ‘Concept evaluation’ on page 46.

ODOUR BASED MOSQUITO TRAP

The M-Tego concept is the starting point of this project. It is based on the Suna trap, but introduces a heating element around the rim of the inlet pipe, and a water container. During the day, the water heats up in the sunlight. This creates a warm, moist atmosphere around the trap which attracts mosquitoes. However, the adding of water does add to complexity for the user.[4] During lab testing, these features have contributed to a 4.9X increase in captures, which was confirmed during field work.

The trap is based on the principle of circulating airflow: mosquitoes get sucked in by a fan, through the inlet pipe and fan, and end up in the catch container. The same air then blends with the odour strips, exhausting scented air.

After capture, about half of the mosquitoes is dead on impact due to the fan, the other mosquitoes usually die in the catch container within 48 hours due to lack of food. Because of the fan, the trap needs electricity. This basic principle will not be changed in this design process. The addition of a heated wire increases power consumption.

The prototypes build of the M-Tego concept looks different from its concept counterpart in some ways. For example the replacement of the plastic canopy with a mesh has led to a faster outward airflow and most likely, more captures. However, this made the prototype more complex in structure as well.

Figure 2. The SMoT system, including the M-Tego concept. SMoT stands for Solar powered Mosquito Trapping system and refers to the entire system, including solar panel, battery and controller.

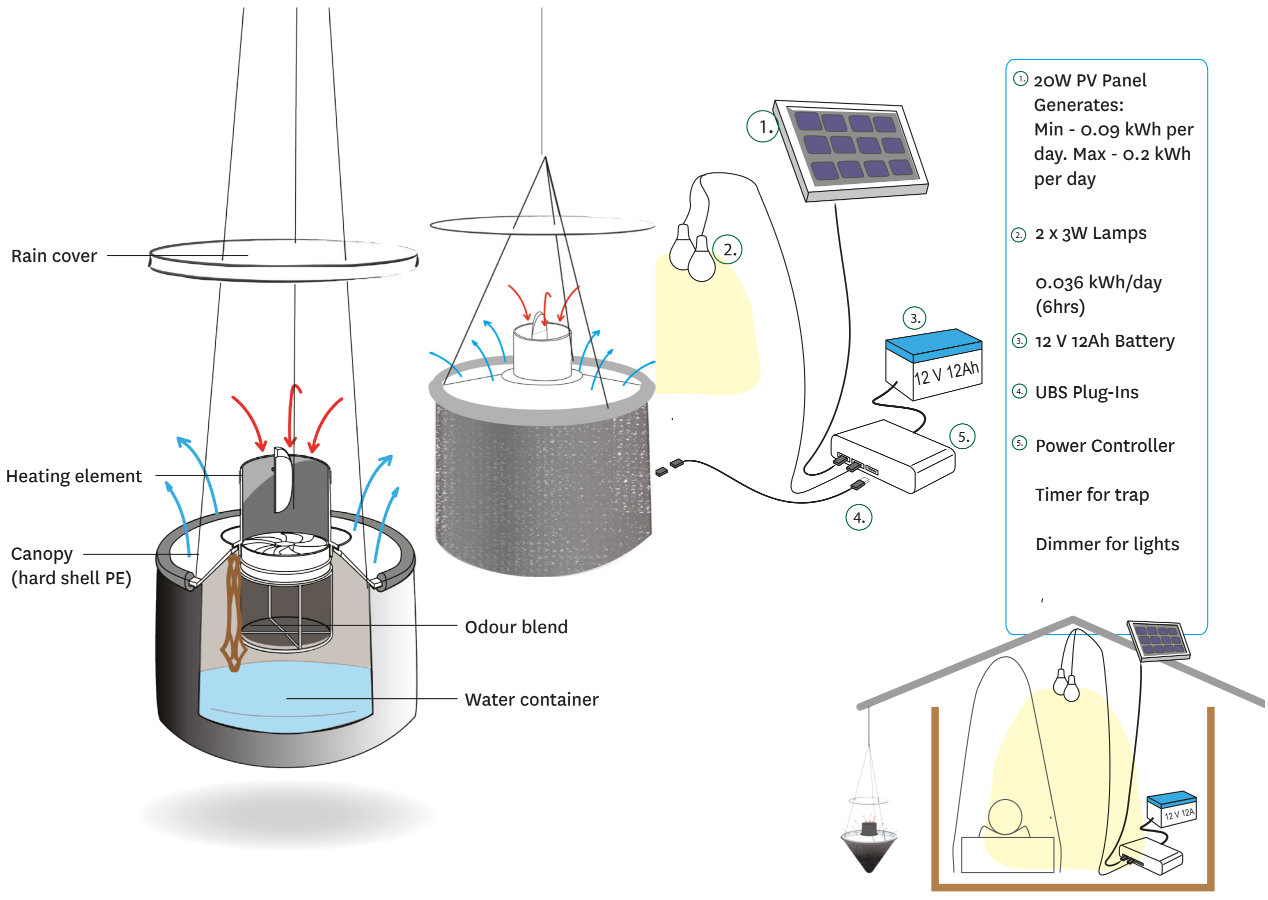


Figure 3. An M-Tego prototype in use in Ifakara, Tanzania during the field work. The M-Tego prototype differs from the concept.

4.9 times more effective than Suna in lab	Improved, but also complex, usage	Low-cost product	Result: Prototype for further testing

Challenges & Approach

This project focusses on the redesign of a mosquito trap, for which a concept was developed by former MSc. graduate student Henry Fairbairn. The result of his graduation project was a concept for a trap that included close-range mosquito cues. In this project, the future of the trap, its embodiment and implementation is taken further.

PROBLEM DEFINITION

In order to become an effective means against malaria, the mosquito trap developed by the WUR and Fairbairn must be further developed to be user friendly, cost effective and sustainable. Next to that, it should be clear who the users are, what the context of deployment should be, and how key sustainability systems are organised.

CHALLENGES

- Iterate on the trap design, and its (mass) production process
- Create an economically viable trap
- Detect, analyse and correct errors in the current design
- Prevent a scenario where the traps fall into disrepair after staff have left by designing a distribution/repair system
- Envision a responsible and realistic EoL (End of Life) scenario

- Gain insights in, and improve, the user experiences by testing in real-life context. Improving the trap's ease of use, including upkeep, installation

- Create a valid roadmap for future mass implementation of mosquito traps in Africa.
- Creating guidelines for implementation of the trap in future scenarios
- Work towards an optimal capture rate by optimising the implementation of novel technology.

APPROACH

A four-phase approach has been created. This is the structure of this report and broadly, how the design process was structured. However, design is rarely a linear process; pieces of advice, insights and ideas come at all phases and don't obey structures.

Within the approach two 'wybertjes' are envisioned: phases of expanding knowledge and therefore, options, followed by a phase of diverging and choosing the best options.

PHASE 1: ANALYSIS
A review of current technologies, trap design, literature and case study lead to insights, and an overview of the ecosystem the trap will be performing in. These insights were translated into a list of requirements for the new trap.

PHASE 2: DESIGN CYCLE
A first iteration on the design of the trap to implement learnings from phase 1, as well as the result of a critical analysis of the current trap. The cycle will result in a series of prototypes to be used in phase 3.

PHASE 3: FIELD WORK
Using the prototypes developed in phase 2, the technical performance, as well as use of the traps will be tested in a real-life scenario. During this phase, the exact structure of the ecosystem will also be considered. Based on new insights, the list of requirements might be revised.

PHASE 4: REDESIGN
Using the insights from the field work, the mosquito trap is then redesigned according to the eco-system of people and products it will be operating in. Along the way, decisions will be made concerning intended use and user group, so there is an integration of design and deployment.

Background

Some of the fundamental topics of the trap functioning, such as mosquito flight behaviour, and the electricity requirement of the trap are explored. Knowledge of these topics is relevant because it might influence the design of the trap or the system in which it performs.

Malaria

"Malaria occupies a unique place in the annals of history. Over millennia, its victims have included Neolithic dwellers, early Chinese and Greeks, princes and paupers. In the 20th century alone, malaria claimed between 150 million and 300 million lives, accounting for 2 to 5 percent of all deaths."[5]

5. Arrow KJ, Panosian C, Gelband H. (2004) Saving Lives, Buying Time: Economics of Malaria Drugs in an Age of Resistance.

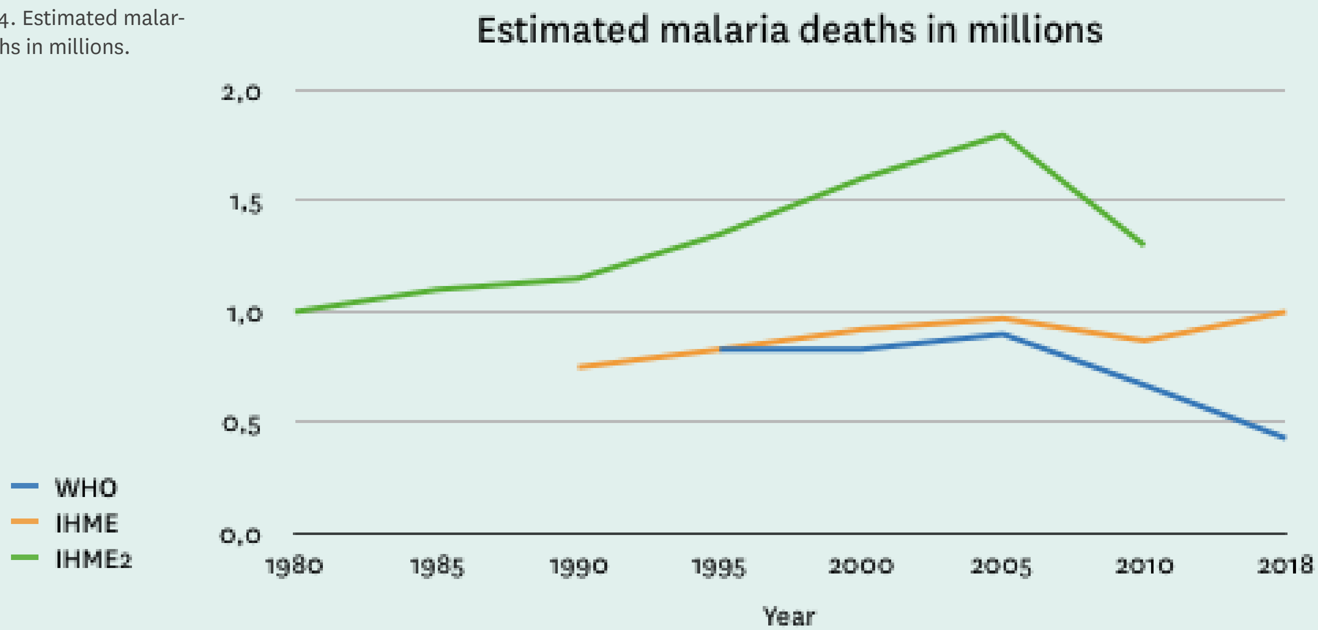
A child dies every minute of malaria[6]

More than 450,000 deaths per year worldwide[7]

Over 10% of household income lost[4]

Off track of 2020 goals

Figure 4. Estimated malaria deaths in millions.



6. WHO (2013) https://afro.who.int/news/child-dies-every-minute-malaria-afri

7. WHO. World Malaria Report, 2017, 2018

8. Murrey et al, IHME (2012) Global malaria mortality between 1980 and 2010: a systematic analysis.

9. Lozano R., et al, (2011). Performance of physician-certified verbal autopsies: multisite validation study using clinical diagnostic gold standards.

The world has been plagued by malaria for centuries and as far as history records. Throughout the 20th century in particular, many efforts have been undertaken to end malaria. Why have some efforts failed, and where have they succeeded? This question is central in this chapter, as well as the question of why mass trapping is seen by some as a promising part of the solution.

Malaria is an infectious disease caused by a parasite. This parasite (*Plasmodium*) enters the bloodstream of a human when a female mosquito is feeding on its blood. The parasite develops while in the insect, and reside in human red blood cells to grow until the blood cell bursts. The invasion of the red blood cells by the parasite causes the symptoms of malaria. A second blood-feeding mosquito can pick up the parasite again, repeating the circle. This process is elaborated further in figure 5. Mosquitoes, and in particular *Anopheles gambiae*, play an important role in the life cycle of the parasite and in spreading malaria amongst humans.

CONSEQUENCES OF MALARIA

Malaria is a potentially deadly disease, although many people can survive a case of malaria, especially when not old or very young. Children in particular are vulnerable to malaria: half of worldwide victims are under five years old. Every minute a child dies because of malaria. Malaria cases had been rising from the 1950s on to 2003, when the total number of malaria victims peaked at 990,000, just shy of a million cases. Of these, 90% were reported in sub-Saharan Africa. Since 2003, the number of malaria victims has dropped to about 450,000 in 2016[7] but is slowly increasing again.

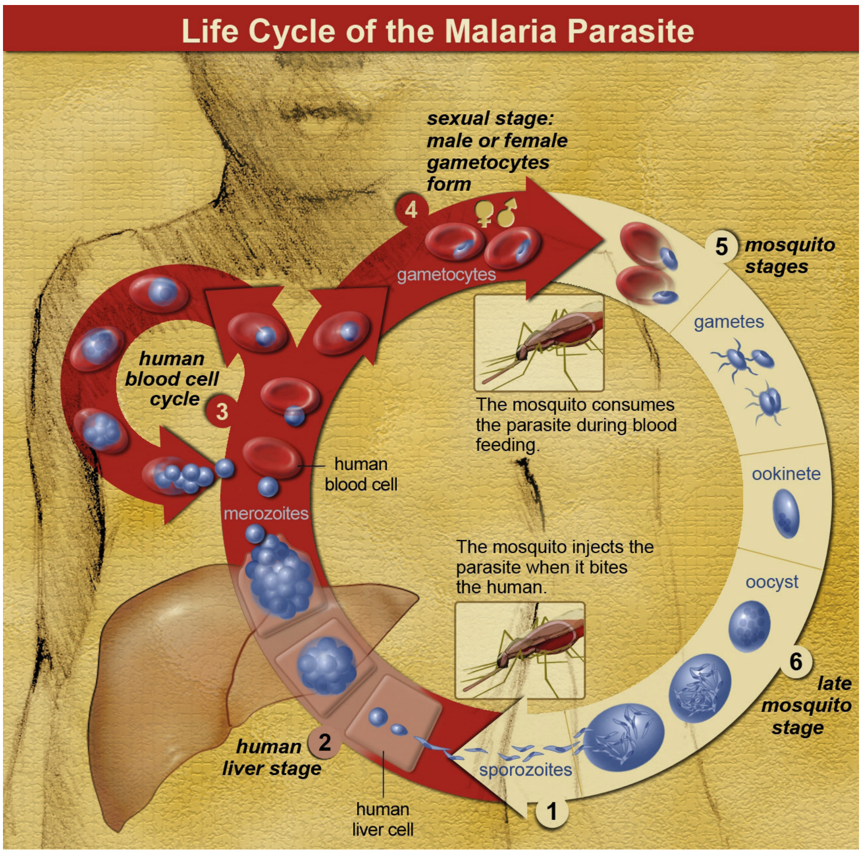


Figure 5. The life cycle of the malaria parasite. Source: NIH (national institute for allergy and infectious diseases)

Next to consequences for people's health, malaria is also an economic killer. Malaria and poverty are often associated with each other and together create a downwards spiral that is hard to break. On average, an African household loses 10% of income due to malaria. It affects productivity, agricultural land usage and learning in school. Malaria and poverty are often associated with each other, since malaria seriously effects the ability to work.[3]

ERADICATING MALARIA

Several attempts have been made to eradicating or at least, control, malaria world-wide, however only in some areas in the world these attempts were successful. Several countries were declared free of malaria after the eradication efforts made in the 1950s and 60s. In northern America and large parts of Europe, malaria was once a common decease, but by means of prevention, vector control and patient monitoring, has been eradicated from these parts of the world. The main reason for successful eradication in these parts of the world has been the high standard of living which enabled enough resources to be spend on malaria prevention and proper care for patients.

Another factor of success was the widespread use of the chemical DDT, which was banned in the United States in 1962 after the publication of the book Silent Spring by biologist Rachel Carson caused concerns for human health and that of many animal species.[11] However, DDT was never fully banned worldwide, and the WHO continued to promote the use of DDT for use of indoor residual spraying (IRS) in tropical countries, if other "locally safe, effective, and affordable alternatives are not available[12]."

The national programme of the USA, the NMEP (National Malaria Eradication Programme, 1947-1951) for example, succeeded in eradicating malaria from the southern states after applying IRS to over 6.5 million households, draining wetlands and applying DDT from planes[13]. However, when the template of the NMEP programme was used for the Global Malaria Eradication programme of 1955, its effects were not as big as hoped for. The CNC gives several causes for this:

- The emergence of drug resistance among mosquito parasites
- Widespread resistance to available insecticides,
- Wars and massive population movements,
- Difficulties in obtaining sustained funding from donor countries,
- Lack of community participation

Especially sub-Saharan Africa did not reap the results of the GME programme, with in most countries not an attempt made.

Malaria can resurge when efforts stop. Yemen, Syria and Russia are among the countries that due to economic circumstances have lowered their investments in malaria prevention and as a result, have seen the return of malaria[14]

10. WHO (2016). World Malaria Report.

11. Carson, R. (1962). Silent spring. Houghton Mifflin Harcourt.

12. Sadasivaiah, S., Tozan Y., Breman J.G.,(2007) Dichlorodiphenyltrichloroethane (DDT) for Indoor Residual Spraying in Africa: How Can It Be Used for Malaria Control?

13. Center for Decease Control and Prevention (CDC) (2010). The History of Malaria, an Ancient Disease.

14. WHO (2009). World Malaria Report.

15. WHO (2016) Global Technical strategy for Malaria.

16. Nothing but Nets (2018) https://nothingbutnets.net

STATE OF ERADICATION EFFORTS

"The targets of the Global Technical Strategy for Malaria 2016–2030 are, by 2030: to reduce malaria incidence and mortality rates globally by at least 90% compared with 2015 levels; to eliminate malaria from at least 35 countries in which malaria was transmitted in 2015; and to prevent re-establishment of malaria in all countries that are malaria free."[15]

Funding for malaria prevention has risen significantly since 2000 (figure 6). However, the WHO estimated that to reach the GTS goals for 2030, an annual USD$ 6.6 billion is required. In the latest edition of the WHO's yearly publication of the World malaria report, it is reported that progress has stalled since 2015 and "the world is off track to achieve two critical targets of the GTS: reducing malaria deaths and disease by at least 40% by 2020." Funding has stalled since 2015, while the total amount of malaria cases have been stable since then as well, with small increases in some countries[7].

This lack of funding results in an interest for cost-effective solutions by some, including the VCAG, the vector control group of the WHO. Others, such as the NGO 'Nothing but nets' rather focus on existing solutions.

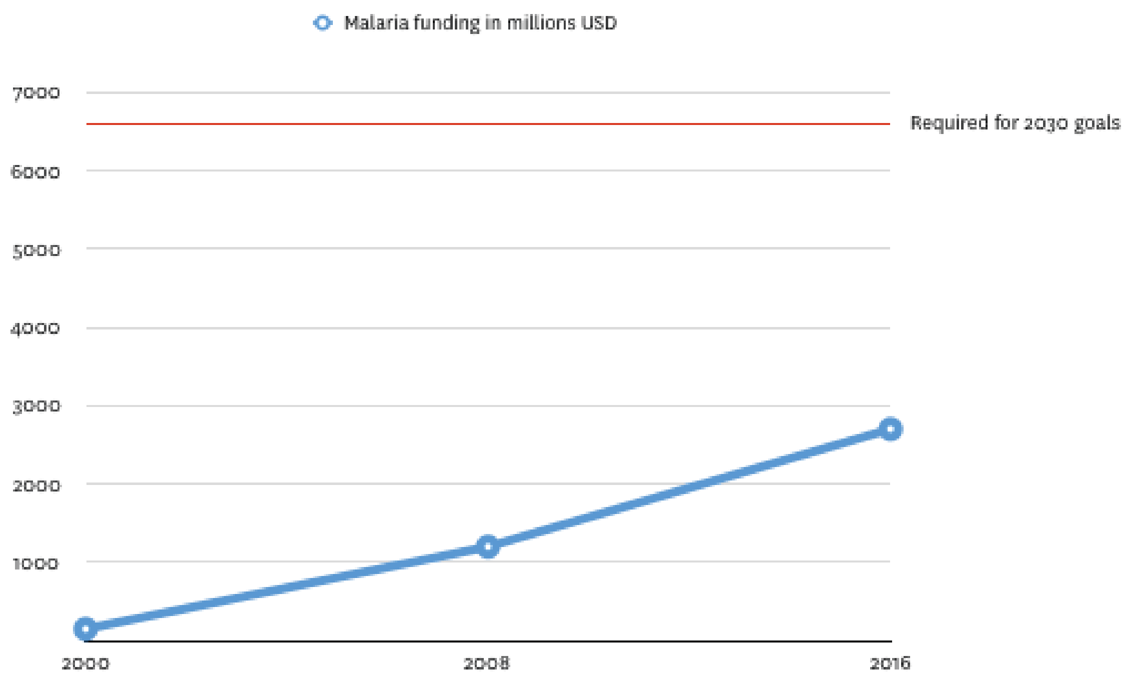


Figure 6. Malaria funding in millions USD. Funding has risen from 149 million in 2000 to 2.7 billion in 2016, but is still far away from the annual 6.6 billion that the WHO deems required.

VECTOR CONTROL METHODS

Vector control is the name for the (temporary) suppression of the number of vectors (carriers) of a disease, so the parasites can't spread as fast. Once all the parasites have died and the disease is therefore eradicated among humans, the vectors are no longer dangerous, as they only transmit the disease once it is established. Vector control is the only way to control infectious diseases there is no other method for, such as a vaccine or effective medicine (current medicine is expensive and not 100% reliable).

There are several means of vector control, listed in figure 8 with their pro's and cons. Prevention of vector-borne diseases using a combination of multiple tools, like mosquito-killing traps, ITN's and insecticides is called Integrated Vector Management (IVM). This method also includes house improvement and other civil operations.

So far, the primary method for vector control has been the distribution of ITNs (insecticide treated nets) or LLITNs (Long-Lasting Insecticide Treated Nets) and use of insecticides both indoor and on breeding waters. This strategy has been under pressure due to rising levels of insecticide resistance among species of mosquitoes able to transfer malaria. Innovative solutions, like gene editing or biolarvicides, might contribute to solving the problem but are years away in development, partly due to ethical debates. In the absence of an obvious solution to insecticide resistance, the WHO continues to recommend universal ITN/LLITN coverage in combination with IRS and larval source control[14].

A combination of trapping or otherwise luring mosquitoes outside a house and preventing biting inside is called a push-pull system. Mass trapping mosquitoes, as part of a push-pull system, is a relatively simple way of capturing and eliminating mosquitoes. However as up to now, mass trapping is by far not as cost-effective as distribution of bed nets.

Mass trapping Mosquitoes

Researchers at the Wageningen University Research demonstrated that mass trapping is a way to reduce the prevalence of malaria across sub-Saharan Africa. Since there is no effective cure for malaria, vector control is the only way to suppress a malaria mosquito population in an area, thus reducing prevalence of malaria.
The proof of effectiveness of mass trapping was given by the first mass trapping pilot research programme on Rusinga island, Kenya.[17, 18]

17. Menger J.D., Otieno, B., de Rijk, M., Mukabana, W.R., van Loon, J.J.A & Takken, W. (2014) A push-pull system to reduce house entry of malaria mosquitoes.

18. Homan, T., Hiscox, A., Mweresa, C.K., Magisa, D., Mukabana, W.R., Oria, P. et al (2016) The effect of mass mosquito trapping on malaria transmission and disease burden (SolarMal): a stepped-wedge cluster-randomised trial.

Figure 7. DDT spraying on Long Island, New York. "Powerful Insecticide Harmless to Humans," the sign reads. Image courtesy of: Bettmann/Corbis

Figure 8. Vector control means, pros and cons

Means	Description	Pro's	Cons
ITN's (insecticide treated nets)	A bed net to protect humans while sleeping. Also kills landing mosquitoes	Very effective during the night / when inhabitants are using it correctly. Also still useful after the insecticides have stopped working or vectors have become resistant. Cost-efficient	Insecticide resistance, has to be replaced every few years, only protects while sleeping. Users have been known to misuse the product.
Insecticides	Spraying the pools where mosquitoes lay eggs, killing the new generation of vectors	Very effective	Insecticide resistance, bad for the environment,
IRS (indoor residual spraying)	Spraying of chemicals indoors.	Effective	Insecticide resistance, has to be repeated every year, costly: $30/ small house. Only works if mosquitoes land on walls
Traps	Luring and trapping the vectors, either killing them or making sure they can't spread parasites	Effective without using insecticides.	Relatively costly, electricity consumption, unknown to the public, fragile and prone to abuse

Figures 9, 10. Protection against malaria by using respectively bed nets, IRS.

Push-pull

If in the near future mosquito trapping becomes an accepted method in vector control, it is unlikely that it will be the only method in use in any malaria project. The combination of diverse means, such as bed nets, traps, and IRS, has proven to be more successful than the sum of its parts, because of the formation of a push-pull system.

A push-pull system is created when mosquitoes are deterred by chemicals inside the house or unable to land on a host due to netting, and consequently try their luck on a secondary source of odour, which we know is a trap.

DISTRIBUTION OF VECTOR CONTROL MEANS

The most common method for distribution of bed nets is through localised health programmes. The distribution happens differently depending on local systems. In Tanzania for example, a voucher system is in place, giving woman who get their child vaccinated against the measles a voucher for a bed net. The voucher was worth around €1.25, and had to be topped up by a buyer's contribution of around €0,80. This system not only stimulates mothers to buy a bed net, but also lets the commercial sector handle all the effort around distribution both present and future[19]. In China's eradication programme, it was common for a household to buy the netting, while the government distributed chemicals for free through government channels[20].

In most cases, bed nets can be both distributed for free and be sold on the local market without cannibalising sales. This is because 'free bed net' programmes often specifically target the vulnerable people in society. Nonetheless there is outrage time to time from commercial distribution channels towards bed net distribution programmes.

Mosquitoes

The mosquito species that spread malaria are several of the hundreds of subtypes of the *Anopheles*, a mosquito genus indigenous to large parts of the world inclusive northern Europe.

While both male and female mosquitoes of the type *Anopheles* can survive on nectar and other forms of sugar, host seeking is an important part of the *Anopheles* lifecycle. In order to develop eggs, the female *Anopheles* needs to find a host, have a blood meal, and then rest for some days while the eggs develop. After laying the eggs, the female is ready to hunt again[21]. The host can be a larger animal, but some mosquitoes, like *gambiae* are anthropophilic, meaning they prefer a human prey. This makes *gambiae* the most effective mosquito species in spreading malaria.

SENSES AND HOST-SEEKING BEHAVIOUR

Long-range cues

Anopheles mosquitoes have two strong developed senses. Their olfactory system, (responsible for sense of smell), can sense odour as well as the presence of CO2. Research has shown that female *Anopheles* have an enhanced sense for CO2 when looking for a host[25] and even more so when being infected by the malaria parasite.[26] To lure mosquitoes in vector control efforts, an effective human-mimicking odour blend has been created, named MB5[27].

Their eyesight is fairly basic but good enough to establish a silhouette of a potential host. Hawkes et al showed that to *Anopheles* mosquitoes, visual clues are important host clues. Bidlingmayer & Ham showed that a dark silhouette the size of an adult human attracted mosquitoes from a distance of 15

19. Khatib, R. A., Killeen, G. F., Abdulla, S. M., Kahigwa, E., McElroy, P. D., Gerrets, R. P., & Kachur, S. P. (2008). Markets, voucher subsidies and free nets combine to achieve high bed net coverage in rural Tanzania.

20. Lengeler, C. Heierli, U. (2008) Should bed nets be sold, or given free?

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22. Hawkes, F. M., Dabiré, R. K., Sawadogo, S. P., Torr, S. J., & Gibson, G. (2017). Exploiting Anopheles responses to thermal, odour and visual stimuli to improve surveillance and control of malaria.

23. Kennedy, J.S. (1940). The visual responses of flying mosquitoes.

24. Bidlingmayer, W.L. (1994) How mosquitoes see traps: role of visual responses.

25. Omondi BA., Majeed S., Ignell R., (2015) Functional development of carbon dioxide detection in the maxillary palp of *Anopheles gambiae*.

26. Smallegange R.C., et al (2013) Malaria Infected Mosquitoes Express Enhanced Attraction to Human Odour.

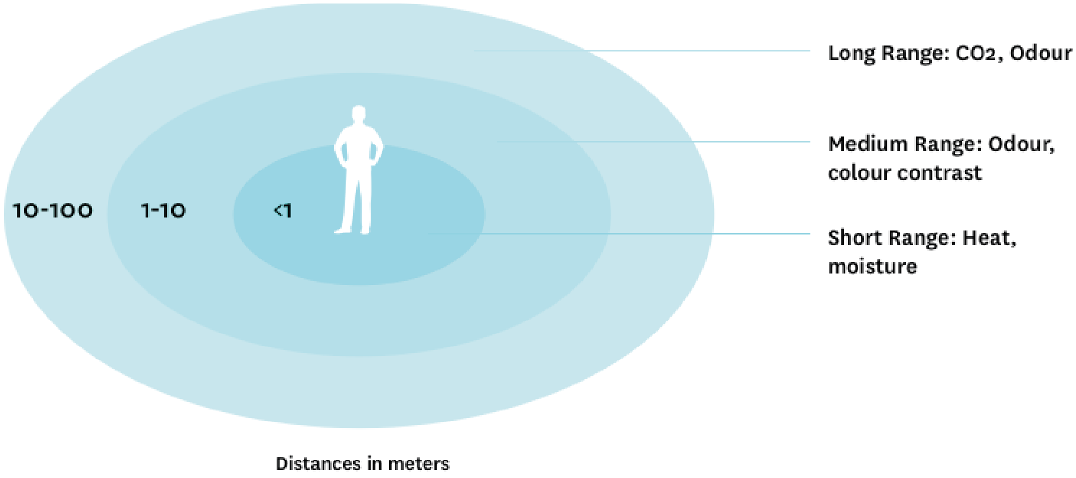


Figure 11. Ranges of mosquito attractants. Data from Cardé & Gibson, (2010) and van Breugel et al (2015). Note that the ranges of longer-range cues are highly depending on wind.

meters in absence of odour attractants[24].

Anopheles mosquitoes have been observed to leave their resting places around sunset[27] which brings them into contact with a greater palette of potential stimuli. When looking for a host, the mosquito will circle upwards in search of a CO2 plume to follow. Once a fluctuation in CO2 concentration has been located, the mosquito quickly follows the plume upwind (surge), while maintaining a sense of location through maintaining visual contact with its surroundings[28]. If it loses the CO_2 plume, it will zigzag (cast) crosswind, trying to relocate it. This is called surge-cast behaviour. Waiting for a host on a place where some odour clues are present is also observed behaviour.

In past and current attempts to create a human-mimicking trap, CO_2 is released near the trap through a tube. However, CO2 is costly and logistically challenging to use for prolonged and geographically spread projects. 2-Butanone, a fluid that might be added to the MB5 mix, was observed by Mburu et al to be a suitable replacement for luring *gambiae* mosquitoes, be it by a small margin[30].

Close-range cues

When approaching the potential host even further, up to around one meter, CO2 becomes a less important guide and odour a more important one. A mosquito will therefore rarely fly into a mouth: the concentrations of CO2 are too high there. In locating a suitable landing zone, moisture and heat play an important part[22, 29].

The studies of flight patterns by Cribellier et al[1] has led to believe mosquitoes are hesitant to come close enough to the trap to be sucked in. The reason why mosquitoes might be hesitant to come close to a mosquito trap is the absence of close-range cues. Once a mosquito notices heat and moisture, it generally lingers around longer, in search of a suitable landing spot. It is thought that the addition of close-range host cues will improve capture rates. This thought and research supporting this claim by Fairbairn was the reason for the inclusion of heat and moist in the M-Tego concept.

Hawkes et al observed that a trap combining heat (in the range of human temperature), visual contrast and odour captured more mosquitoes than 'human landing catches', which is a human capturing approaching mosquitoes.

Other observations from Cribellier et al are that mosquitoes, when threatened by sudden airflow, will fly up along the vertical axis. While this makes a hanging trap more successful in capturing mosquitoes that are very near the inlet, a standing trap is more attractive and consequently captures more mosquitoes overall.

27. Van Loon, J. J. A., Smallegange, R. C., Bukovinszkiné-Kiss, G., Jacobs, F., De Rijk, M., Mukabana, W. R., . . . Takken, W. (2015). Mosquito Attraction: Crucial Role of Carbon Dioxide in Formulation of a Five-Component Blend of Human-Derived Volatiles.

28. Cardé, R.T., and Gibson, G. (2010). Host finding by female mosquitoes: mechanisms of orientation to host odours and other cues.

29. Cardé, R.T. (2015). Multi-cue integration: how female mosquitoes locate a human host.

30. Mburu, M. M., Mweresa, C. K., Omusula, P., Hiscox, A., Takken, W., & Mukabana, W. R. (2017). 2-Butanone as a carbon dioxide mimic in attractant blends for the Afrotropical malaria mosquitoes *Anopheles gambiae* and *Anopheles funestus*.

PLACEMENT OF THE TRAP

At first glance, one might think that placing the trap close to a house would increase the attractiveness of the house, and therefore draw more mosquitoes to the house. However, this is most likely not the case. A house where people, and often, cattle and smaller animals, live in, has such high odour and CO2 concentrations that a mosquito will be drawn to it from hundreds of meters away. The distinctive contrast a house has also plays a role. No currently available mosquito trap, when placed several tens of meters away, will be able to compete against a house (figure 11). Instead, the trap is placed close to the house, so it will serve as a distraction to mosquitoes about to enter the house and a second option for mosquitoes unable to find a host inside.

Because of this, it is deemed likely that the best position for a mosquito trap is right outside the house, under the eave (an opening between the roof and the wall). This way, mosquitoes are tricked before entering the house or when leaving the house after an unsuccessful attempt to find a host. The mosquito trap can play a part in a push-pull system.

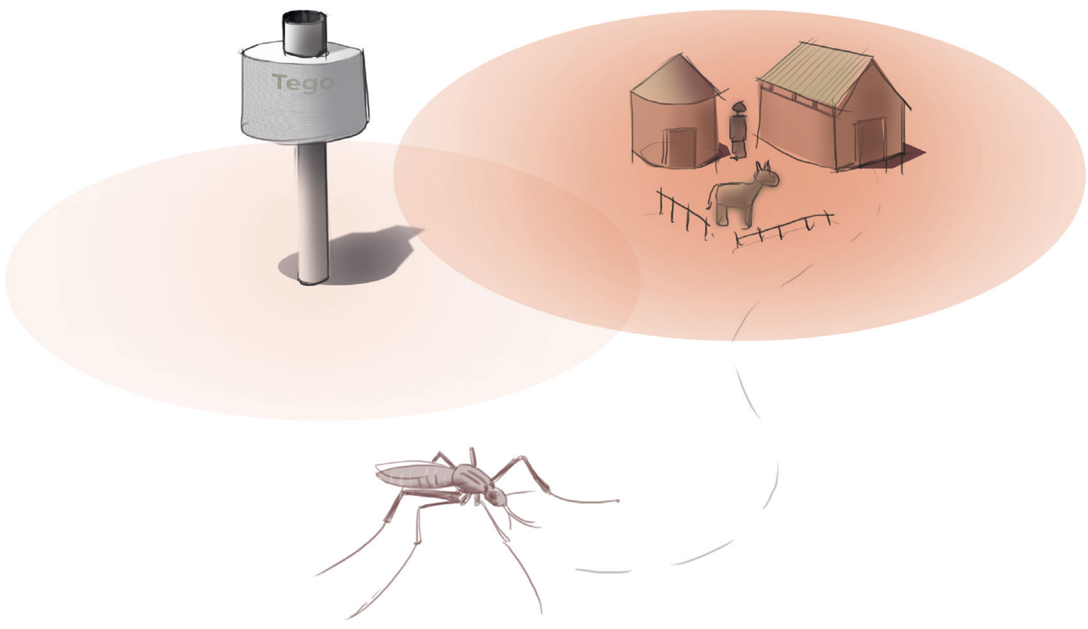


Figure 11. Artist impression of attractiveness of a trap vs a house. A house or village is far more attractive to a mosquito than a trap. It has CO2 output from animals and humans, plenty of odours, contrast, and real humans.

Electricity

The trap, because of the fan and heating elements, needs electricity to perform. This hinders a roll-out over rural Africa, since many households to not have electricity. However, the amount of households with electricity is growing. 15% of Tanzanians, many in rural areas, have access to electricity through off-grid solutions, like solar energy or generators[31]. The grid in African countries is not reliable in all areas and blackouts are common. Given the abundance of sun light and the desire for climate neutral solutions, the M-Tego concept utilises solar power for powering the trap.[2]

MICRO-GRIDS AND HOME SYSTEMS

A report from the industry organisation GOGLA and the World Bank Group published in January of 2018 reported that the total OGS (Off-grid solar) sector is now providing improved electricity access to over 73 million people[32]. Of these, most are so-called Pico systems, which only power a few lights and are characterised by a Watt-peak of under 11,000 W. However, because of the emergence of PAYG (Pay as you go) systems, larger SHS (Solar Home Systems) have become more accessible to the African market. While larger systems account for about 11% of sales, they constitute 70% of PAYG sales[33].

There is a push from governments and international companies towards micro-grids in rural areas. Tanzania has exempted solar solutions from import tax, however batteries are still taxed. In the Democratic Republic of Congo, an estimated 62 million people live off the grid. The government of the DRC has awarded BBOXX, a UK startup founded in 2010, with a contract for delivery of 2.5 million micro-solar systems[34].

Many of the companies involved in delivering solar energy to the masses in Africa employ a vertically integrated business model, where design, manufacturing, deployment and maintenance are tightly integrated. Most combine a pay-as-you-go system with service and a low down payment. The added benefit of distribution through power companies is using their local networks and (often) trusted brand, and repair systems in place.

31. Japhet, B (2017). How many rural Tanzanians have power?

32. World Bank (2018) Access to Electricity.

33. GOGLA (2018) Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data.

34. Kenning, T. (2018). DR Congo contracts BBOXX to provide off-grid solar to 2.5 million people.

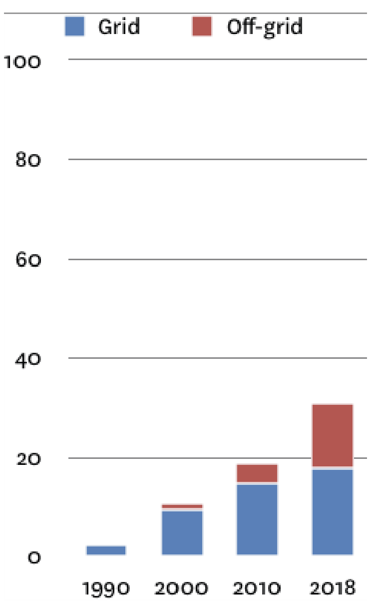


Figure 12. Percentage of Tanzanians connected to either the electricity grid or an off-grid source of electricity.[31, 32]

Figure 13. Brands of MSC. Together, these companies have over 20 millions customers in India and SSA.

Conclusions

MALARIA

Resistance

Some malaria parasites have become resistant to medicines and in some areas malaria mosquitoes are becoming resistant to pesticides. This is reason not only for concern, but a re-evaluation of current tools and possibility for introduction of new tools, such as mosquito traps.

Off track

Overall, malaria control programmes world wide are off track to malaria eradication. The combination of non-effective means and lack of funding is the cause of this. Lack of funding might result in interest in cost-effective solutions, but also means lack of interest in unproven solutions.

Resurging malaria

Malaria will resurge in areas where control is assumed and funding for ITNs or other prevention tools stops. Continued measures are needed.

MOSQUITOES

Anopheles mosquitoes are attracted to CO_2 and other human-mimicking odours on the long range, as well as dark/light contrast. To keep them ‘interested’ on the close range, moisture and heat were introduced in the M-Tego concept.

However much research there has been done into mosquito behaviour, at best we can speak of the ‘influences’ that certain design features, such as colour contrast, seem to have on mosquito attraction. There are still a lot of things that are uncertain, such as attractiveness to materials, and the relative effect of each influence is unclear. Therefore, we cannot speak of design parameters when designing a mosquito trap and it is impossible to foretell if a design will be successful.

TRAPPING

So far, scientists agree that the optimal location for a mosquito trap is near human houses since some mosquito species are strongly developed to prefer to be near human households. Especially *An. gambiae* is known to be anthropophilic.

The most logical way to provide the mosquito trap with electricity is through solar energy, in a lot of cases electricity cannot be provided through the grid, and deployment in sub-Saharan Africa means abundant sunlight.

A Culex mosquito (gener-
al house mosquito)

Applications

To better understand how the future product should function, it is important to look at the current and future applications of mosquito traps and user groups of these applications. Then, the user demands and needs can be taken into account in future design efforts. At the end of this chapter, these user needs are translated into product specifications.

Past and current application of mosquito traps

In order to create a strategy for successful implementation of the trap, the past use cases of mosquito traps were studied. In particular, the reasons for failure (or success) of an application type are looked for. The learnings for success are compiled in a shortlist. Then, a first look ahead is taken to determine what are likely scenarios in which a mosquito trap will be utilised in the future.

RESEARCH PURPOSES

In mosquito research, traps serve as important sources of information. They are being used for monitoring local mosquito populations and malaria prevalence in mosquitoes. The Suna trap, along with other branded traps such as the CDC Light trap and the Sentinel, is being used for this purpose.

When this type of research is performed in the field, the ease of setup, along with size, weight and volume of the trap are considered important. However, the performance of the trap is considered as by far the most important factor. For illustration, custom build 'Human Decoy Traps', which involve a researcher sitting in a tent all night, are preferred over an autonomous trap if that means performance increases.[35]

RUSINGA ISLAND

The use of a mosquito trap for vector control has become a more common thought along the scientific community, causing the first steps towards scientific experiment in the field.

The largest and best-documented research study with a mosquito trap (the Suna, from Biogents) in Africa was performed on the Rusinga island in Kenya. The island saw a decline of 70% in mosquito population and a 30% drop in malaria cases. In part, this effect can be explained because the trap was deployed "in combination with mosquito nets, anti-malaria drugs, and a solid social strategy", but it does show the potential of mosquito trapping. The Rusinga case study can help discover pain points in the user experience (of both the research team and recipient) and deployment model.

Trapping benefit to the inhabitant

Not only the traps serve the benefit of the inhabitant. Along with the trap, a solar panel and battery are installed in participating households. This has great side-effects to the inhabitant, such as increased hours of light used for studying or relaxation. The extra benefit is useful for research projects that need to convince inhabitants to participate.

This did however result in a shift of priorities to the inhabitant. Before, during, and after the project the main perceived benefit of the system was the electrification and the lights[36].

35. Own experiences from conversations with scientists in Ifakara, Tanzania, and observations of the research facilities hence.

36. Oria, P. A., et al (2015). Combining malaria control with house electrification: adherence to recommended behaviours for proper deployment of solar powered mosquito trapping systems, Rusinga Island, western Kenya.

Figure 14. Mosquito trap setup for sampling mosquitoes near Ifakara, Tanzania. Mosquito traps for this purpose will remain a niche market.

Figure 15. Prof. Willem Takken on Rusgina Island, Kenya. This is research project, but with the intention of creating a long-term sustainable trapping effort.

37. Barrett K, Okali C. (1998) Partnerships for tsetse control: community participation and other options.

This was also reflected in the amount of broken traps versus broken lighting systems found by Tubben in 2016. He found of the 81 homes inspected, 62 still had a working lighting system, versus only 17 households with working traps. The modularity of the system allowed for repairs of the light bulbs, but since spare Suna parts were not available repairs on the traps was made impossible.

Property and ownership

The lights and installation on private property gave people a sense of individual ownership, unlike a tsetse control programme executed in Busia some years prior. After this research programme, traps were destroyed by natural circumstances (floods, rats) and left by the local inhabitants because they believed the traps remained researchers' property[37]. Clear communication about property is important.

Post-project maintenance

Discussions were held with the CAB (community advisory board) and inhabitants about the proposed continuation of the project. Though consensus wasn't reached on some topics, the main advise was clear: keep SMoTs private property and make sure a local repair system is in place.

Financing the maintenance of SmoTs in local groups was conceived as a possible route to afford spare parts for the less privileged members of the community. This idea was perceived as bad by some members of the community who had bad experiences with group financing. Reasons were bad trust in community members, fear of embezzlement, and gossip. The same level of distrust was also expressed towards a governing body; they could favour parts of the island of spend the money ill, based on previous experiences with island leadership. It was decided on setting up local groups that know and trust

Figure 16. Since there was no electricity grid on the Kenyan island Rusinga, solar panels were given to participating households. All households on the island participated.

38. Oria, P.A., Wijnands, M., Alaii, J., Leeuwis, C. (2018) Options for sustaining solar-powered mosquito trapping systems on Rusinga Island, Western Kenya: a social dilemma analysis.

39. Tubben, N. (2017) Sustainability of solar powered mosquito trapping systems for malaria control in Kenya.

each other[38]. However, this system was not fully developed before the research team left, and it is unclear to what degree it has gotten off the ground. The lack of available spare parts made any repair system challenging.

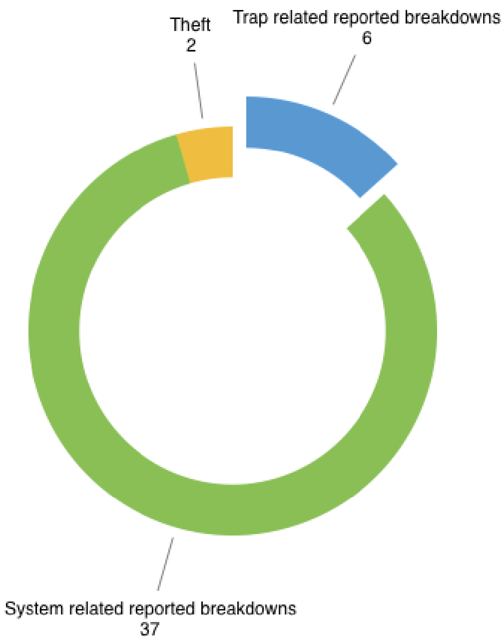
Post-project breakdowns

A study by Tubben in 2016 researched the status of the SMoT systems 9 to 11 months after the research team had left[39]. A few of the trained technicians were still taking calls from people with broken traps and recorded the amount of incidents. In case of an incident, they would discuss a reasonable price for the repair. As visualised in figure 17, only 6 of the incidents can be contributed to the trap, the majority had to do with bulbs, wires and batteries being broken.

Spare parts of the Suna trap were not available anymore after the researchers departed, and the cost of other spare parts through the only electrical shop on the island inflated heavily due to transport costs, taxes and overhead. This underlines the importance of having a repair system that includes a way to distribute spare parts, has people on the ground, and doesn't heavily costs the user.

One note about this diagram is that system-related issues are more likely to be reported because the system causes the lights to function, which is the most desired function of the system. Trap-related breakdowns might not be reported as often because people don't really care about the trap.

Figure 17. Trap, system repairs and theft cases.



MODEL OF TYPICAL CURRENT IMPLEMENTATION IN RESEARCH PROJECTS

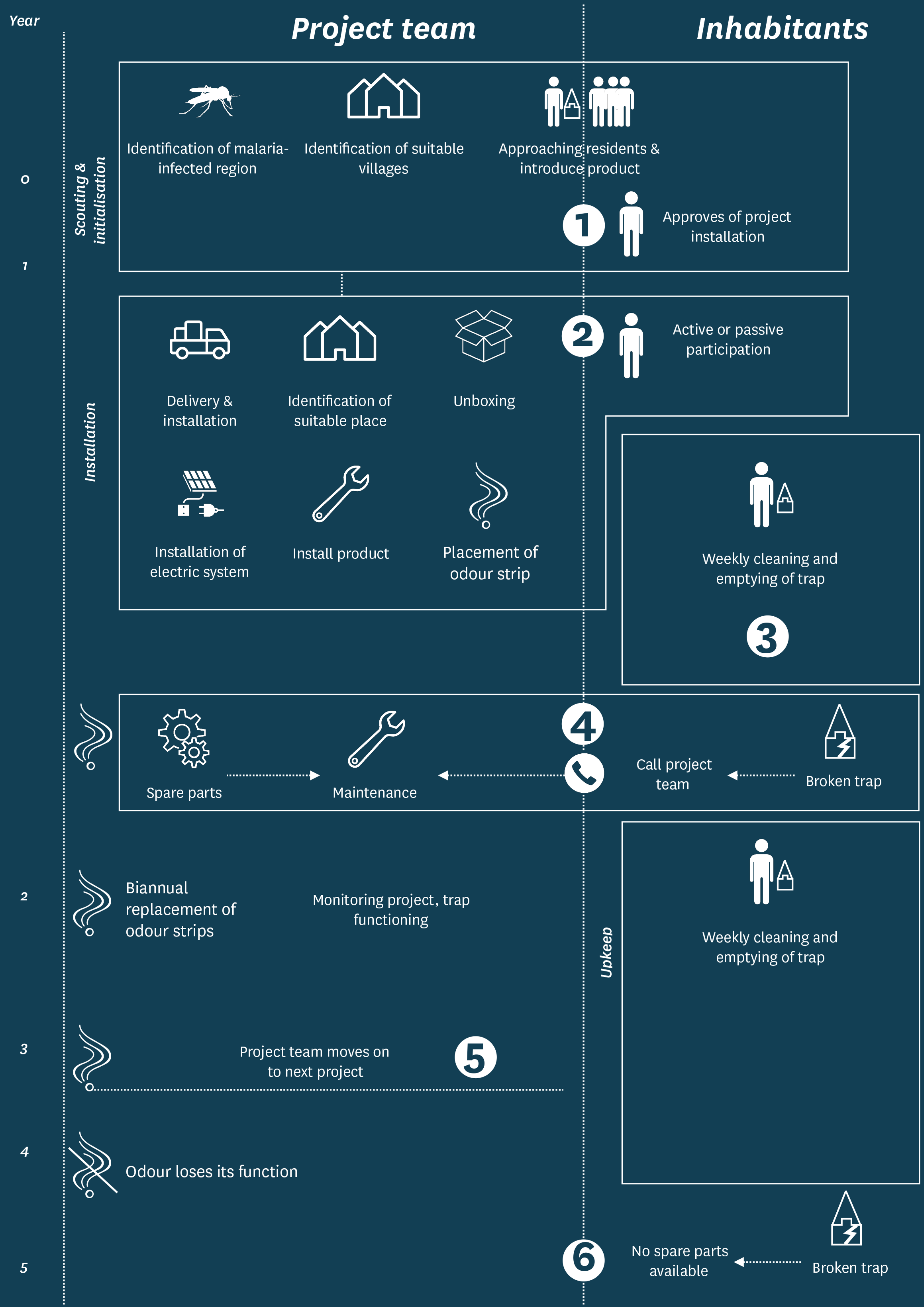
Figure 18. Model of current implementation of mosquito traps in research studies.

The inhabitant and scientist steps and actions of the case study in Rusinga were mapped out in figure 18 (right).

On the right, the actions of the project team are seen, while on the left, the actions of the inhabitants. The years are counted on the utmost left. Before the project start years can go by spend on finding funding, partners and defining project goals.

After a stage of initialisation and gaining approval of the inhabitants (1) and installation (2), the team might stick around for a while, usually for monitoring the intervention effects and scientific research. Meanwhile, the user takes care of the daily upkeep (3) and monitoring of their household's mosquito trap. In case something breaks the inhabitant is expected to report it (4). However eventually but inevitably the project team moves on to another project, leaving behind the traps but generally little backup equipment. When another trap breaks from that moment on, the inhabitant will have to repair the trap themselves with the resources they have available or can collect. Without replacement, the odour will also lose its strength and eventually, function.

The main lesson to be learned is that with systems with the complexity of these (solar system, mechanical parts in the trap) will naturally decay once the support structure has left. An alternative support structure has to be in place and proven to function once the original support structure has been taken away.


Year
Project team
Inhabitants
0
1
Scouting & initialisation
Identification of malaria-infected region
Identification of suitable villages
Approaching residents & introduce product
1
Approves of project installation
Installation
Delivery & installation
Identification of suitable place
Unboxing
2
Active or passive participation
Installation of electric system
Install product
Placement of odour strip
Weekly cleaning and emptying of trap
3
Spare parts
Maintenance
4
Call project team
Broken trap
2
Biannual replacement of odour strips
Monitoring project, trap functioning
Upkeep
Weekly cleaning and emptying of trap
3
Project team moves on to next project
5
4
Odour loses its function
5
6
No spare parts available
Broken trap

LOCAL BELIEFS ABOUT TRAPS

The HBM (Health Belief Model) is a theoretical framework that can be used to assess the likeliness that a public health improvement tool will be successful. Oria et al (2015) uses the HBM to assess the SMoT after the Rusinga project. The data from a project in Burkina Faso, where ITNs were handed out, is compared as well. The project in Burkina Faso was considered partly successful[40].

As seen in figure 19 and 20, the HBM results are drastically different for different regions in Africa. Education plays a major role in reducing misinformation (like the source of malaria) or superstitious beliefs such as potential cures for malaria. This means that assumed base knowledge levels have to be put quite low when considering future implementation and simply 'dropping off' traps in a community won't work.

The perceived effects in Rusinga, such as overestimating the performance of the trapping method, brings along danger of neglecting other sources of protection. In interviews by Oria[36], half of the interviewees in beach districts stopped using ITNs, partly because they did not see as much mosquitoes as they used to. In one-third of interviewed households, there was no ITN present in the bedding area. Half of the interviewees said that the main reason to continue using ITNs was because researchers told them to do so.

It is deemed likely that without such stimuli, people would (falsely) rely on the traps to protect them. This is not a great strategy since a mosquito trap doesn't guarantee protection. Therefore a design should not communicate that it will take away all mosquitoes.

In appendix A 'Background information', section 'Risk Compensation' this effect is explored further.

Figure 19. HBM for SMoT deployment in Rusinga, Kenya.

	Stage of HBM	Belief (ideal)	Rusinga ITN, traps
1	Perceived Vunerability	"I am at risk of contracting malaria"	I can get malaria all-year round.
2	Perceived Severity	"If I contract malaria my health is at serious risk"	People regard malaria as a major health treat, especially to children
3	Perceived benefit outweighs perceived costs	"The SMoT will help me more than it will cost me in time and effort"	Most people do what is neces-sary for upkeep and safe keep-ing, but there is also neglect.
4	Perceived Effects	"I see that the SMoT works, e.g. reduced mosquitoes"	SMoT kills most mosquito's so I don't have to use the ITN

Figure 20. HBM for South-west Burkina Faso. Adapted from Toé et al (2009)

40. Toe L.P., Skovmand O., Dabire K.R. et al. (2009) Decreased motivation in the use of insecticide-treated nets in a malaria endemic area in Burkina Faso.

	Stage of HBM	Belief (ideal)	South-west Burkina Faso
1	Perceived Vunerability	"I am at risk of contracting malaria"	Beliefs like "everyone already has malaria"
2	Perceived Severity	"If I contract malaria my health is at serious risk"	Seriousness of malaria was not fully understood.
3	Perceived benefit outweighs perceived costs	"The usage of ITNs will help me more than it will cost me in time and effort"	Low motivation to use ITN's, only when in distress about number of mosquitoes. Lots of neglect.
4	Perceived Effects	"I see that the ITNs works, e.g. reduced amount of mosquitoes, less chance of getting bitten"	ITNs cannot prevent malaria

IMPLEMENTATION BEST PRACTICES

From the research done in Rusinga, literature[41, 42] and expert opinions, a set of 'best practises' were compiled. These are guidelines taken from a range of Base of Pyramid projects that were deemed appropriate for the future implementation of the M-Tego.

Implementation

- Have a system for repair in place and running prior to leaving the site
- Work with local people
- Leverage existing infrastructure rather than building new struct
- Add-on to existing products and services

Design

- Co-create the solution with local people
- Envision user scenarios
- Envision product abuse
- Design for customisation

41. Viswanathan, Madhubalan & Sridharan, Srinivas. (2011). Product Development for the BoP: Insights on Concept and Prototype Development from University Based Student Projects in India.

42. Mink, A. (2016) Capability driven design.

43. WHO (2016) Mosquito (vector) control emergency response and preparedness for Zika virus.

Future applications

Now that the application of the mosquito trap so far has been examined, the future applications can be predicted.

MALARIA AND IVM PROJECTS

In most implementation scenarios as a public health tool, M-Tego will be used in combination with other products and education, and distributed in part through programmes that benefit the health of those not able to afford the protection means themselves. Programmes that integrate the use of various tools can be characterised as Integrated Vector Management (IVM) programmes. Mass trapping might also occur in other types of projects that cannot be categorised as IVM but do intent to fight malaria.

Often, these projects are initiated by a government body and carried out with the help of partners. When organising a project to combat malaria, handbooks published the WHO are a first place to look. Also, in order to obtain the trust of donors and be classified as a proven means in vector management, a WHO recommendation is extremely helpful, if not required by some partners.

Currently, 'mosquito traps' are not a intervention class that the WHO discerns, in contrary to for example ITNs or IRS. However, one of the first steps towards making a mosquito trap a common means to eradicate malaria was made on March 18, 2016, when the WHO published VCAG recommendations titled "Mosquito (vector) control emergency response and preparedness for Zika virus". In it, traps are considered a potential way to control mosquito populations, if further research is done.

"Studies should be carried out to demonstrate the overall feasibility of use

of traps for large-scale control of Aedes mosquitoes and to assess impact on disease. Studies should include evaluation of the sustainability, feasibility, cost effectiveness and community acceptability of vector traps in diverse use settings, as well as long-term management of traps."

-VCAG, March 18, 2016[41]

INITIAL RESEARCH PROJECTS

This call for further research will not remain unanswered, as evidence so far suggests that mosquito traps are excellent tools for reducing mosquito populations. The second use case is therefore, research projects. These field evaluations of effectiveness and usage generally take several years and require tens of thousands of traps. While a mosquito trap from a trusted brand is preferred, the effectiveness of the M-Tego in lab results sparks interest to use it in these projects. The end point of the initial research projects would be the acceptance of the mosquito trapping method and traps by the WHO.

GENERAL RESEARCH PURPOSES

Before and after the initial projects to prove effectiveness of mass trapping, there will still be some demand for traps, as researchers will continue to research mosquito populations. For this purpose, traps like the M-Tego might be suitable. This is however a niche market, that has already been found by other parties, such as Biogents. As most scientists select traps by (proven) effectiveness through publication, this market might be attractive to enter sometime after the initial research projects.

LOCAL MARKET

Like bed nets, traps could also be sold on the local market. Untreated bed nets are widely available in stores, and likely some people buy them. They are sold in Ifakara for 10,000 Tsh (€3,77). At the moment, the value of vector trapping is not well known among the people of Ifakara, Tanzania, and likely also not by others. To some, it even a frightening thought; more than once, the question has been posed; "if it catches mosquitoes, can it catch lions? Will it catch.. me?". But above all, the trapping effect only becomes noticeable when there are multiple traps installed in a certain area.

More on the potential of the local African market in chapter 'Business model'.

End Users

There are three user groups of this product. Two of those will have to deal with the product on a daily basis. First, there are the researchers and NGO workers who will implement the trap in existing and new malaria eradication projects. The researchers have to distribute, install, and maintain the traps for the duration of the research project. The NGO and government workers have some of these tasks at a later stage, but will be less involved in the use phase. At the same time, the end users are the people living in the houses where the traps are installed. They have to deal with the trap for the duration of the project and beyond. All three groups have different needs and wishes.

To identify user needs from all groups, interviews were conducted with Monicah Mirai, PhD candidate at the WUR and originating from Kenya, Africa, and Sander Koenraadt, associate professor at the WUR and involved in the organisation of a new mass trapping effort involving a push-pull system. They were interviewed as they both have experience with mass trapping projects and therefore, might have insights into the demands that a future trap needs to meet.

While in Ifakara, Tanzania, the trap was shown

Figure 20. An African farmer.

to an array of scientists during a presentation of the project, and follow-up conservations took place with three of them during the remainder of the field work. Lastly, several people at the WUR also provided insights into user needs, specifically for scientific use.

During the field work in Ifakara, local people were invited to participate in a user test. The results of these user tests can be found in the chapter 'Field work'.

RESIDENTS

The main resident where the trap will be installed might not care much about catching mosquitoes. This was shown during the Rusinga project were in some cases, with some traps that were barely maintained. However, his motivation to provide maintenance to the trap might be improved by visible results, or clear education about purpose, and additional benefits.

Might be a jack of all trades: part time farmer, businessman, fisherman and carpenter.
Is constantly looking for ways to generate income. Is the provider for a (large, extended) family and cattle.

Is interested in additional benefits besides the trap; lights or electricity provided by the system. Is aware of mosquitoes spreading malaria and of the dangers of malaria, but is also prone to risk compensation and superstitious beliefs. To become truly invested in the project, he first needs education if that is lacking. Secondly, confirmation of ownership status, and third, to be shown the benefits of the system.

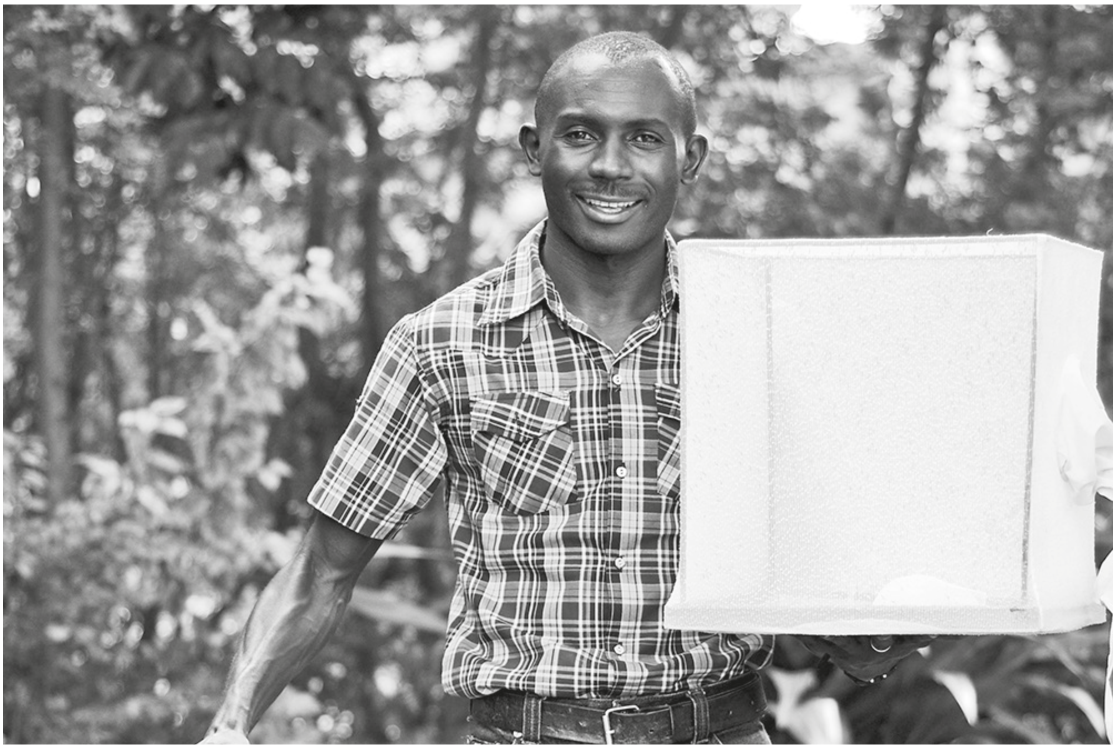


Figure 21. Fredros Okumu, chief scientist at Ifakara Health Institute

RESEARCHERS

Researchers need a portable trap that is fast in installation and easy in maintenance. If something is broken spare parts need to be available fast so it doesn't disturb the project. Traps need to be cheap and production lead times short. Above all, they need the traps to perform. Logistical challenges, such as transportation of CO_2 tanks or changing batteries, can be overcome.

NGO AND GOVERNMENT WORKERS

For this group, the proven effectiveness of the system in relation to the costs of it is most important.

The people that eventually have to install the traps in projects are less capable of overcoming the obstruction of CO_2 or transport, and therefore, like the researchers, need a small, portable trap as well. The logistical challenges of CO_2 are too difficult and labour-intensive to overcome for this user group.

Once the system has been installed, the repair needs to be simple and cheap as well.

Applications Conclusions

Current and past use cases
So far, there has been one large-scale project in Africa that involves the use of mosquito traps. Next to that, mosquito traps are in use by scientists around the world for monitoring mosquito populations. This project was partly successful and future lessons were mainly about the prolonged sustainability of the systems.

Future use cases
There are three future use cases that were discussed in this chapter. First is the scientific research that has to be done for product acceptance. Secondly, the other scientific uses, such as monitoring. Third are the malaria projects in which subsidised traps are installed in African communities. All of these applications serve different goals (figure 23).

User needs
The varying user groups demand different things from a trap design (figure 22), but it might be possible that the final product is the same. Many of the conditions and needs are the same regardless of application, like the desired sturdiness, portability and cost-efficiency of the trap.

Figure 22. The needs of different user groups

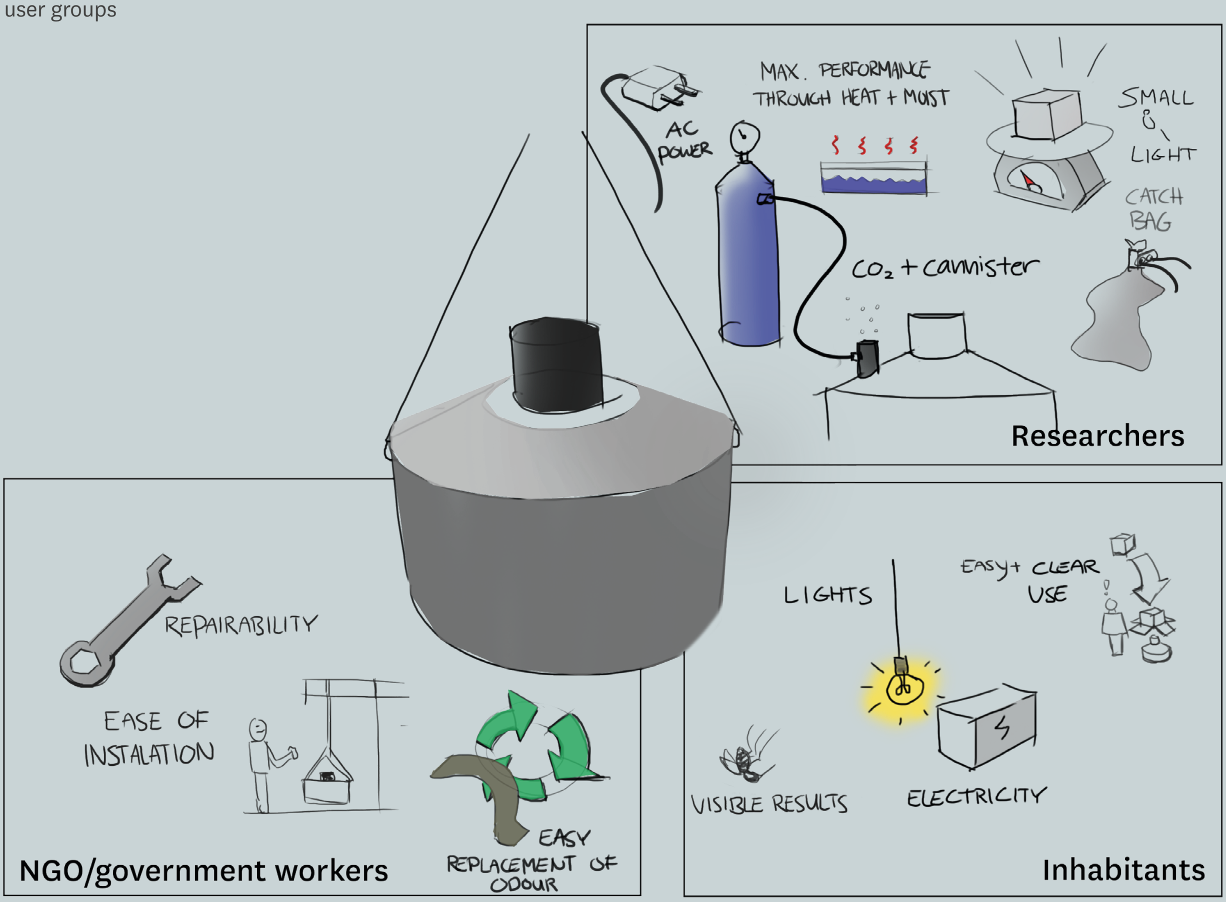


Figure 23. Phases of usage and associated properties such as buyers, users and required properties.

	Research projects	Other scientific use	Malaria projects
Goals	Prove the technical effectiveness of mass mosquito trapping	Monitoring	Get the trap to as many people as possible for as long as possible
Requirements for realisation	Successful experiments	Market introduction Proven results	Successful phase 1, WHO recommendation
Batch size	Tens of thousands	Thousands	Tens of thousands up to millions
Buyers	Researchers, donor funded	Institutes, Universities	Governments, NGO's
Users	Researchers, home-owners	Researchers	Workers in governments, NGO's, home-owners
Required properties	Capture rate Cost-efficiency Robustness Beneficial to owner	Capture rate Robustness	Cost-efficiency Sustainable Ease-of-use Beneficial to user

Implementation enablers
It was also discovered that in order to make an implementation effort successful, a long-term sustainability plan is needed. In the case of Rusinga Island, discussions were held with island inhabitants, but no plan was implemented fully.

- While locals want to help the less privileged with upkeep, they do not trust a local organisation to do it for them. They will however, accept a foreign organisation.
- For locals, provided electricity in a project is a great motivation for participating

Implementation barriers
Besides the possibilities of future implementation, there are barriers to successful implementation. Some of these are:

- The people of Rusinga island have a distrust in government, and many more local communities might share that sentiment.
- The belief that malaria is serious is not understood in all of Africa. This might lead to misuse of the SMoT systems. Product design can play a part is these matters, such as a friendly design that connects mentally to something the user is already familiar with, but education about the dangers and causes of malaria is critical.
- Good capture rates might lead to risk compensation, which might lead to diminished end results.
- Poverty might lead to theft of systems

Concept evaluation & ideation

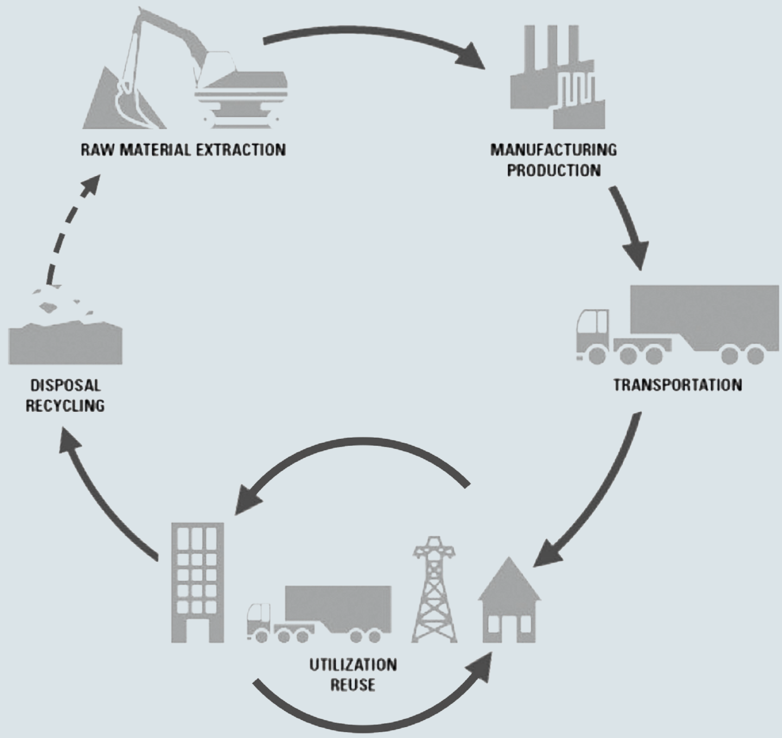
Before embarking on field work to evaluate the design's weak points in a real life scenario, the concept design was evaluated. From this evaluation, several ideas came up to improve the product on levels of production, use, maintenance and more.

The ideas gathered at the end of this chapter resulted in new (sub)concepts, which were taken to Africa in the form of 3D printed miniatures for user testing.

Life cycle analysis

A method to evaluate the design of the trap was used by looking at the stages of life the product goes through (figure 24).

Figure 24. Lifecycle of a product. The transition from disposal to raw material extraction is not yet fully reality.



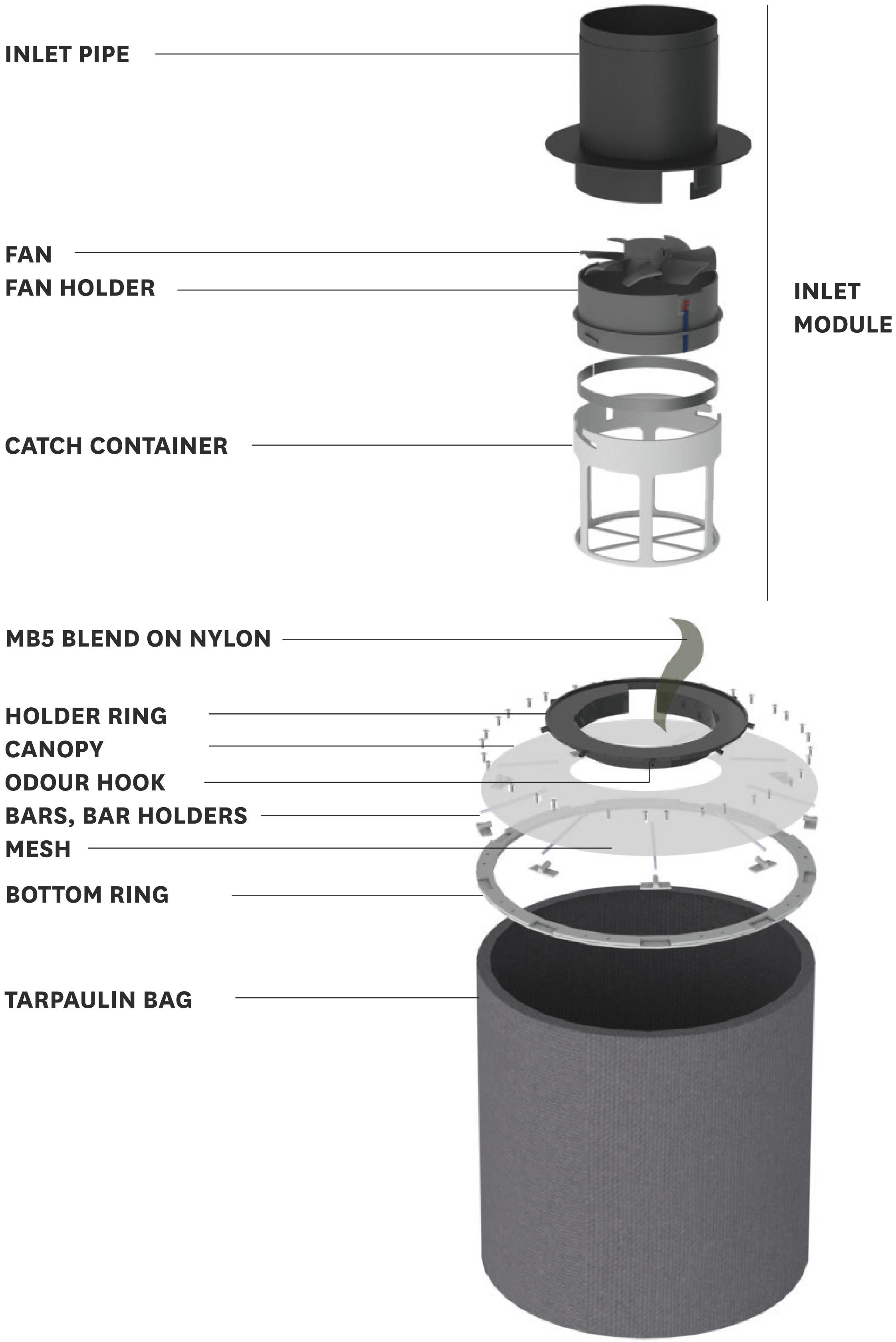


Figure 25. An exploded view render of the M-Tego prototype. Notice the number of parts in the canopy: 11 3D printed parts, 9 metal rods, and 36 bolts and nuts.

MANUFACTURING

The production of the M-Tego I prototype was aimed at small-batch production. This is reflected in the choice for 3D prototyping and complex assembly, which is doable only for very small batch sizes before becoming very costly. Figure 25 shows an exploded view of an M-Tego prototype.

Other choices, such as the injection-moulded PE canopy as described in the concept report by Fairbairn, do hint towards mass production, but the majority of choices in embodiment design for manufacturing has not yet been made.

Therefore, there is much freedom to work within and most choices made so far can be re-evaluated if deemed necessary. However, the main principles of mosquito attraction and capturing through airflow will not be re-evaluated.

DISTRIBUTION

The ease of distribution of the product is affected by several product properties: mostly size, shape and weight. The weight of the product can be minimised by choice of materials and minimising the total volume of parts. The shape of the product should be convenient; so either very small, stackable, or collapsible in the event of transportation. The size should be so, that someone can comfortably carry several traps.

The M-Tego concept features a collapsible base, intended for water storage. It also is a large visual clue for mosquitoes, providing contrast with most backgrounds. The material choice for this part was Tarpaulin, which is a woven Polyethylene mesh that can be made waterproof. Tarpaulin is extremely lightweight (75-100 grams per square meter are available, or about as light as standard paper) and foldable.

INSTALLATION

The chosen method for placing the trap optimally has been suspending it on the side of a house. For optimal results, the trap should be at 50 cm from the house and at 55 cm from the ground. Hanging is a good way of keeping the trap safe from flooding and smaller animals.

While most African houses have features like extruded wooden beams that make hanging the product possible, not every house does. For these houses, the trap can either be hanged closer to the house (as in figure 26), or a custom solution has to be found.

No true solution has been found to wandering creatures around the trap, such as animals and children, who might damage the trap. Improvised fencing has been used so far, but the concept does not specify a different solution.

Figure 26. A Suna trap hanging next to a house.

FUNCTIONING

The main concept behind the M-Tego and its predecessor, the Suna, is the luring and sucking in of mosquitoes. On the long distance, mosquitoes are lured by the scent of an odour-drenched piece of fabric*. Therefore, it is important that the odour is spread in the wind properly. Secondly, it is important that the air speed is fast enough to suck in the mosquitoes that approach the inlet pipe. As explained on page 11, the same fan is the cause of both important functions.

*The MB5 blend used so far was put on nylon sourced from ladies' thighs, 15 denier. The MB5 is a fluid at room temperature.

There have been some concerns that the reduced size of the M-Tego compared to the Suna could lead to an airflow where air is sucked up directly after being exhausted from the canopy, leading to a circle of airflow that is not beneficial for spreading scent. However, measurements of airflow show that this is not the case.

While some air is being sucked in again, most plumes are exhausted (figure 27). In most cases, wind is responsible for further spreading of the scented air. The speed with which air escapes the trap depends on mesh size and density, and fan performance.

Moving the air outlet to for example, the side of the trap is not an option, as mosquitoes will land or fly around the side, and not come near the inlet point. Changing the complete functioning of the trap was considered at multiple point during this process, but found not to be within a possible project scope.

Performance

In dual-choice lab tests, the M-Tego prototype captured an average of 4.9X the mosquitoes captured by a Suna trap. In earlier tests[2], it was shown that the addition of heat and moist led to increased capture rates. This is novel technology for a mosquito trap and has not been deployed on a large scale. (UV) light, CO_2, and odour blends are more commonly found.

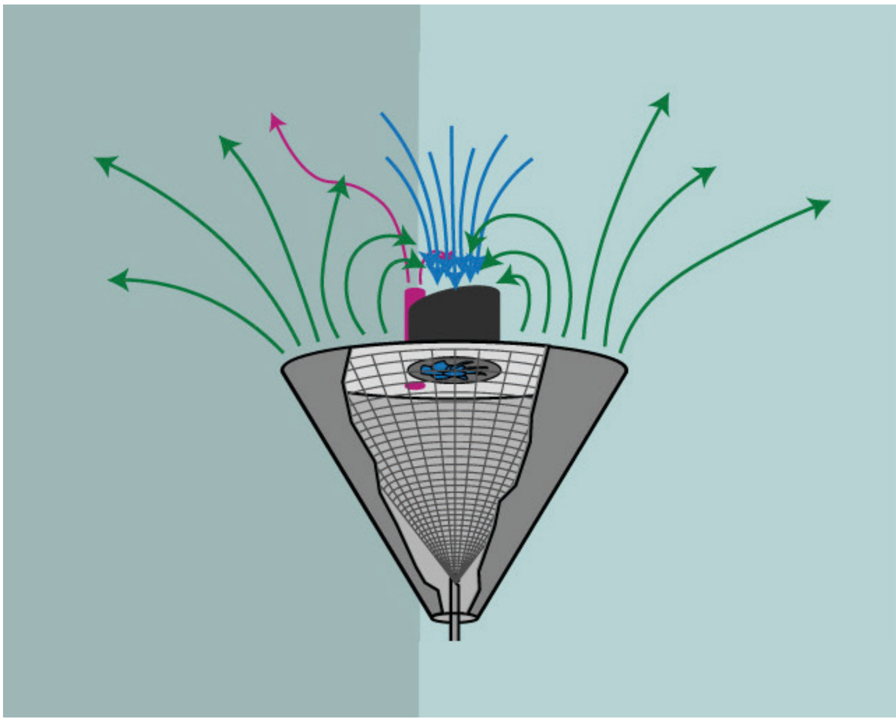


Figure 27. An impression of how the airflow around a standing trap works. Image adapted from Cribellier et al (2018).

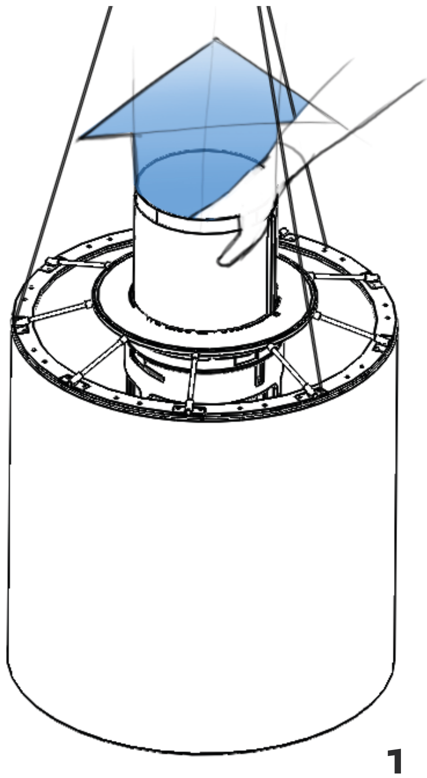
Blue arrows signify air being sucked in by the fan, green arrows air being exhausted from the trap.

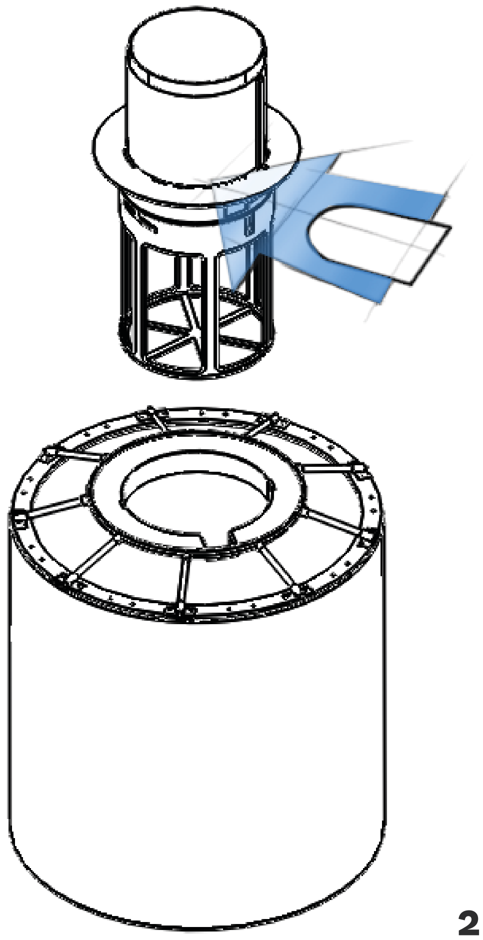
USE

Required User Actions

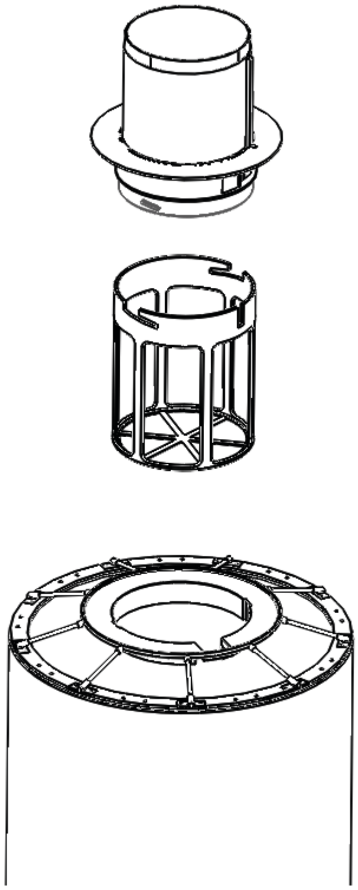
In order to maintain the traps in working condition, several actions need to be performed weekly. They are mapped out here.

1. Take out the inlet module. The inlet module can only be taken out or put back in in one way. In case the odour needs replacement it is accessible from here.
2. Slide a piece of plastic between the catch container and the fan module, in the dedicated slot. This will prevent mosquitoes from escaping the catch container.





3. Now the catch container can be put away for letting the mosquitoes die, and emptying if this is the case.
4. In case of fan breakage, it can be easily removed by twisting clockwise.
5. Every two days, the water container has to be replenished with 2 Litres of water.



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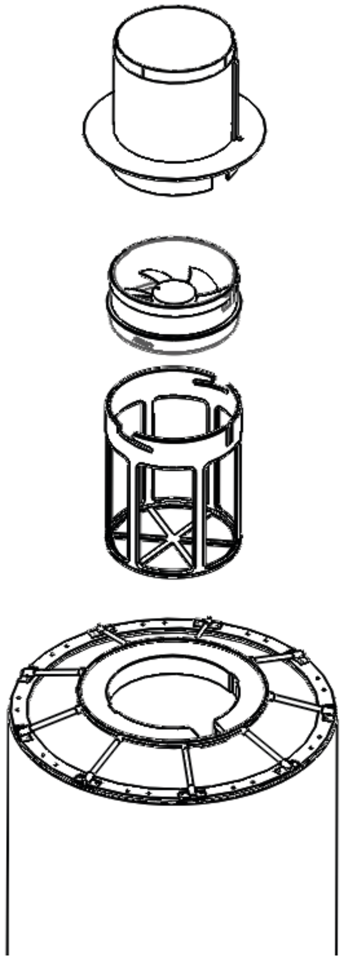

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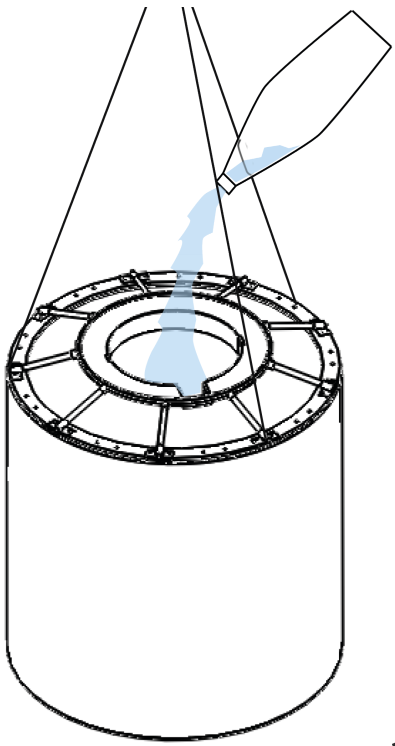


5

Long-term maintenance

Every half a year, the odour has lost its scent and needs to be replaced. The odour strip hangs on a hook on the inside of the bottom ring. Therefore, it is accessible, but not entirely secured. It is accessible after the inlet module has been removed.

END-OF-LIFE

Every product has an end of life. It is important to design this moment as well as any other, since a wrong end-of-life phase can mean disaster for the environment.
The end of life has been given little thought during the conceptualisation phase of M-Tego I and is therefore open to interpretation and iteration.

Conclusions about M-Tego I

We have seen that the M-Tego I prototype has performed quite well technically, and from the evaluation in this chapter a couple of points in which the trap is doing well too can be added.

- The trap is lightweight, fold-able and small volume-wise, which benefits distribution.
- The trap has some smart material choices (mesh, tarpaulin)
- The use of heat and water are innovative and effective.

However, also several points can be named where concerns about the usability, production or distribution are present.

- The used construction is complex, leading to long production cycles and high costs.
- The electronics are removable and exposed to the elements.
- The user interaction seems unwieldy (this is a point of research in the next chapter 'Field work').
- Overall embodiment is not at a production-ready level
- End-of-life was not given much thought yet.

FURTHER RESEARCH

There also are some things that as of this stage, nothing concluding can be said about. While the number of steps in the user process can be counted and tested with local participants in a user test, nothing can be said about the perceived user experience in the local context.

Also, while the dual-choice lab experiments give a clear indication of mosquito preference, it is unclear if the same preference will be given to the M-Tego in a real-life scenario.
It is also not entirely clear what the optimal parameters are for mosquito capture.

Preliminary ideas

During the evaluation, several ideas for improvement came up that might improve the trap in the same ways that are described in the life cycle analysis: ideas that make the product cheaper to manufacture, simpler to use, or better to recycle.

TOPOLOGICAL CHANGES

During testing with prototypes in Wageningen, it became clear that while the current catch pot/inlet module was somewhat suitable for lab testing, is could still be improved a lot in terms of user friendliness. This would make long-term use easier for the user. A main pain point is the emptying of the catch pot, which requires the removal of the entire inlet *module* before removal of the catch *pot* can be attempted; a tedious process that requires careful attention by the user, because mosquitoes inside might still be alive.

To prevent escapes when the catch pot is taken out and when the fan isn't operating during the day-time, the automatically closing hatch, present in the Suna trap, is reinstated. A new system was designed for this configuration in which the handle of the catch pot contains a mechanism for locking the lid of the catch pot, preventing accidental opening of the hatch. This interaction is both elegant and simple.

It was thought that in order to optimise life span, electrical connections should be fixed as much as possible: reducing chances of dust and water getting between them. And because the catch pot should be as accessible to the user as possible, it should be the only part a user would have to interact with if it were located on top of the product. If fitted with a handle, the user would have a direct clue where to take out the catch container (figure 28).

A new figuration of the inlet module would foresee in both these wishes and create an assembly where the fan is fixed in the base of the design (figure 29) and the catch pot would become an accessible container on top of the design. This re-configuration would also reduce the chances of dust and water getting inside the fan. In case of fan breakage, a technician or homeowner with the proper equipment, can replace the fan by removing the catch container from the base and unscrew the fan.

It would also reduce the number of injection-moulded parts in the top half of the assembly from four to two, reducing costs significantly.

Figure 28. Topological changes in the concept. The mesh inside the catch container is cone-shaped, as a flat mesh would fill up with mosquitoes fast, reducing necessary airflow.

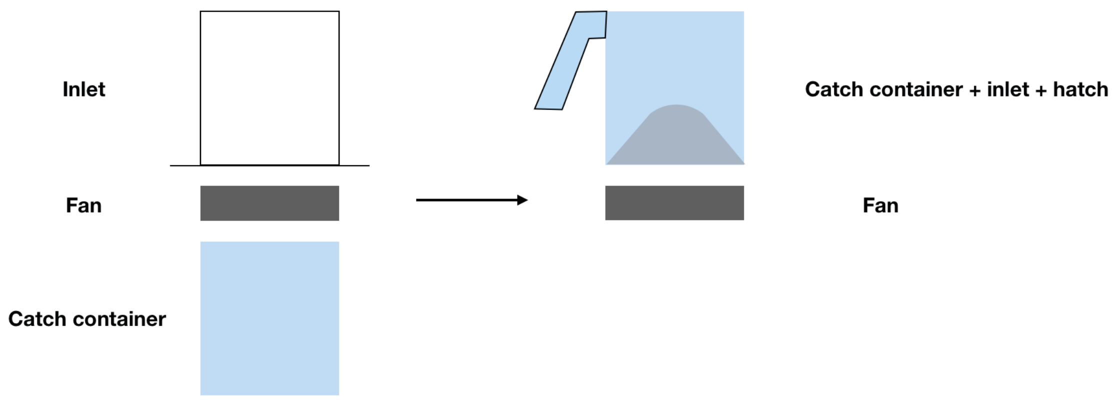
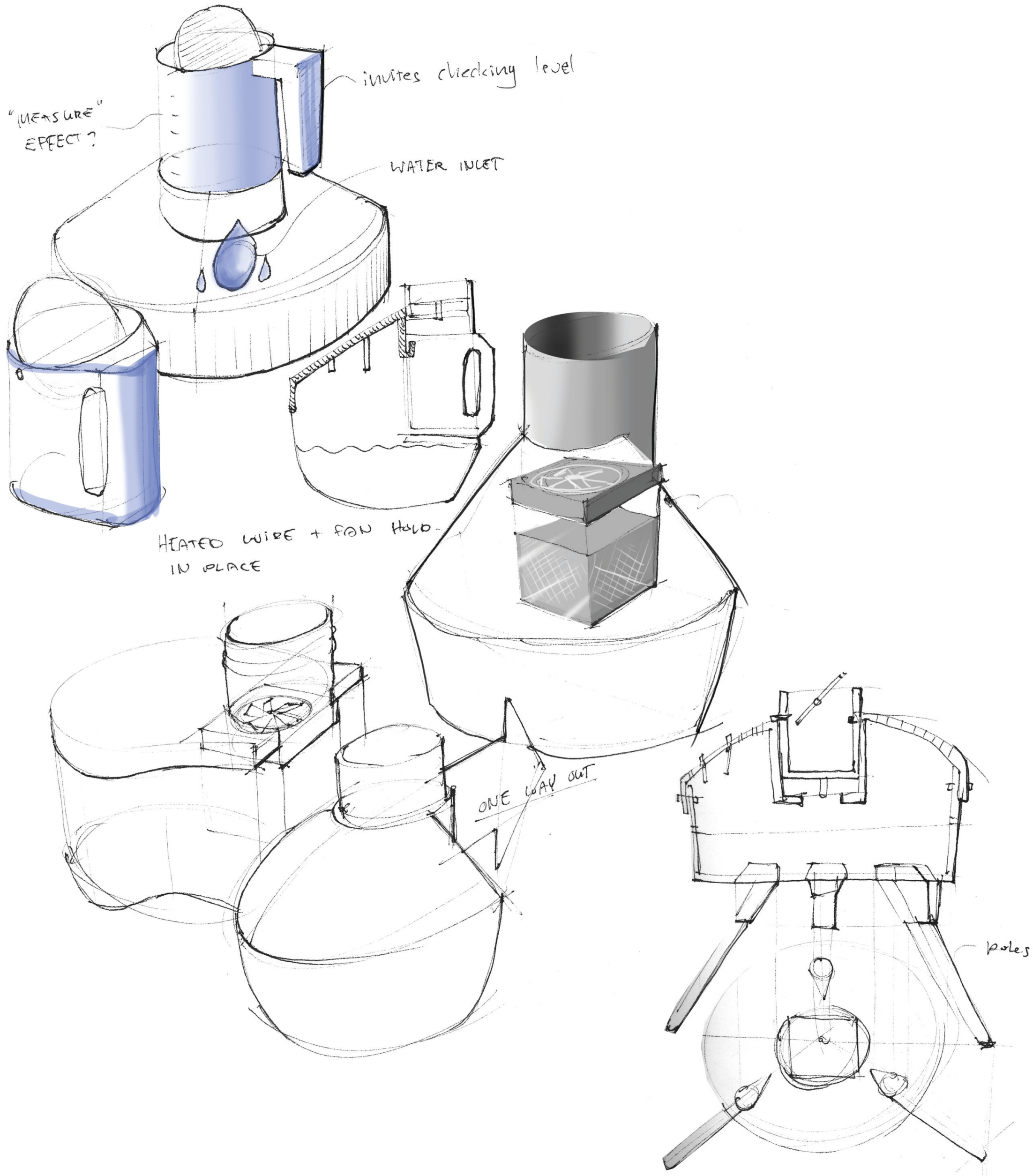


Figure 29. A catch pot with handle would make interaction more straight-forward.



PRODUCTION

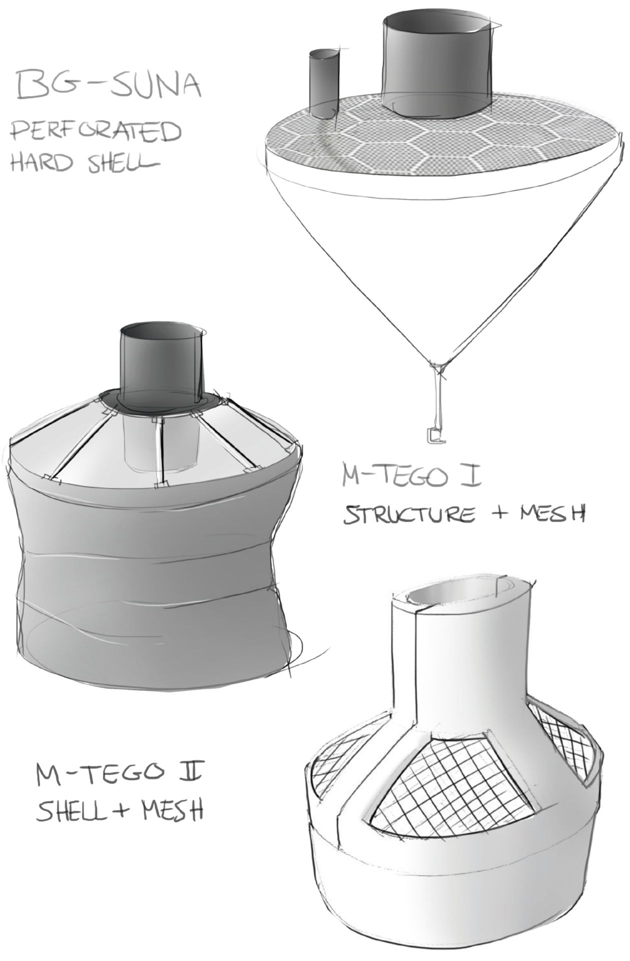
In an iterative process of sketching, discussing, and testing for production possibilities, a search was conducted for a shape of the design that would minimise the number of parts, reduce their complexity, and enhance their functionality. Soon, it was decided that instead of the canopy with it's many parts (figure 31), one part could be created, either by lasercutting or by injection moulding, that would replace all of them.

Testing of the laser cutting and consequent heat forming of a Vikureen sheet around a mould was successful: however, it would still require multiple parts and assembly steps. Since there will be tens of thousands of these traps produced, injection moulding would be preferred in both production time and costs.

Figure 30. For the construction of the canopy, there are three options. First is the hard shell that the Suna uses. It is sturdy and durable, but the many perforated holes turned out to be bad for the outwards flow of scented air.

The second is the construction that the M-Tego I uses. It is lightweight and aerodynamic, but complex and therefore costly to construct and not as strong.

The third option is a merger of the two previous; large mesh outcuts provide the good outwards airflow, while a hard shell piece enables a strong frame.



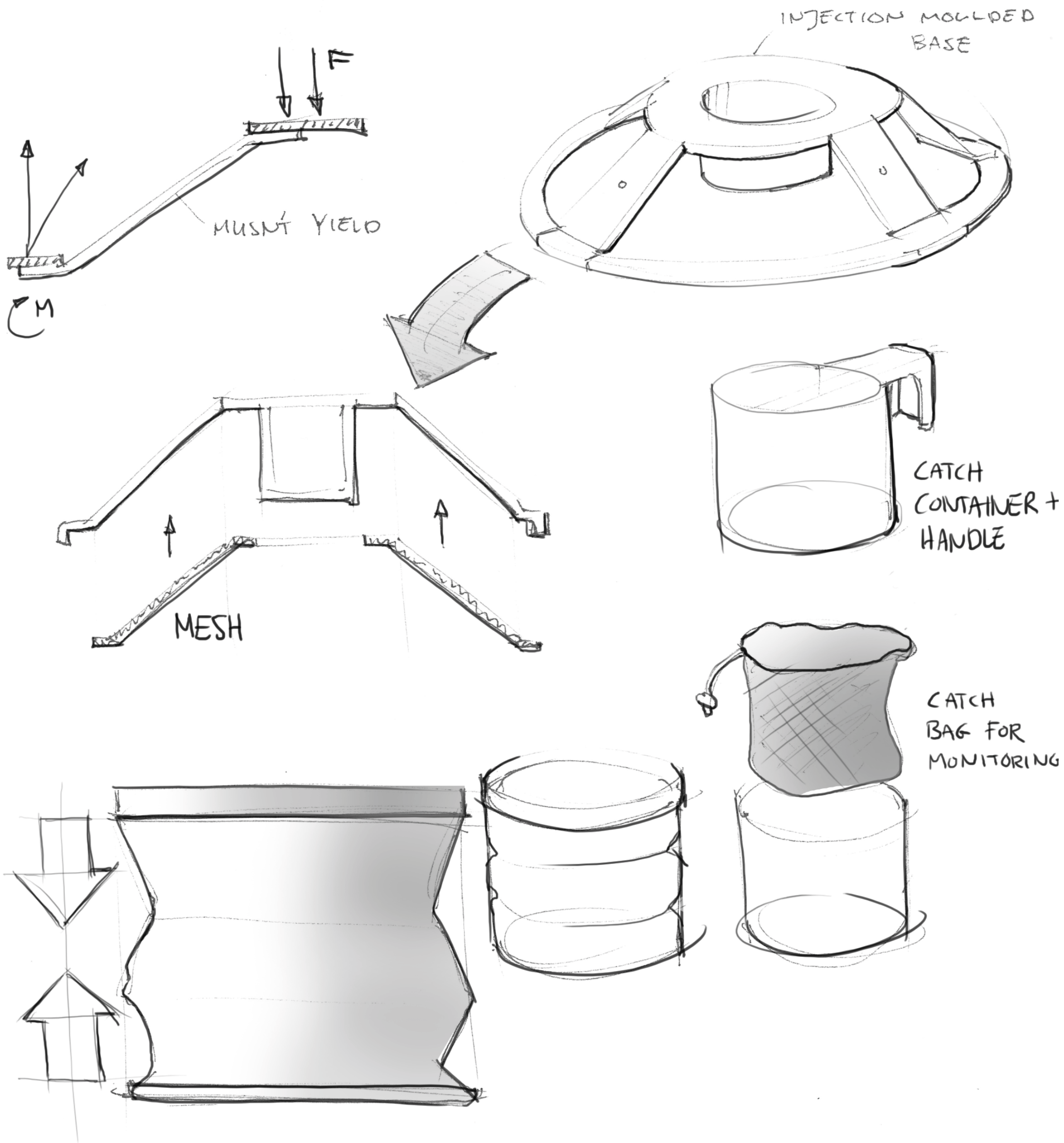


Figure 31. Comparison between the first render of a 'unified' canopy and the M-Tego I prototype canopy assembled and in exploded view.

TARPAULIN HEIGHT

It was thought that if height can be reduced without making the trap less attractive to mosquitoes, a design with no further collapsible bag can be considered. However, while the amount of volume is not required for optimal airflow, the dark shade of tarpaulin does serve as an important visual clue. At the same time, the bag 'closes' the design without the need for further parts that need tooling.

ATTACHMENT OF CANOPY TO TARPAULIN BAG

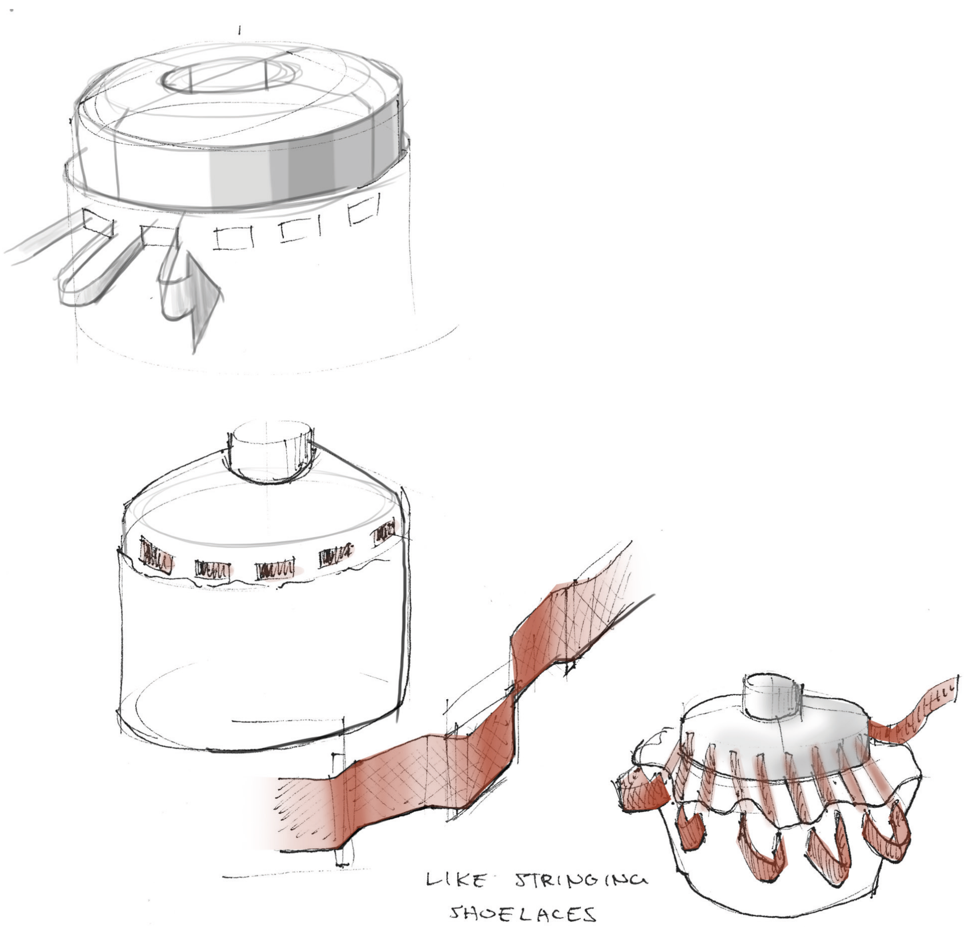
The connection between the canopy and water container was considered a point that took too much time during assembly and is difficult to assemble by hand.

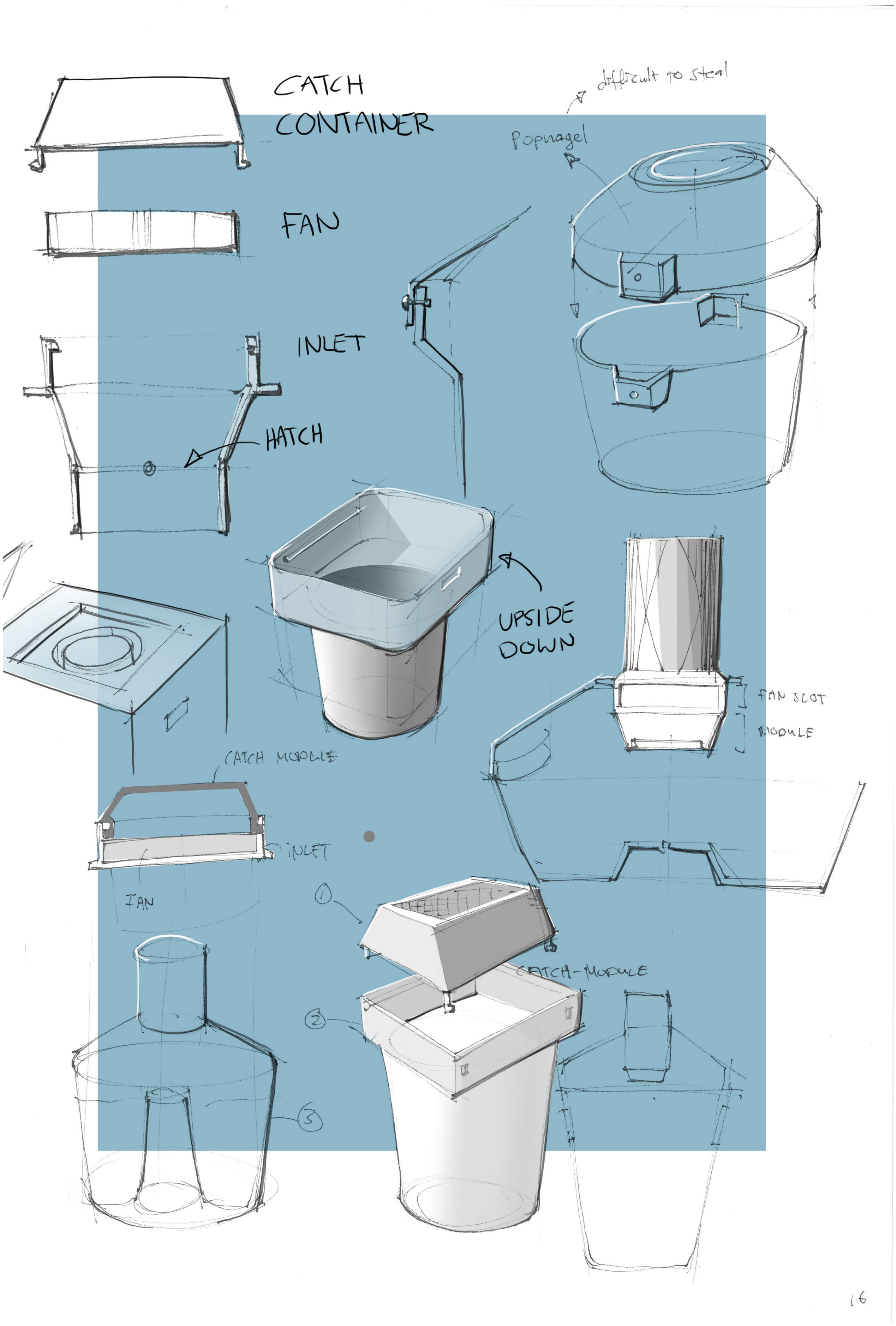
Multiple options are considered to solve this problem, including the use of braiding (figure 31), a technique often used locally. However, this is still a labour-intensive way of connecting parts and therefore, a click-finger system was considered.

PLACEMENT & INSTALLATION

Initially, the method of suspending the trap was considered not optimal, because of the possibility that animals and children will see it as a toy, and break it. However, no suitable replacement was found. A standing trap would become accessible to insects and other small animals, while a frame to mount it on a house would greatly reduce flexibility of the trap and increase costs.

Figure 31. Braiding as an option for connecting the bag with the canopy.




CATCH CONTAINER
FAN
INLET
HATCH
difficult to steal
Popnagel
UPSIDE DOWN
FAN SLOT
MODULE
CATCH MODULE
INLET
FAN
1
2
3
CATCH-MODULE
16

USE & UPKEEP

In case of usage in a research programme, a researcher will have to carry multiple catch pots. Therefore, a catch bag is preferred over a catch pot, because they are easier to carry. However, a person not involved in research activities will prefer a catch container since it is easier to clean.

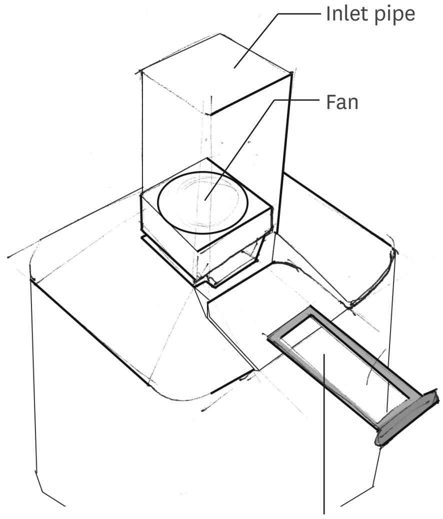


Figure 32. Replacement of the odour tray.

Replacement of Odour Tray

The MB5 and potentially 2-Buthanol require a position in the product where they can be replaced. Their replacement is not as frequent as the catch container and therefore don't have to be as accessible. The analogy with a sim card was found to be suitable and the design for removable slots was based on this comparison. Ideally, the chemical blends are placed in the direct airstream of the fan; the odours would be blended as well as possible with the air inside the trap, and consequently, spreading the odour to outside as good as possible. This would mean that the strips should be placed directly underneath the fan, and a way was derived to place the strips here (figure 32).

END OF LIFE

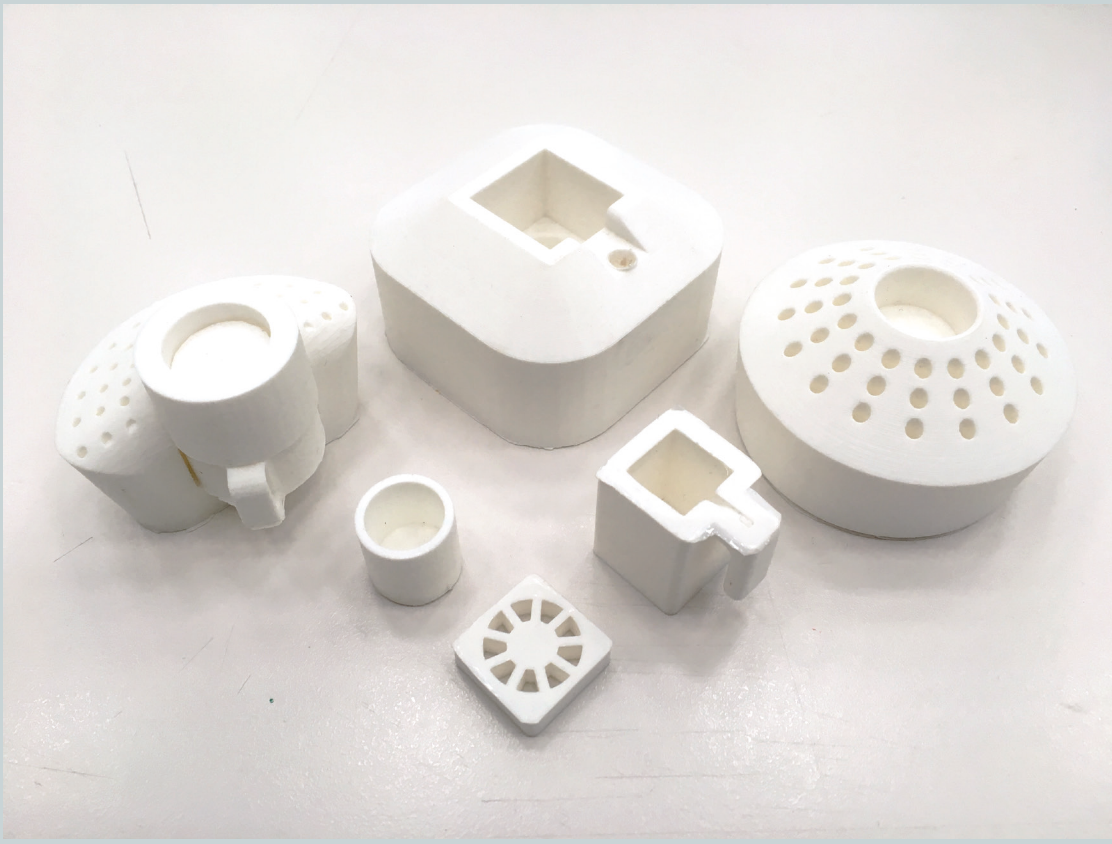
Circular economy
Preferably, all M-Tegos are brought together at a point where materials that are still good can be re-used by the manufacturer. This process is called the circular economy, and it saves both costs and the environment. Broad collection of used M-Tegos is difficult, since convincing users to bring back their products once broken is difficult, and the initiators of a trapping project (governments, NGOs) generally lose their feel of responsibility once the project is finished. However, if a local network of distributors could take responsibility for the collection the loop could be closed

Conclusions

In this chapter, a closer look was taken at most of the principles and choices made at a concept level, and first steps were taken towards future enhancement of the embodiment design, including production and usage. Two main ideas were the topological change introduced on page 50, and reconstruction of the canopy on page 52.

These ideas were make into 3D printed models (figure 33), which were taken on in the field work. Other ideas and inspiration was saved for further use in the final embodiment phase.

Figure 33. Miniature 3D printed models of M-Tego variations



Field work

Examples of failed design for BoP (Base of (economic) Pyramid) are numerous, largely due to lack of understanding and implementation of local customs and norms. If a water pump features a complex design or repair scheme, it is likely to fall in disrepair soon if not equipped with a support structure for the local population. The LifeStraw, a project aimed at bringing clean water to the masses through a filter equipped straw, failed initially because Africans, like us, don't drink while lying down at a muddy pool.

Adapting the design for local culture is perhaps the largest challenge of this project. In order to create a design that will be used for prolonged periods of time, talking to users, interacting with them and listening to them, is of vital importance. These are the goals of the field work.

SEMI-FIELD PROTOTYPE EVALUATIONS

One of the goals of the field work was to determine mosquito preference for M-Tego over the existing Suna trap in a semi-field setting. This data is relevant for redesign; while the M-Tego was tested in the lab in Wageningen, there is no indication if the collected data is similar to catch rates in the field. By doing semi-field experiments, this can be checked. If the data is consistent between the lab setting and the semi-field setting, a redesign can then be tested in the lab in dual-choice experiments with the confidence that the trap will perform similarly in the field. Secondly by testing the prototypes of the M-Tego concept in the field, the technical and social sustainability can be tested. Thirdly, the data could be used for publishing purposes, which is a wish of the client, the Wageningen University and Research. Publishing will lead to an increased exposure in the scientific community and might lead to faster acceptance of mass trapping as a part of a malaria project.

PRODUCT/USER EVALUATIONS

The goals of the user testing was to gain insights into the user experience with the product: the pleasant, difficult, frustrating or good experiences that people have when using the product. Particular interest was aimed towards cultural differences that might make usage of the product more difficult, especially as might be foreseeable over a prolonged period of time.

TECHNICAL EVALUATIONS

As the conditions on the African countryside are quite different from those in a lab setting in Wageningen, the Netherlands, the product was extensively tested in the new environment, to see what still works and what needs more attention.

ECO-SYSTEM

Something else that was looked at was the environment of the trap: what could block, slow down or aid a deployment of traps? These are loose insights that were gathered over the month the field work was performed.

Semi-field experiments

SETUP

A more detailed description of preparation, method and circumstances can be found in Appendix C: Semi-field details.

A semi-field experiment was set up using the 3x32 method. This is a solid scientific method for determining trap preference, since all variables, like the screenhouse and odour blends, are randomised. The experiment was done 15 times, of which 6 are fully usable results and another 6 are useful in part. One replicate was considered as loss, due to two failed trap batteries. Finally two more replicates were done to determine the effect of CO_2 on trapping.

The Ifakara Health Institute has build the so-called mosquito city (8°06'28.4"S 36°40'00.4"E) on a piece of land several kilometres from the city. There, screenhouses are constructed in which semi-field experiments can be performed (figures 34, 35). The IHI was selected because of availability of these facilities, as well as close ties to the WUR, and location in the countryside of western Tanzania.

The M-Tego traps were hanged outside the houses. Inside each house, a setup with CO_2, a fan and odour was placed to simulate a human inside (figure 36). The experiments ran for around 12 hours every night.

CO_2

CO_2 is an important lure for mosquitoes, especially on the longer range. To create CO_2 in the semi-field setting, a mixture of yeast and molasses was used.

Figure 34. Screenhouses used during the semi-field testing, near Ifakara, Tanzania.

Figure 35. Setup of a trap in close proximity of a mimic house inside a screenhouse.

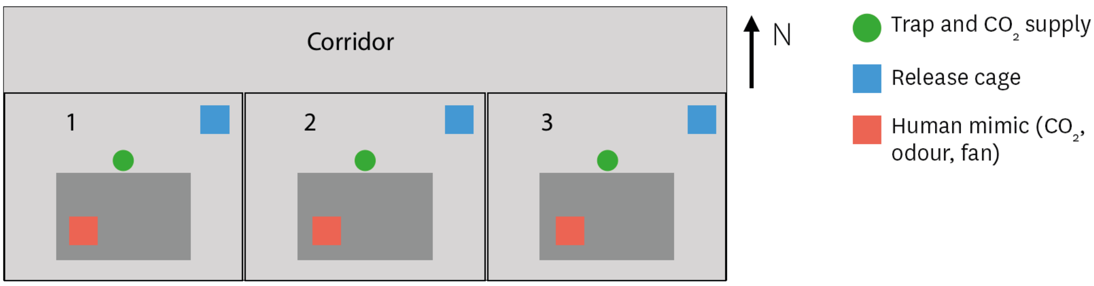


Figure 36. Setup field work.

RESULTS

In figure 38, the results of the semi-field experiments are shown. Missing data points are because of failing batteries and incorrect airflow, caused by melting traps. After the experiments, it was determined that neither one of the blends nor one of the houses is statistically more preferable to mosquitoes than another.

Overall, the semi-field results confirm the tests done in Wageningen by showing an average 4.5X more captures by the M-Tego prototype versus the Suna.

Also, two replicates were done to determine the effect of CO_2 on performance. A big performance drop was recorded as expected (figure 39).

Figure 37. the author fasting an inlet module with the purpose of starting a new experiment. Photo by Kasian.

Figure 38. Amount of captures per replicate and average number of captures per trap over the valid replicated of 13 in total. Missing data points are because of failing batteries and incorrect airflow because of melting traps.

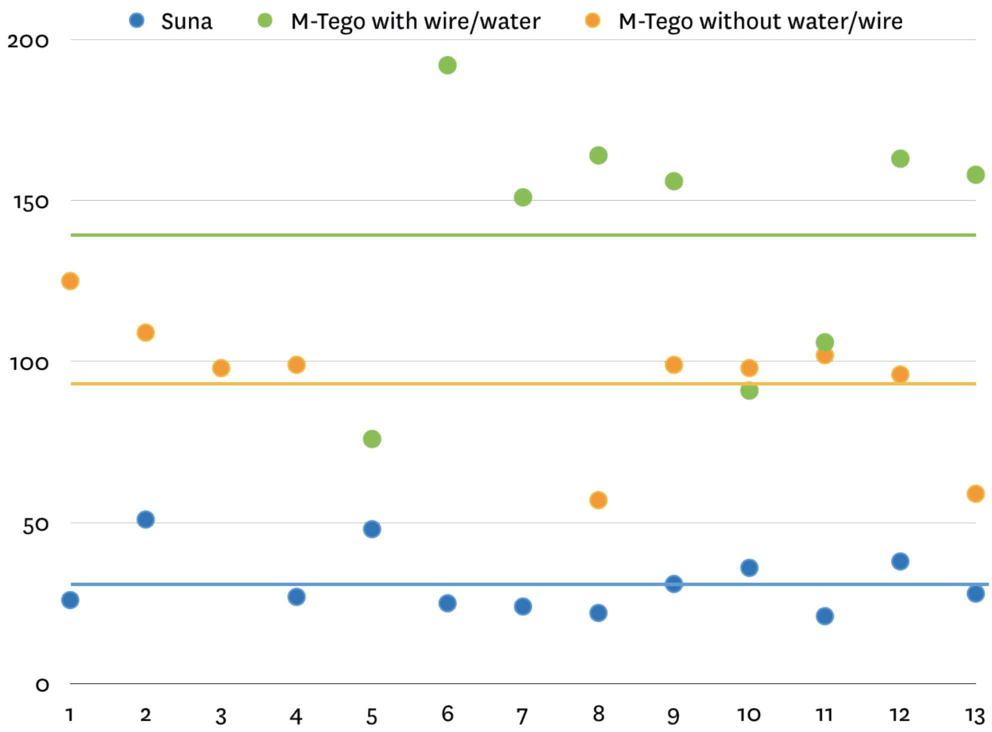
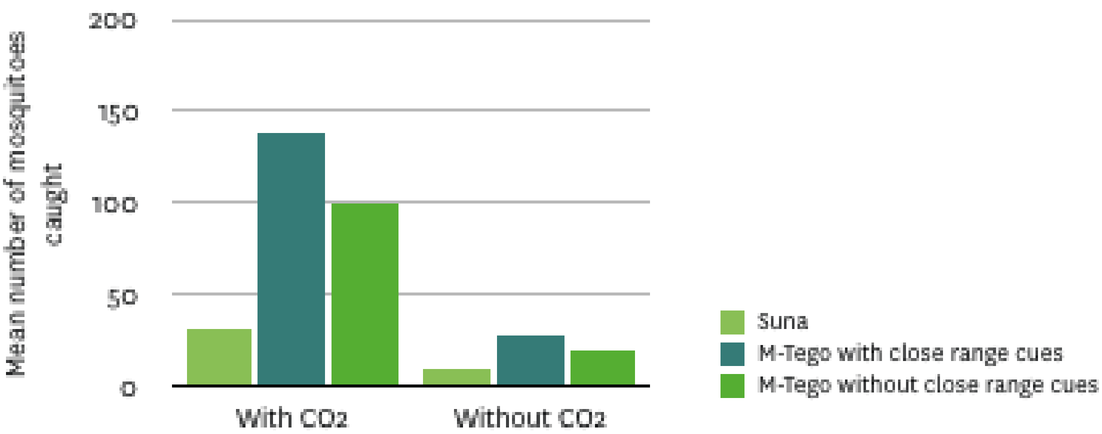


Figure 39. Effects of a CO_2 source on trapping performance.



User tests
METHODS

By performing user tests, focus groups and interviews, conclusions can be drawn on potential improvement points for the trap in terms of user-friendliness and in lesser extent, social sustainability.

Each participant of the user test was asked to perform a number of steps, which are described in Appendix G. Before doing these steps, the user was asked for consent concerning taking pictures and recording quotes, and asked to think out loud and share any emotion they might feel. For reference, the emotion wheel (figure 42) was handed to the participant. The observer filled in the micro emotion scan. The participant was told what the device is, and After completing all the steps, the participant was asked to sit down for a debrief. The low- and highlights were discussed, and the participant was asked additional questions about placement and ownership (appendices B, G). Of the ideas conceived in the first round of iteration, miniature 3D prints were created. When every thought about the process was outed, the miniatures were shown to participants and discussed.

The method

The micro emotion scan is a method adapted from interaction designers I worked with before. Any user performing a user test will only remember the highlights and lows of a user test. Therefore, it will be difficult to extract data about every user step in hindsight. The micro emotion scan follows the user every step of the way, qualitatively monitoring emotions, quotes and insights per step. The quantitative part of the scan can be used for detecting difficult, annoying, but also pleasant steps of the usage of a product. The mean, but also minimum and maximum data

Figure 40. User test in progress. The user is looking for a way to detach the catch container. Kasian helps translating some terms.

Figure 41. (a part of) the micro emotion scan used to evaluate the user experience.

Phases	First Look		Setup				Use	Upkeep			
	First look	First touch	hanging	unfolding	filling water	plug in	Looking at it work	unplug	take out tube	loosen mosquito container	Store mosqui contain
Experience											
Insights											
Quotes											

points of any step can be quite revealing, if enough data is collected.

Details

Of the 15 participants, 11 were male, 14 originated from Tanzania, and 4 had received a higher education and worked at IHI. 10 were IHI personnel, not in a scientific function, but rather as electrician or caterer. Therefore, they had no significant knowledge about mosquito behaviour or mosquito traps. In two cases, translation was needed and provided by Kasian.

Dead mosquitoes, originating from the semi-field test, were placed in the catch pot of the setup trap, the trap was void of water and closed at the moment the users first interacted with the prototype. The trap was not functioning at the moment of first interaction. After the first tests in the semi-field setup, where M-Tego was fully functioning and one man nearly burned his hand to the trap, it was decided to tell people the inlet might be hot, but not actually turning on this feature in the interest of protecting them.

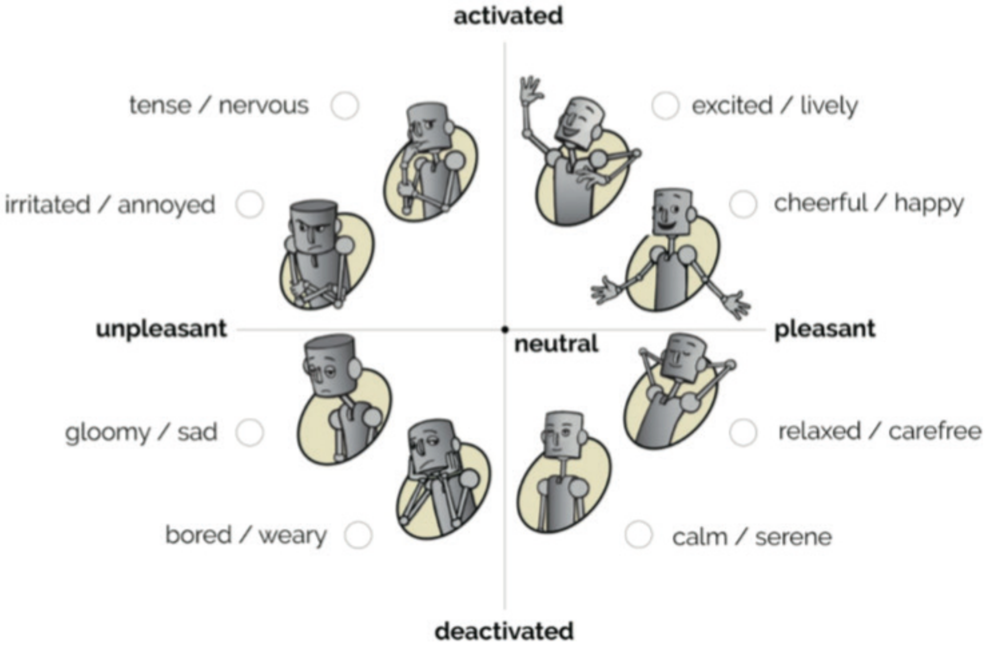


Figure 42. The emotion wheel. Emotions are ranked from 1 (tense) to 10 (excited). Passive emotions lay more towards the centre, while active emotions are at the high and low points.

USER INSIGHTS

From the user testing, it can be concluded that while the user journey is not perceived as particularly bad, there are some pain points that need to be addressed. The 'taking out' of the mosquito container is unwieldy, in particular due to ill-fitting connections and non-ergonomical steps, such as forced rotation of the inlet module and a hidden slot for closing of the catch container.

The water container is something interesting in its own right; since there is no indication of how full it should be, users get confused or afraid as to how full it should be. On the contrary it is perceived as a fun interaction.

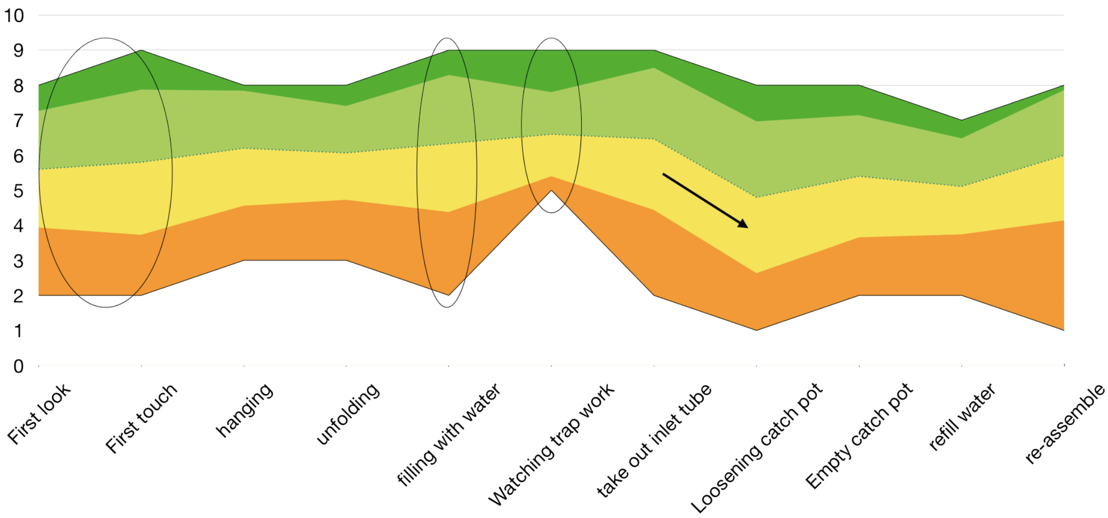
Analysis of the Micro emotion scan (figure 43)

If we look at the mean number that is attached to the emotion of the user, we can see where the highs and lows in the user experience are. Combined with the standard deviation p, we can conclude whether this number is significant.

Due to large deviation in the first two phases, looking and touching, the average number is 5.8, which is slightly calm, and mostly neutral. After this, most users seem to regain confidence as the number rises to 6.2 for hanging the trap, 6.1 for unfolding, and 6.3 for filling it with water. During the steps 'hanging' and 'unfolding', the emotions' SD lowers to around 1.5, which is the lowest among the steps. However, this last step was considered both an easy, fun step, as one that brings uncertainty, so the range of emotions reflect that. The average emotion then keeps rising to 6.6, the highest recorded average, on the moment the trap is functioning and the user can sit back, enjoy, and feel relaxed. This is also the point with the highest minimum score: 5, or 'neutral'.

After this highlight, two more disappointing steps take place: taking out the inlet module and loosening the catch pot. Due to some incidents with non-fitting traps, some participants got irritated or nervous because the system didn't work. This made the 'loosening catch pot' the lowest score, a 4.8. However, some people did succeed and felt relaxed or even happy. After this step, emptying the catch pot seems easy and fun, and people feel more calm. If the previous step was less frustrating, people might find this step boring, but now it's an easy diversion. During the last two steps, refilling water (5.1) and re-assembly (6.0),

Figure 43. The Micro emotion scan averages, standard deviation and maximum/minimum scores.



people are more relaxed, although for some, the experience of a previous step was such a disappointment that the last steps couldn't be saved. Those people kept feeling nervous or frustrated.

On average, researchers are one full point less happy during interaction with the trap than non-researchers. This is true for all steps except 'unfolding the bag' (figure 45). Below (figure 44) is shown the MES of one of the participants. Here, typical ups and downs are shown; from the excitement of beginning to the frustrations of loosening the catch pot.

Figure 44. The MES of one of the scientists' user tests.

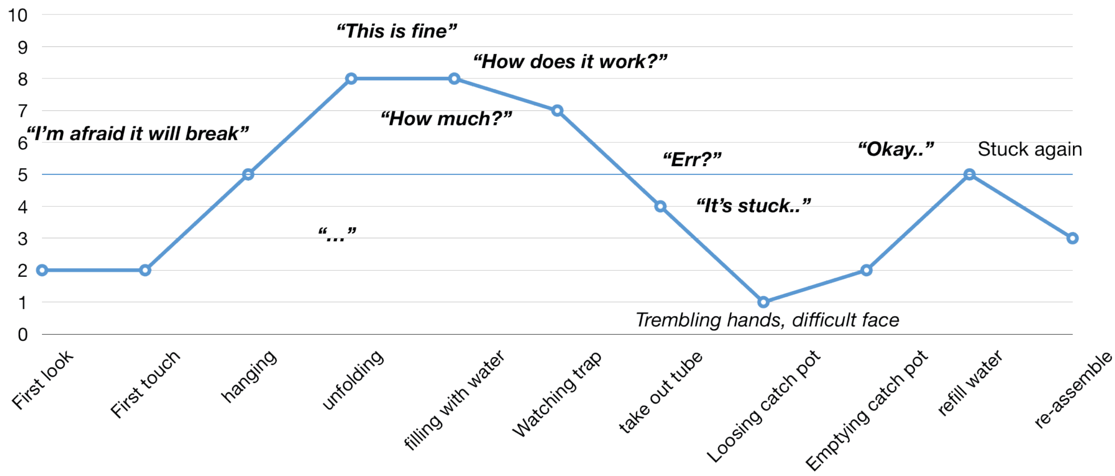
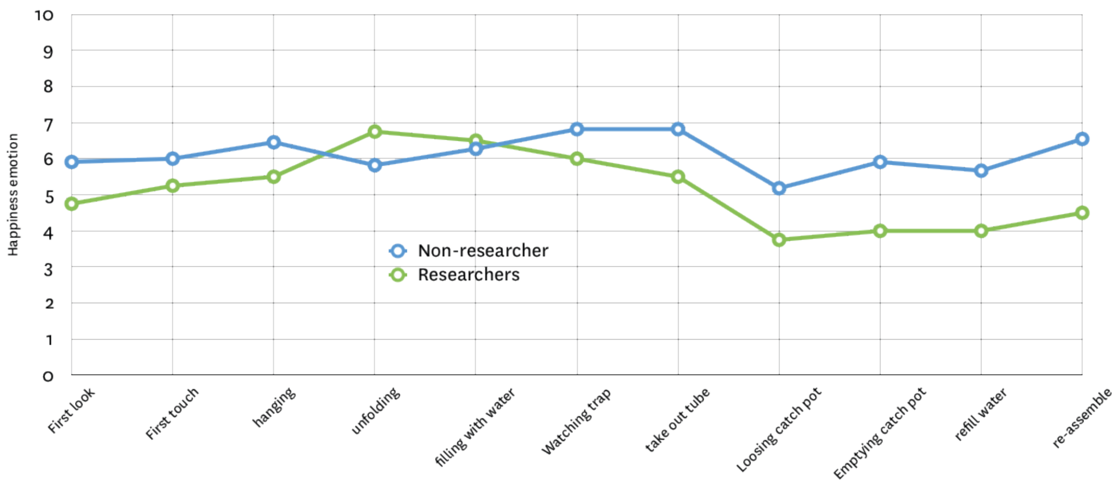


Figure 45. The average score of a researcher is one point below that of a non-researcher.



Pricing preferences

Several participants were asked what the price would be they would be willing to pay for the product (the trap, not the entire system with a solar panel). Answers ranged from 9,000 to 16,000 Tsh, or €3,45 to €6,09. A few users remarked they would be willing to pay for it, but were unsure how much exactly because they doubted the performance would be worth their money. Other comparisons were made with bed nets, which cost 10,000 Tsh (€3,80) in a non-insecticide version.

“It is difficult to say, because I don’t know if it is going to work better (than an electric fly zapper that costs 15,000 Tsh, or €5,70)”

The cost was mentioned by several local scientists as well, who depend on grants and donors to execute research programmes. A figure was not made explicit, but any cut on costs compared to conventional trapping was taken as gain.

It should be noted that these people, however interviewed in rural Africa, were still in a privileged position compared to those on the countryside suffering from malaria.

Technical Insights

Four prototypes of the M-Tego, the same that were used in lab testing at the same time in Wageningen, were taken to Tanzania. After arrival, all four started showing signs of breakages, leakage, short-circuiting or other shortcomings. In this chapter, the shortcomings are explored and explained. Lessons from the incidents are applied in the redesign of the trap.

ELECTRIC SYSTEMS

The electricity system of the M-tego revolved around two parts requiring electricity: the fan and the Nichrome wire that heats up during the night. During the first tests, the wire expanded too much, causing it to short-circuit, heat too much, and heated the plastic rim too much, causing it to start smoking. After the system was turned off, one man burned his hand on the wire. Potential solutions to these problems are:

- Using a material that doesn't expand as much when heated
- Using a construction where the wire is separated enough from itself so it doesn't short-circuit, either by forcing the material in place or spatial separation.
- Using a construction where the wire is in a position where it cannot short-circuit. For example, having the wiring in one line rather than five.
- Pre-heating the wiring (before assembly), so it expands and an oxidising layer forms before usage of the trap.
- Finding an alternative for Nichrome wire that is more suitable and sustainable.

The wiring of the fan is connected to the wiring of the Nichrome wire in a parallel circuit. In the prototype the fan wiring is connected to main wiring using copper tape, which has a sticky surface on one side to be applied to the desired point of connection. After applying the tape to both parts, they can be put together to close the electrical circuit. The glue used in this copper tape quickly released even after firm re-installation. The glue released due to heat and high humidity, and lost its stickiness after contact with sand and dust. After attempts to reinstate the original system, it was given up on and the wires were tied together directly. This fixed the inlet pipe and fan together, which was no problem because the two parts had no need for separating during the testing phase or afterwards.

The traps were connected to the battery manually, whereas in a real-life scenario, there would be a controller to turn on the trap automatically around dusk.

The formula for heat transfer through (solar) radiation is $q = \varepsilon \sigma T4 A$, where ε is 1 for black and zero for perfectly white bodies. The colour is therefore of vital importance to heat intake.

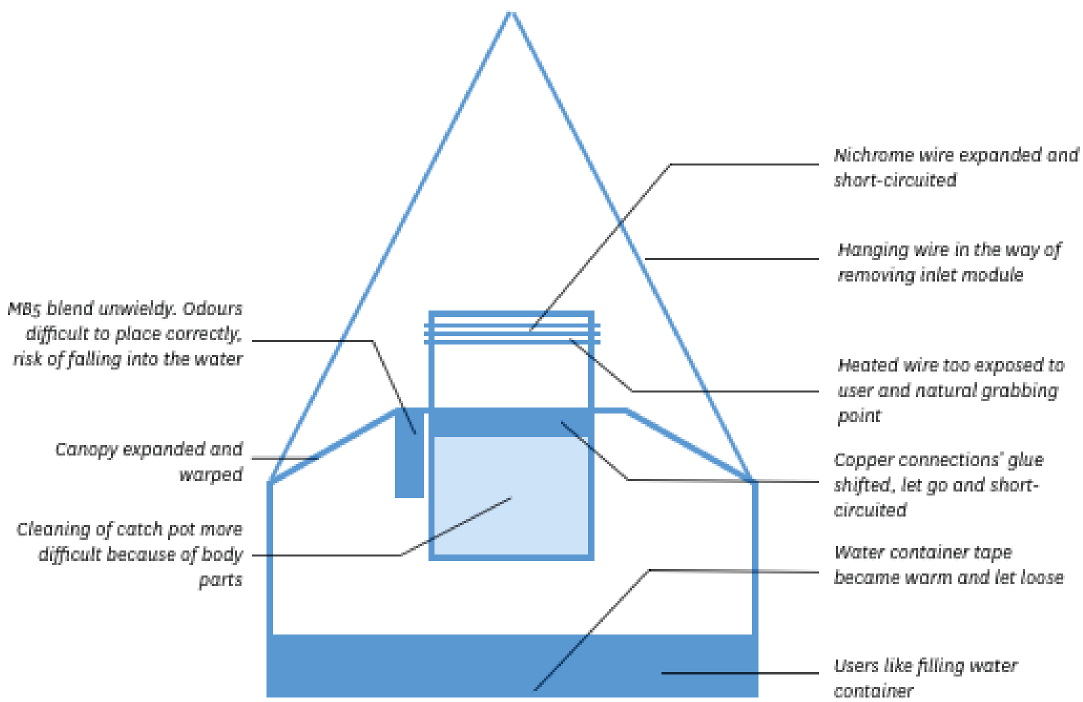
MECHANICAL SYSTEMS

The 3D-printed parts expanded significantly due to the heat and sunlight (more specifically, UV light). The parts were black, which sped up the process. Despite that the parts had not been in direct sunlight for prolonged periods of time, this expansion caused several parts to being unable to fit together anymore.

- The catch container fit to the fan was less smooth, as the fan enclosure has swollen more than the catch pot.
- The catch pot and fan's twist contact points rotate in opposite directions. This is useful when the user is disassembling the catch container to empty it, but very tricky when assembling the product again: fastening one part will loosen the other. The swollen parts made assembly even harder.
- The glue and tape that held the water container together on one of the traps, let loose and caused the water container to break on most prototypes, especially those that were being used for testing of the water.

Overall, sunlight and heat contribute most to the problems that arise. Parts that should fit together should adjust for expanding and warping, or be made using production techniques and materials that do not suffer from these effects. Secondly, the heated Nichrome wire was difficult to control; it would slide down the pipe, short-circuit and expanded when heated for the first time.

Figure 46. An overview of shortcomings in the prototypes during use



Holistic evaluation of tested traps

To summarise the lessons learned from user, technical and system evaluations, as well as the Semi-field environment, figure 47 was created to showcase the difference between M-Tego and Suna, and the M-Tego without close range cues (water and heated wire).

The score given to some points, like product pricing, is an estimation. The score for 'user upkeep' is to indicate what trap is easier to use than another, and based on the number of (complex) user actions.

Prices were estimated for the 'system' parts and it should be noted that the price for system parts, such as solar panels, has dropped since 2012 when the original Suna traps were released. An updated, 'future Suna', which includes a 1W fan and likely will be released sometime in 2019, is added for comparison.

The performance of the Suna has been given a certain baseline number of 100, to compare to the traps that were tested in the field work. As can be seen, the performance of the M-Tego per € gets the highest score of 4.7, but the M-Tego without heated wire gets a higher score for performance per Watt. It is thought that since an M-Tego without heated wire can be sold for around €80 including solar system, it is more suitable for projects who want a higher community coverage, but do not have a lot of funding.

Given that mosquito traps are novel technology in the field of vector control, and the lack of sufficient funding, the performance per money spend is by far the most important benchmark in convincing influencers within NGOs and governments to consider mosquito trapping.

Figure 47. Holistic comparison of traps and trap configurations.

Name	Suna	M-Tego without wire/water	M-Tego	"Future suna"
Price product	€70	€24	€27	€42
Price product + system	€157	€80	€103	€97
Power consumption	3.3W	3.3W	12.9W (9.6+3.3)	1W
User upkeep	3	2	3	3
Performance (relative)	100 (baseline)	290	480	100 (baseline)
Performance / Watt	30	88	37	100
Performance / €	0.6	3.6	4.7	1.0

System insights

REPAIRS

In the search for repair shops and manufacturing possibilities in Ifakara, no official repair stores were found. The activities at the street side that looked similar to repairing activities, were mostly linked to automotive repair activities; welding and smithing of metal parts. Shops that also produced items, most notably clothing and textile, were open for (clothing) repairs but were not specialised, nor interested, in Tarpaulin. When asking around among locals, no shops emerged as the go-to place for repairs. Some people referred to a person they knew rather than a shop. For specific activities I was referred to specific people; the person to repair a kitchen appliance would not be the same to repair a motorcycle.

In general, there seems there isn't a market for repairs, but rather community-based networks in the absence of a repair channel. In the predominantly agricultural Ifakara, there is a repair shop for tractors and several garages for vehicle repairs. In these garages, other welding-based manufacturing operations, like that of fences and bed frames, are not shunned.

In the capital, Dar-Es-Salaam, there are factories and workshops where more complex manufacturing, such as injection and rotation moulding are done.

If an organised repair structure was to be build from scratch, people would have to be recruited, trained and organised per village or township.

Figure 48. The Sun King shop in Ifakara.

On the 20-minute drive by Bajaj between Ifakara and Mosquito city, where experiments took place, there are several villages. Two of these, each consisting of around 10-15 households, have not yet been connected to the electricity grid. From a quick visual inspection 3 households were in the possession of at least one solar panel, most likely sold or leased by a MSC. This shows the presence of both the structure (shops in figure 48) as well as the upcoming market among farmers (figure 49). On one of the trips a man was seen cycling wearing a Sun King t-shirt, who could have been an employee visiting a customer.

END-OF-LIFE

Trash is collected by home-owners and burned in small piles on the side of the road. This is a weekly event in some of the villages surrounding Ifakara. Everything considered trash (mostly plastic drinking bottles, plastic bags, packaging material, but also organic material) is collected by sweeping it into a pile bordering the house. The burning occurs in the morning. In densely populated areas, trash is collected and dumped at the side of the road. In one instance, a dumping site was found within 10 meters of several street food stands. Throwing trash from vehicles is considered normal behaviour.

The organised garbage system only collects garbage in a few bins scattered around the main street, and is often full before picking up all the garbage. After collection, the garbage is dumped at a site approximately 10 kilometers from the town.

Scientific use

While in Ifakara, several researchers mentioned the potential of a small Human Decoy trap if available to them. Since the researchers are focussed on different research topics, the usage of such a trap also varied; from collection and analysis of mosquito types in an area, to testing the effect IVM methods have on the amount of mosquitoes in neighbourhoods. All are benefited by a small, easy to transport and set up trapping method, preferably one that does not require humans to operate it all night long.

Figure 49. Solar panels on a farm in Tanzania.

Conclusions of field work and implications for design

POTENTIAL OF M-TEGO

Overall, the potential of the M-Tego for malaria control has been confirmed. While in the field, the capture rates were 4.4X that of the Suna, and during user testing the participants did not object to most parts of the interaction.

Potential of a low-cost M-Tego

The M-Tego without the heated wire or water performed surprisingly well in the semi-field, capturing 2.9X more mosquitoes than the Suna. This relatively high performance leads to the idea that a low-cost M-Tego without additional close-range host cues might be an interesting idea.

DESIGN CHANGES

Next to the positive things M-Tego achieved, there are some points that can be changed in order to optimise the functioning or user experience. Next to many small changes that need to be happen at a detailing and production level, some larger changes need to be introduced as well.

Topology

As expected, the structure of the inlet module is not optimal for users. Both researchers and non-researchers had their difficulty with finding and isolating the catch container. Therefore, the next iteration of M-Tego will likely have a different topology.

Heating & power

The heating elements of the M-Tego, the NiChrome wiring around the inlet pipe, consumes too much power to run a full night on a 12AH battery. Either choices have to be made to increase capacity of battery and solar panel, or an alternative, low-power heating source has to be found.

Water container

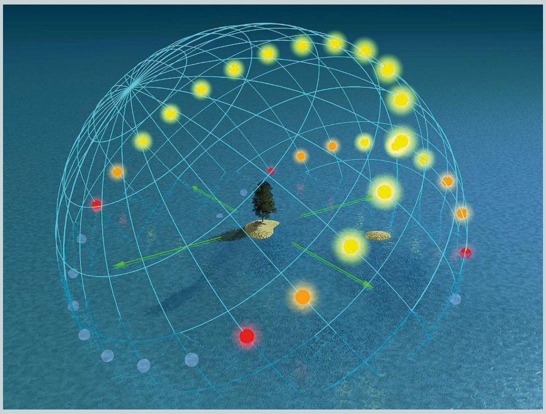
Due to the circumstances the water container is placed in, it is deemed unlikely that a large number of traps placed near houses will heat up enough during the day to attract mosquitoes in the evening and night time. Most African houses found in Ifakara and surroundings are placed in the proximity on trees, save for some shops on the main street (figure 51). Every smart home-owner has planted trees around the house, sometimes generations ago, to make sure shadow falls on the house and lawn.

Since malaria-ridden countries often lay around the equator, the sun rises high in the sky (figure 50), making direct sunlight on the trap from the side difficult. Overhanging roofs (figure 52), where the traps are usually hung, are common. This causes shadow and thus, reduced heating.

Therefore, the temperature of the water will likely remain under the ambient atmosphere for some time during the, if not the whole, night. One user speculated during a user test:

“So in the hot season, the cold water will attract mosquitoes, no? Most of the time we use water to cool down”

Adding the water container also adds user effort, and when traps are not properly maintained the water container is a potential site for mosquito breeding, which makes the problem larger.



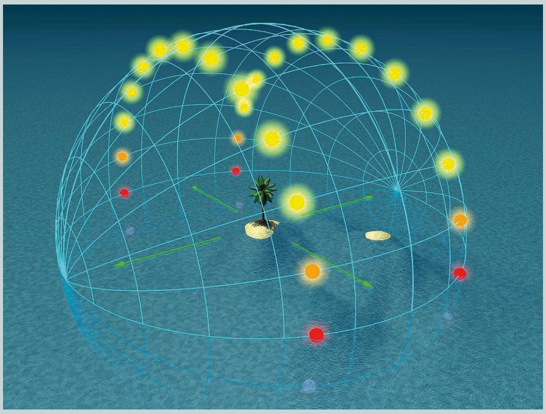


Figure 50. Light falls differently depending on longitude. This makes it difficult for sunlight to reach the water container, which is positioned on the bottom of the trap.

Figure 51. The many trees often planted around houses provide shade throughout the day.

Figure 52. Houses often have overhanging roofs. This makes hanging the trap possible but also provides shade to the trap.

Design strategy

NEEDS LEAD TO PRODUCT DIVERSIFICATION

Following from the conclusions about a low-cost M-Tego in the previous chapter and the conclusions about user needs at the end of the chapter 'Applications' (also in figure 53), it can be concluded that different user groups have different needs and therefore, might need different trap designs.

For example, in the early research phase, the performance of mass trapping needs to be proven; this is a phase where product costs are less relevant than later on, when the traps need to appeal to NGOs who might have less to spare. The feature set of the M-Tego makes it possible to separate features between models in order to create M-Tegos that are phase- or user-specific.

Figure 53. Shared and required functionality.

	Research projects	Other scientific use	IVM projects	Company-initiated projects
Goals	Prove the technical effectiveness of mass mosquito trapping	Monitoring	Get the trap to as many people as possible for as long as possible	Get the trap to as many people as possible for as long as possible
Required properties	Capture rate Cost-efficiency Robustness Beneficial to owner	Capture rate Robustness	Cost-efficiency Sustainable Ease-of-use Beneficial to user	Ease-of-use Sustainable Cost-efficiency Beneficial to owner
Required additional functionality	Heated wire	Heated wire Catch bag	Heated wire* / None, to save costs	Heated wire / none depending on company success
Shared functionality	Plug into PV systems Easy odour replacement Contrast Mesh canopy No addition of water?			

*Some IVM projects might require high-performance, and will therefore need the heated wire. Other, under-funded projects will opt-out.

Adaptive design

For production purposes and cost savings, it would be convenient that separate designs share parts.

One way of creating a line of products that share the basic components and differentiate on a functional level is through 'adaptive design'. This design approach shares characteristics with modular design but differs in some ways. Where modular design focusses on the standardisation of parts so that they are interchangeable, adaptive design focusses on providing the best user experience based on making user add-ons available that can be added or removed based on needs.

Power consumption

Initially and through field testing, it became clear that the power consumption of the heated Nichrome wire would be quite high, 14.4 Watts, which required it to run from a dedicated 12AH battery, and even then only lasted 10 hours rather than the desired 12 hours. Next to the heated wire, the fan also needs around 3.3W of power. Usually during research projects, the inhabitants of a house where experiments are done are offered lighting or phone charging as compensation: a battery with 6 AH (ampere-hours) capacity is considered suitable for this use.

The electrification of Africa happens at an amazing speed, as seen in the chapter 'Background'. However, for the coming years, electricity is still seen as a luxury good in rural Africa. Therefore, people are cautions on what they spend their electricity and might not take in a trap that consumes half their available electricity. If they do, and find out the trap prevents them from watching an important game of soccer, they shall be very annoyed and most likely stop using the trap. Optimisation of power consumption is therefore of utmost importance. The two parts responsible for power consumption, the fan and the heated wire, should be thoroughly analysed and optimised.

The M-Tego is in need of power optimisation, since the current system would need at least a 26 Amp-hours battery, and likely a 30W+ solar panel as well, to power it during the night.

This would significantly increase costs, and therefore prompted the search for a Nichrome wire alternative. Eventually, it was decided that Polyester heating mats (figure 54) are most suitable for this use. Flexible, tough and produce-able in all sizes and wattages, these are suitable for this product.

A surface of 120 cm^2 Polyester heating foil with a surface temperature of 37º would consume around 5W of power (in Appendix D, heating test were done). Together with the future fan (1W) leads to 6 amp-hours of battery consumption for 12 hours of usage. This makes a 12 Amp-hour battery suitable again as the minimum battery configuration. However, as household demands increase with the introduction of radio's, television and smartphones, a larger battery might be desired.

Figure 54. A polyester heating element. A great variety exists of plastic carriers with each their own properties. Polyester is cheap, flexible and durable.

Product configurations

Now that power consumption is no longer a barrier or differentiator between M-Tego models, two configurations remain (figure 55). The Standard edition offers all the performance for a soft price, whereas the science edition offers features such as a CO_2 tube and the catch bag, which makes field sampling easier. It should also contain an AC power supply.

The reason for this pricing proposal is partly strategic and not only derived from the production costs: the scientific community is likely more willing and able to spend more money on research equipment, compared to donor-funded projects. This surplus may then be used to either finance further R&D, lower the price of the standard M-Tego, or to cover investment costs. Further market research should show if this is a sustainable idea.

Other aspects to take into account is shipping costs. The transport of a shipping container filled with 'standard edition' M-Tego's for a mass trapping project will be cheaper per trap than the delivery of a single trap to universities and research institutes around the world.

The difference in features, batch sizes, and stricter regulation in Europe and the western world makes the standard edition can be produced and sold at a lower cost than the Science edition.

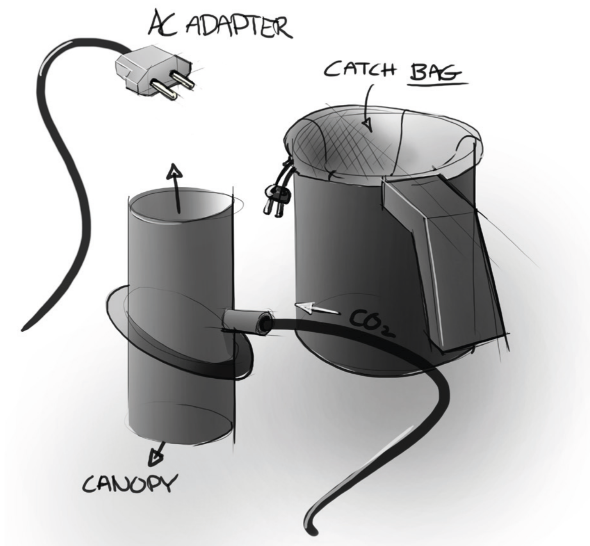


Figure 55. Proposed product configurations.

	Standard Edition	Science Edition
Purpose	Mass trapping in Africa	Monitoring, experiments
Base	Standard Base	
Heat	5W Polyester heating mat	
Catch container	Catch container	Catch Bag
Odour	MB5	MB5 + CO2 cannister
Battery	20Ah Lead-acid battery	
Solar panel	20W Solar panel (peak-watt)	
Price trap	€24	€40
Total system cost	€79	€95

Product requirements

To summarise, here are all the product requirements that have been gathered from all earlier analysis and research.

MOSQUITOES

Luring

1. As a long-range attractant, either CO_2 or 2-butanone, is required for luring in mosquitoes.
2. The odour blend needs to be applied to a fabric or such that can ingurgitate the fluid. A holder needs to be as close as possible to a strong airflow, such as directly beneath or above the fan.
3. On the close range, a heat source is needed for short-range attraction. This heat source cannot use more than 5W of power.

Containing

4. The mosquitoes need to stay inside the trap after capture until death.

USERS

5. The trap needs to be as affordable as possible.
6. The trap should be more cost-effective than the usage of ITNs, or at most $27.61 per annum in use.
7. The system should be as affordable as possible.
8. The catch container needs to be easily removable by any kind of user.
9. The trap should function for at least a week without any intervention of the user.

Scientists

10. The trap needs to catch as many mosquitoes as possible.
11. The trap needs to attract and catch as little other insects as possible.
12. Scientists need catch bags, rather than catch containers, for monitoring purposes.
13. Scientists need to use CO_2 in some experiments and a convenient way of attaching the supply to the trap.

Executing members of a malaria programme

14. The trap should function well without CO_2.
15. The trap should be as light and small as possible.
16. The trap should be as small as possible in a packaged state
17. The trap should be as easy to repair as possible

Inhabitants

18. The trap should use as little electricity as possible, and at most 8Ah of battery capacity.
19. Inhabitants need to see the direct results of the trap, but at the same time:
20. The product should not communicate about reduced risk of contracting malaria.
21. The trap should be extremely easy to understand.

ENVIRONMENT

22. The trap needs to perform in high temperatures (up to 50º C in direct sunlight) and high levels of UV radiation.
23. The trap needs to withstand normal winds (up to 6 on the Beauford scale) and mild rainfall (IP 53). The traps vital features should be protected against the elements.
24. The product should be able to operate in humid conditions (up to 95% relative humidity) in tropical/subtropical climate zones.
25. The trap needs to sustain at least three years of normal usage under these circumstances.

TECHNICAL

26. The trap should plug-and-play in common Micro-home systems.
27. The trap should consist of as few parts as possible.
28. The trap should be as cheap to manufacture as possible
29. The trap should use as little electricity as possible.
30. The trap should function for at least 10 hours per night on the charge collected by a 10W solar panel
31. The trap should have a circular shape and be around 30 cm in diameter.
32. The airflow should be at least 3.5 m/s (vertical downwards) at the inlet pipe and around 1.5m/s (diagonal upwards) at the canopy.
33. The fan, odour tray and tarpaulin bag of the trap need to be easily replaceable

M-Tego II: Final design

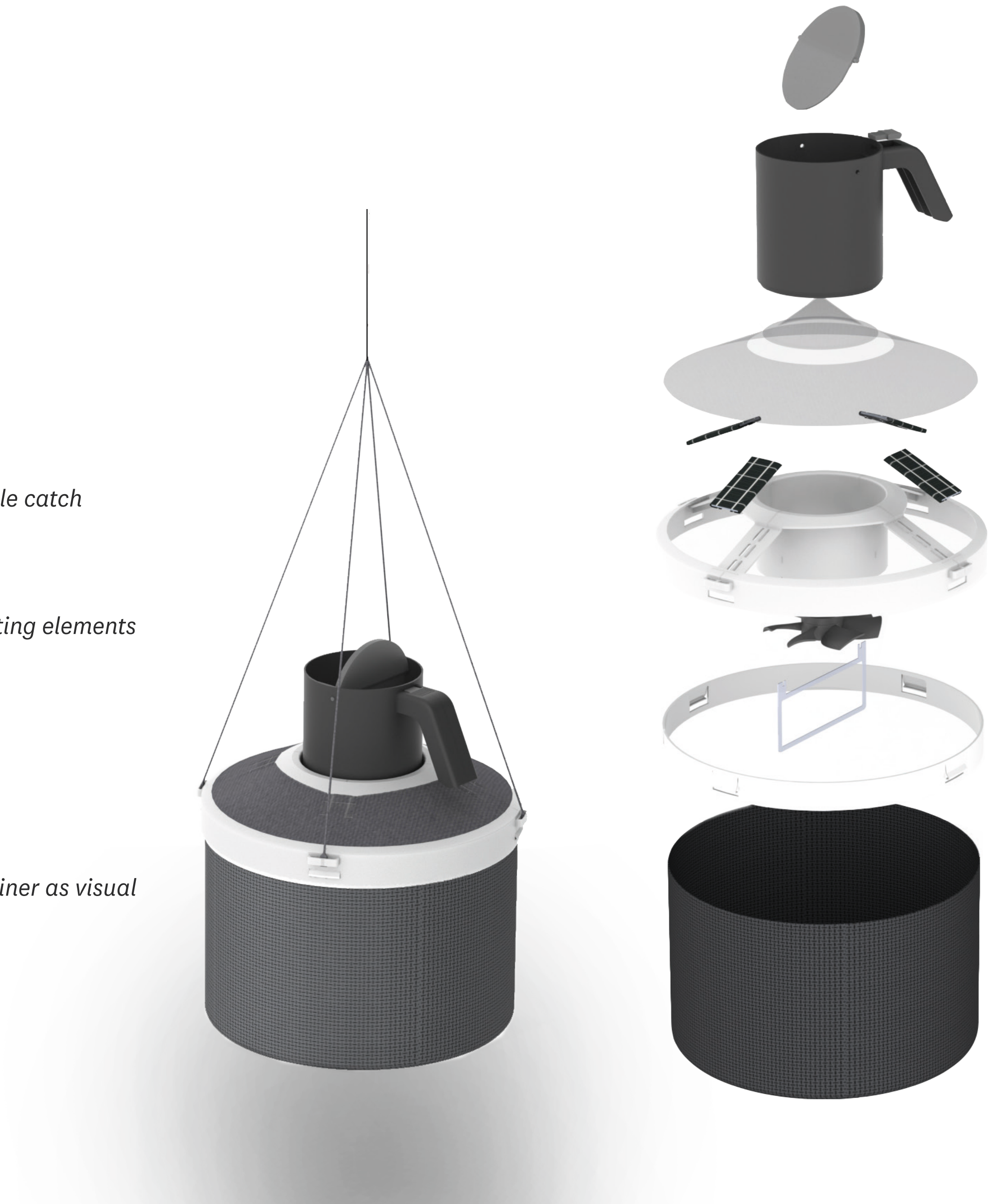
The final design is called M-Tego II, as a natural continuation of the M-Tego concept. All that is learned from the proto-types, user research is poured into it while keeping costs to an absolute minimum.

After a look at the usage, the design is discussed part-by-part. Then it is evaluated on aspects of costs, expert and user opinions and lab evaluation of the capture rate.

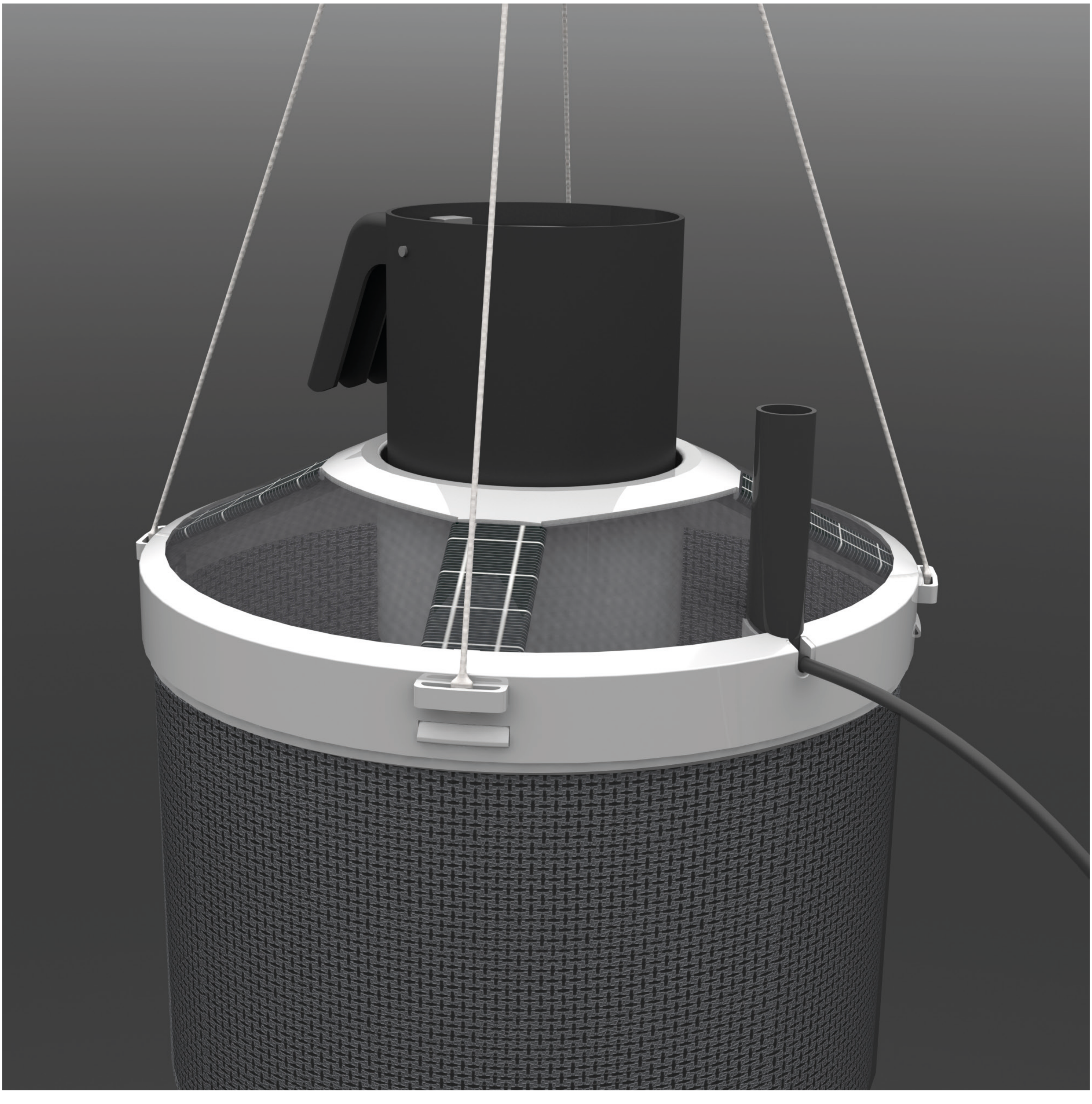
Easily removable catch container

Polyamide heating elements

Foldable container as visual clue

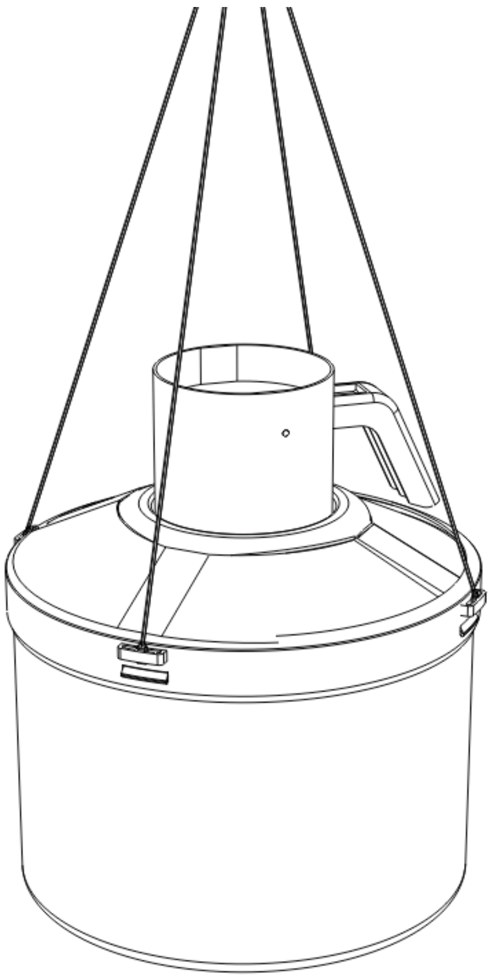


M-Tego II: Science edition. Notice the CO_2 canister that, along the not shown catch bag, differentiates it from the Performance M-Tego.



Usage

Here, the user actions and maintenance of the M-Tego II are shown and described.



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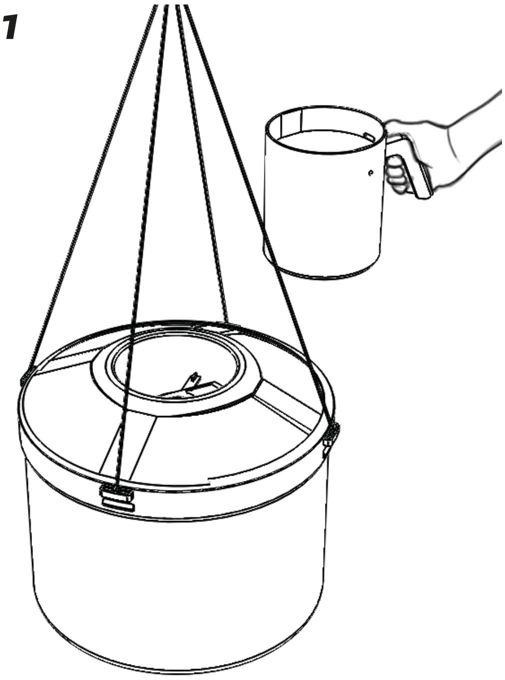
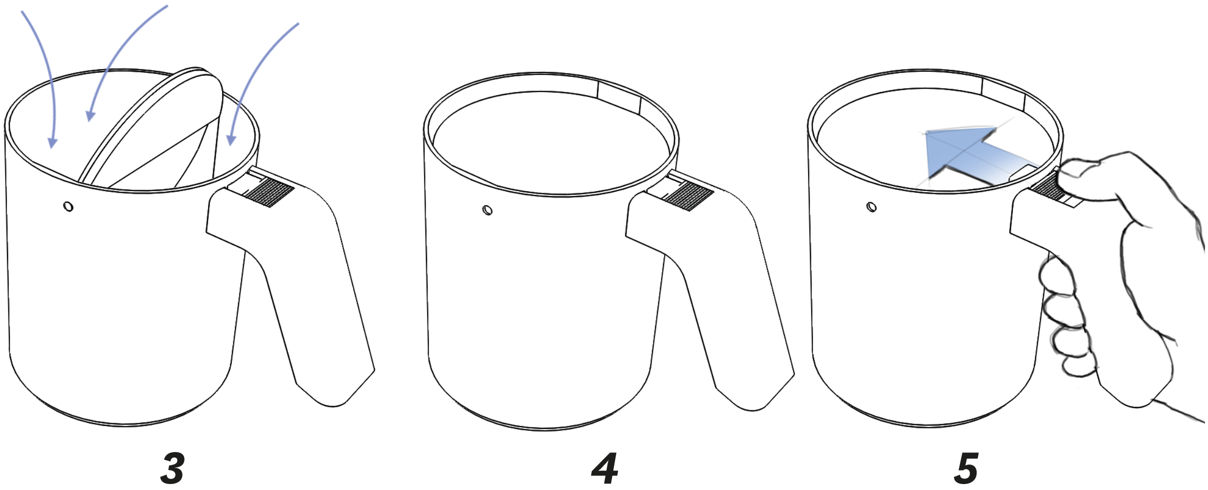


2

WEEKLY UPKEEP

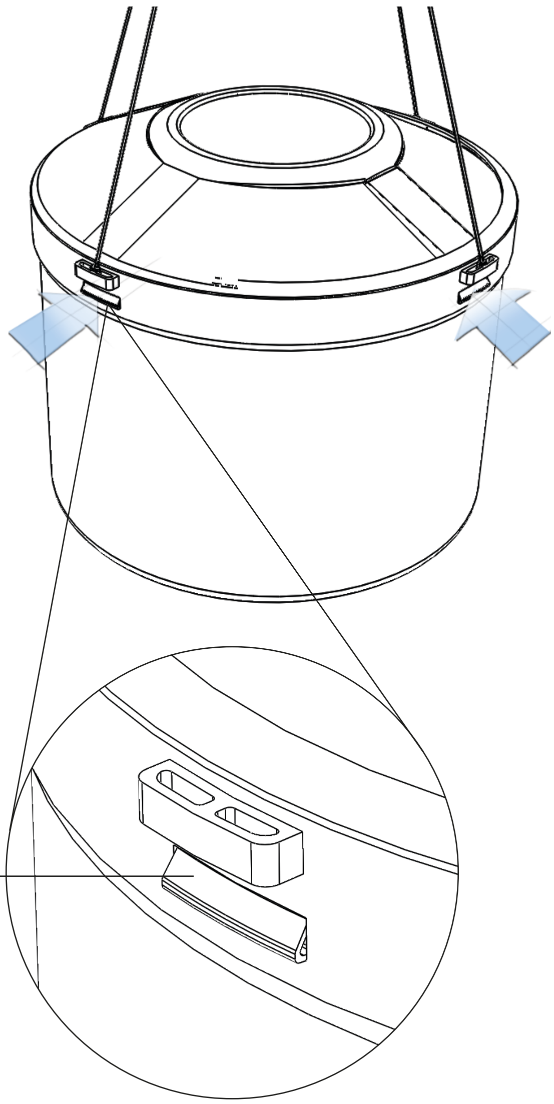
In day-to day use, the user operations are quite simple. At least once a week, the user takes out the catch container by lifting it from the canopy (1) and shakes out dead mosquitoes (2). It is advised to do this at the end of the day, when all mosquitoes inside have died. Apart from shaking out the mosquitoes, the catch container might need cleaning with water.

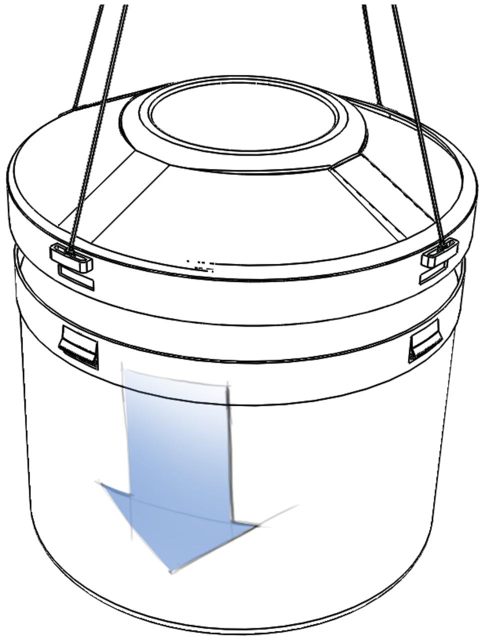
Because of the timer attached to the controller, the mosquito trap turns on and off during the night. This limits user interaction to moments of maintenance.



During operation, the fan sucks open the hatch, enabling mosquitoes to enter (3). When the fan shuts off, the hatch falls to a closed position again (4). The user can secure the hatch by sliding the lock over the hatch (5).

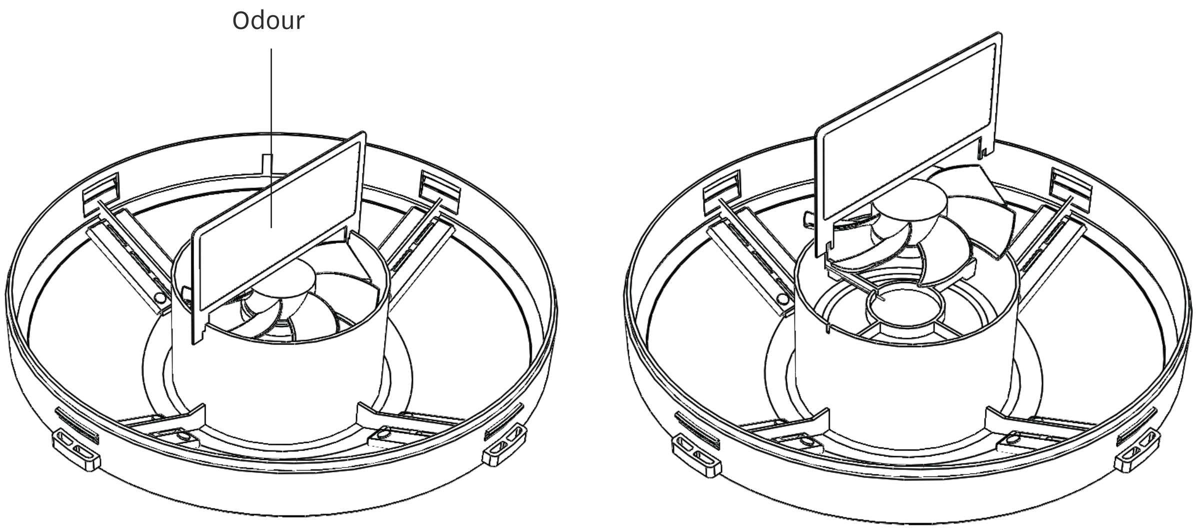
Figure 56. A rendering of M-Tego being used in an African home.





MAINTENANCE

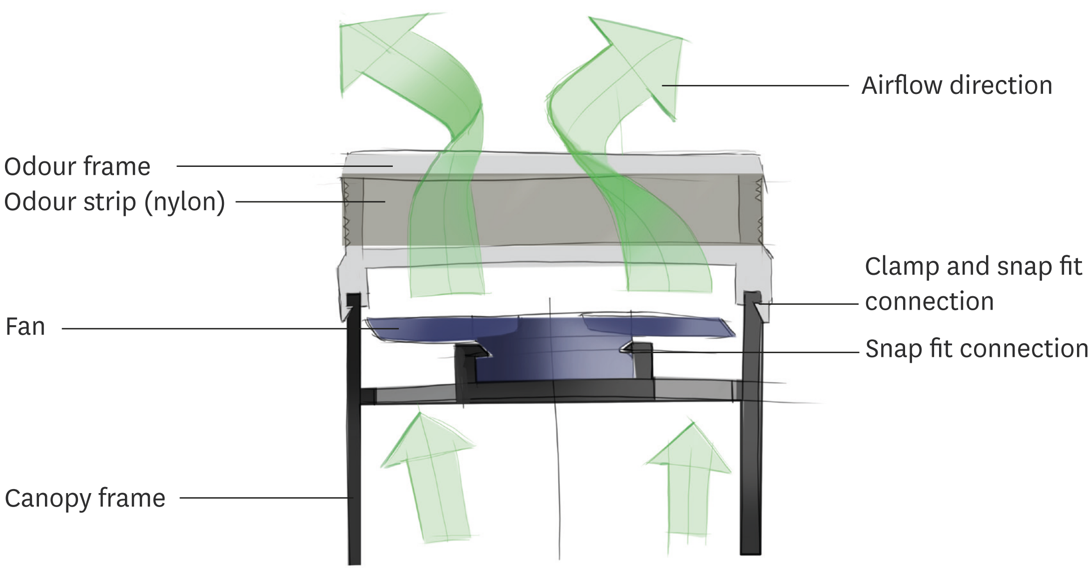
Should more intensive maintenance be required, such as replacing the fan or accessing the electronics, the tarpaulin bag can be removed by pressing the click fingers on all four sides and sliding the ‘bag holder’ down. The click fingers can be pushed in two at a time, making it doable for one person.



Once every half a year, the odour must be replaced. The odour tray, a part that the odour is wrapped around, is accessible once the catch container is removed and the canopy is flipped.

Once the tarpaulin bag is removed, a technician has access to the electronics, such as the heating elements and the fan. The fan is clicked into the canopy and can be removed with little effort. Below (figure 57) these connections can be seen in a cross-section view.

Figure 57. Cross-section of the fan, odour and lower canopy frame. Seen upside down, as in the figures on top of the page.



A schematic of the electronic circuit can be found in Appendix E.

An overview of *System electronics* is given in Appendix F.

For an overview of important design decisions, see Appendix H.

Part-by-part look

In this chapter, the design is taken apart and explored per part. For each part, the vision behind it, manufacturing processes, features and cost are given.

ELECTRONICS

The product contains various electronic parts. The specifications of the *system* (solar panel, battery and controller) were not examined in much detail and are shown in appendix F.

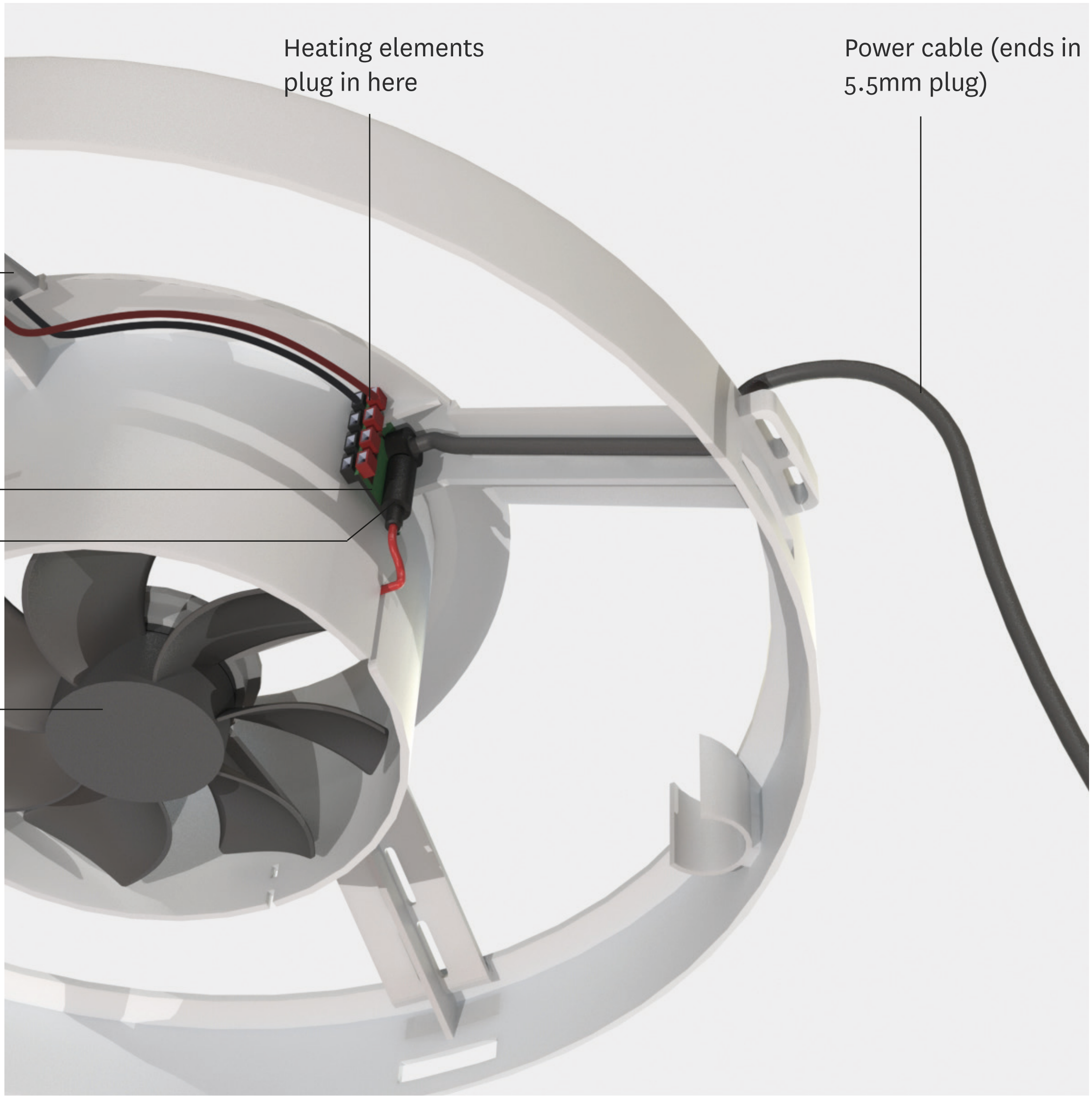


Figure 58. A view of the canopy and electronics as seen from below.

FAN

The fan sucks the mosquitoes into the inlet pipe, where it remains stuck on the bottom of the catch pot. The placement of the fan under the catch pot has many advantages, such as easier access by the user. It does however, also mean that a surplus of mosquitoes can mean reduced sucking power.

The fan has an advertised 50,000 hours of lifetime, which is 3000-5000 nights or 10-13 years. It is expected that this number is greatly exaggerated and only tested in lab scenarios. The fan also has an IP 55 waterproof class, which means that dust is unable to enter the vital parts of the fan, and that water, if projected by a jet from any direction is unable to enter vital parts. This means that a trap should be able to survive a minor rain shower.

The fan used in the M-Tego prototype consumes 3,6W of power. However, Biogents has showcased a fan that only consumes 1W of power while maintaining performance. Therefore, it can be assumed that this new fan will become available if a partnership is entered and can be used in future iterations of the M-Tego II.

Figure 59. A fan of the type JD-120. Made in China and without casing producible for around €1 each.

Figure 60. Polyamide heating element.

HEAT ELEMENTS

As explained in the ‘design strategy’ chapter, the heating elements are Polyester heating mats with a total power requirement of 5 Watts.

A search was conducted for the optimal placement of the heat elements. There were no significant capture differences found between placement of Nichrome wire on either the top of the catch container or on the canopy. A third option was explored: placing them under the fan. This might cause the entirety of the trap to heat up. This was explored in Appendix D, but found not to be the case as hoped. Since there should be no electronics on the catch container, the canopy was selected as location for the heating elements.

PCB

A small PCB was imagined as a way of connecting and removing the fan cable, power cord and heating elements wiring. The PCB design can be found in appendix E. Depending on cost of a controller with build-in timer, a chip with timer build-in might be added to the PCB.

CANOPY FRAME

The canopy is an injection-moulded polypropylene part. It is the skeleton of the entire product and has many features that support the heating elements, electronics, and mesh. The outer rim also contains the hooks for hanging the trap.

Polypropylene was selected because of its heat resistance, mould-ability and low price. On top of the canopy the aluminium mesh layer is fixed.

The canopy frame is the skeleton for the entire product. Below, the features are shown where the canopy frame connects with other parts of the trap.

Figure 61. Fixtures in the canopy frame

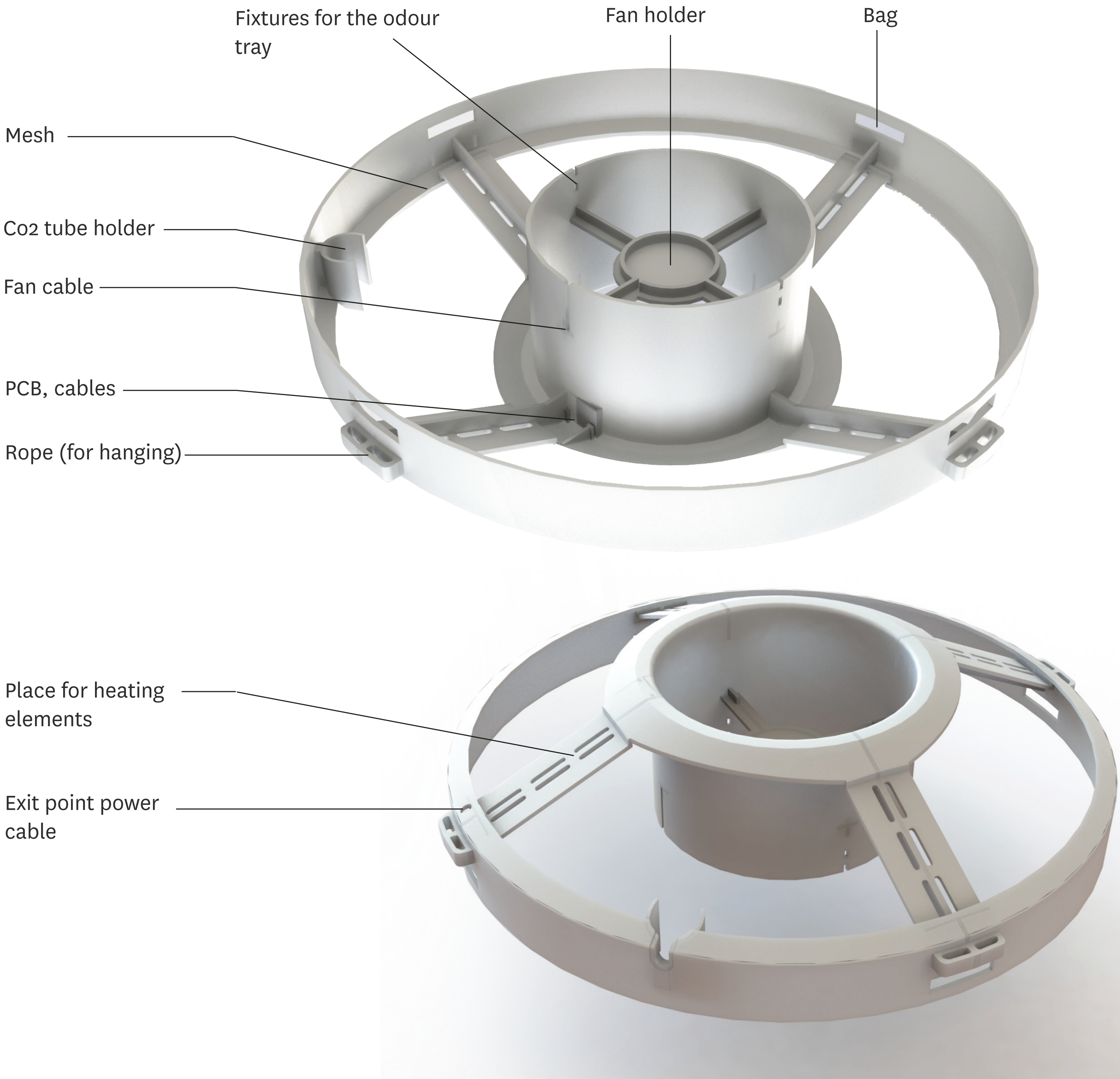
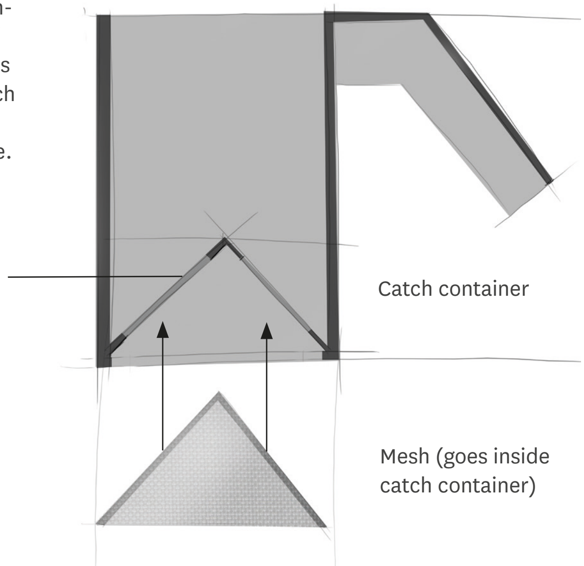


Figure 62. An exploded view of the catch container and mesh. Because of the cone-shaped features at the bottom of the catch container, the mesh is more easily fixed in place.



CATCH CONTAINER

The catch container is made from a polypropylene, with UV stabilising additives added to the raw material. In the main container, the closing hatch and slider are pressed in place. The hatch closes when the fan is off, and gets sucked open by the fan when on. It also has features for a cone-shaped mesh at the bottom (figure 62), so the airflow isn’t obstructed by caught mosquitoes as fast as would happen with a flat bottom.

The aperture of the mesh at the bottom of the catch container should be small enough that mosquitoes don’t get sucked through. This translates in around 0.2mm.

ODOUR TRAY

Figure 63. The odour tray. The nylon can be wrapped around it or hang in another way.

The odour tray is plastic frame that the odour-drenched nylon can be wrapped around. The serrated edge gives the nylon extra grip. By placing the odour directly under the fan it will be spread optimally.

It is made from sheet polypropylene for strength and cost reasons.

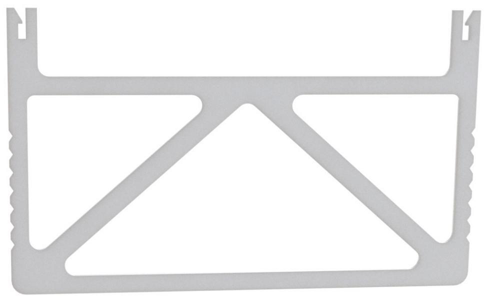


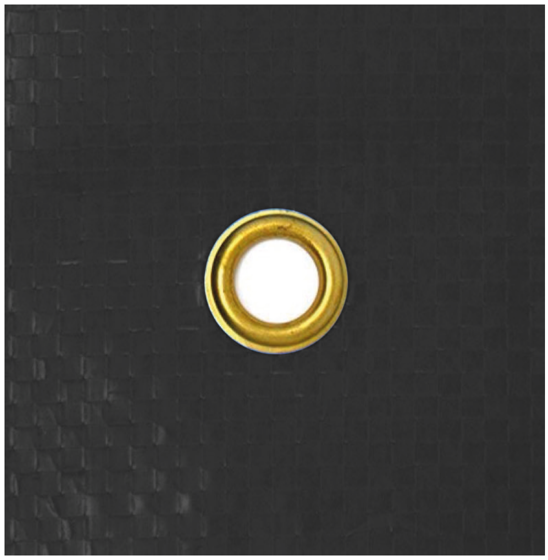
Figure 64. The tarpaulin bag in unfolded state

BAG

It is important to have a void volume under the fan to properly circulate the airflow. The bag as introduced in the M-Tego concept was kept because of its foldable properties. A bag also is a visual clue for mosquitoes while maintaining a cost-effective design.

A woven Polyethylene bag (figure 64) is attached to the canopy with a laser-cut and bend band. The material is also known as Tarpaulin. The band connects to the canopy using click fingers, which can be pushed in again when access to the canopy is required. The band is glued to the bag. The adhesive that is to be selected should have no negative effect on mosquitoes attraction, or this should fade with time as has been seen also with the usage of PVC pipe.

Figure 65. a metal eyelet insert for water evacuation.



Tarpaulin is typically made from a woven Polyethylene mesh. A 100 grams/m^2 density gives the bag enough strength, but is also lightweight.

Using a eyelet insert, water that enters the tarpaulin bag can evacuate immediately (figure 65).

Colours and contrast

Contrast plays a role in luring mosquitoes on the medium to close range. It is known that of contrast, black/white contrast plays the largest role in this process. Arguably, the transition from a grey cone in the Suna to a darker tube in the M-Tego I contributed to making this the more attractive trap. This cylinder has been kept in the final design because its benefit and cheap production and material costs. The contrast within the trap has remained equal, with a white canopy covered by a black mesh.

Figure 66. A fine mesh is required.

MESH

As can be seen in the next chapter, ‘Evaluation’, the type of mesh used influences the functionality of the trap heavily. If the mesh is too ‘closed’ the odour cannot leave the trap well enough. But if the mesh is too ‘open’, the strong airflow escaping the trap will deter approaching mosquitoes.

Aluminium was selected as the material for the mesh because of its strength, formability and recyclability. It is cheaper than steel, but more durable than polymer mesh.

Production

After consulting with people familiar with outsourcing production, it was deemed best to start production in mainland China. Parts and moulds can be produced the cheapest there, while expertise on injection moulding is limited in production facilities in sub-Saharan Africa.

While production in China is likely the cheapest on a part level, labour costs are rising due to the quickly aging population[44]. Assembly therefore, might be done best in Africa. Shipping loose parts to Africa instead of products will also lower shipping costs, since loose parts are more compact when packed together. Also, import taxes in most African countries over loose parts are lower than over completely assembled products.

44. Rapoza, K. (2017, Februari) Forbes. China’s Aging Population Becoming More Of A Problem.

45. Custompartnet.com

46. Tempelman, E., Ninaber van Eyben, B. and Shercliff, H. (2014). Manufacturing and Design. 1st ed. Delft: Butterworth-Heinemann.

Cost price calculation

The results of the cost calculation can be seen in figures 67 and 68. For a full overview, see Appendix I: Cost price calculation

The total manufacturing cost of the 'standard' M-Tego II in a series of 100,000 units is approximately €6,32, and €6,99 for the science edition. In a series of 40,000, these costs are €7,62 and €8,45, respectively. In these overviews, the larger series 'Science edition' is used.

The costs for this product are determined by a number of factors. The materials, processing, moulds, assembly, and off-the shelf parts all contribute to total costs. As can be seen in figure 67, the costs for the fan and heating elements, which are off-the-shelf (OTS) parts are around one third of the total costs.

While mould costs for the injection moulded parts reach €87,000, the cost per part drops exponentially as production series increase in size. The costs of the moulds was calculated using tools available at Custompartnet[45] and literature examples[46].

In figure 68, the costs are divided by part. The canopy and catch containers, utilising large moulds and injection moulding, are in the top 4 of expensive parts, along with the fan and heating elements.

Figure 67. The most significant manufacturing costs divided by process step. OTS parts take up a significant one-third part of these costs, since they include the pricey heating elements and fan.

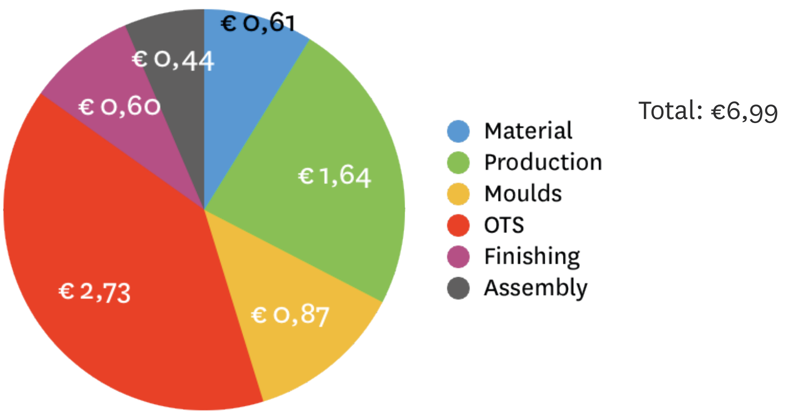
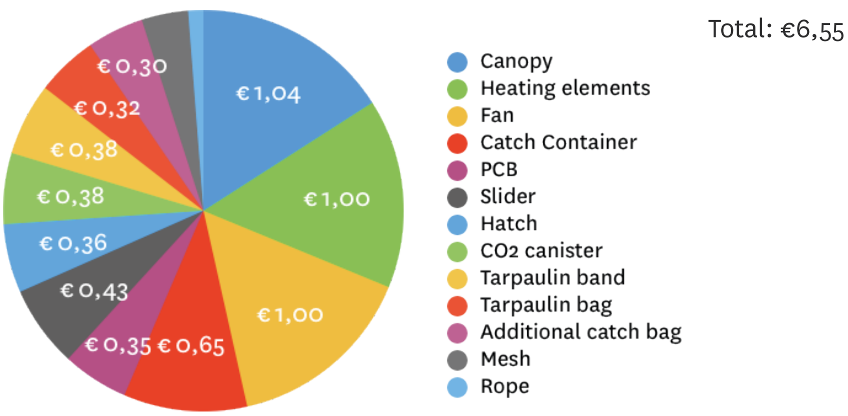


Figure 68. The manufacturing, material, mould and finishing cost per part.



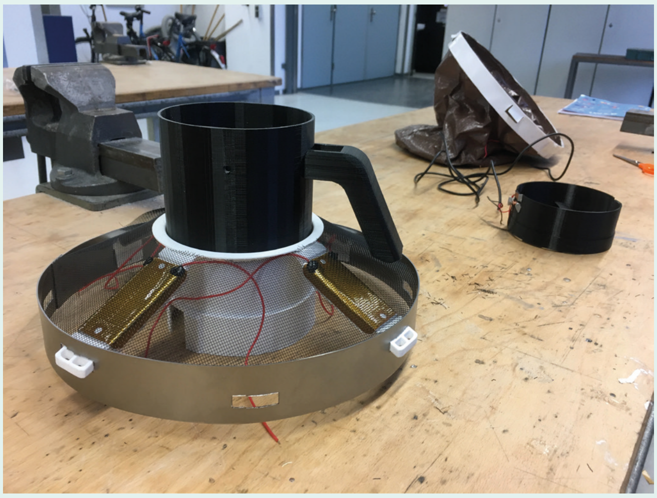
Evaluation

Prototype construction

A prototype was constructed for lab testing and expert validation. The goal was to make the prototype look as much as possible like the finished concept and test added features.

Figure 69 and 70. Prototype construction.

Bottom: final 'visual' prototype



Lab testing

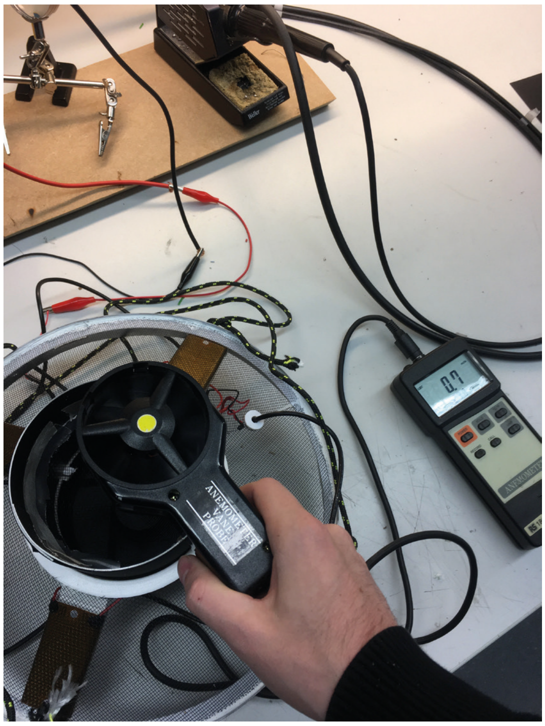


Figure 71. re-configuring and measuring air speeds around the inlet of the prototype.

Dual-choice lab experiments were conducted in Wageningen mosquito lab (figure 72) to test the performance of the trap compared to the Suna trap. The comparison to the Suna trap is fitting because all previous traps have been compared to the Suna as well: it is the benchmark.

Initial tests were partly successful; the M-Tego II prototype caught mosquitoes. However, it caught around 30% less mosquitoes than the Suna trap. It was thought that decreased airflow was the cause. It turned out that the Suna had an airflow of around 3.7 m/s at the inlet, while the M-Tego II, due to odour positioning and catch container, was at around 2.2 m/s.

Second prototype
Adjustments to the prototype were made (figure 71), which resulted in an increased average airflow of 3.4 m/s again. However, overall performance in lab tests decreased. It was hypothesised this was due to the materials used and in particular the glues and silicone putty.

Third prototype
The third prototype was constructed using no glues or silicone kit. When a layer of denser mesh was added, the trap performed about 2.5-3X better than the Suna. It is hypothesised that the air exiting the canopy was going too fast through the porous metal mesh, scaring mosquitoes. The polymer mesh that was used before in the M-Tego I is less porous, decreasing this effect. It was used in a third iteration. While a 2.5-3X performance is a good increase, it is not at the level of the M-Tego I at its 4.9X increase.

The 2.5X increase in performance translates into 7.3X the performance per € for just the trap, or about 5X the performance per € for the entire system.

Estimated 2.5-3X times the performance of the Suna

7.3X the performance per € compared to the Suna.

It is expected that with further enhancements, it is possible to reach a 4X increase once again. Mosquito activity was low during these tests, due to the cold weather in the testing period.

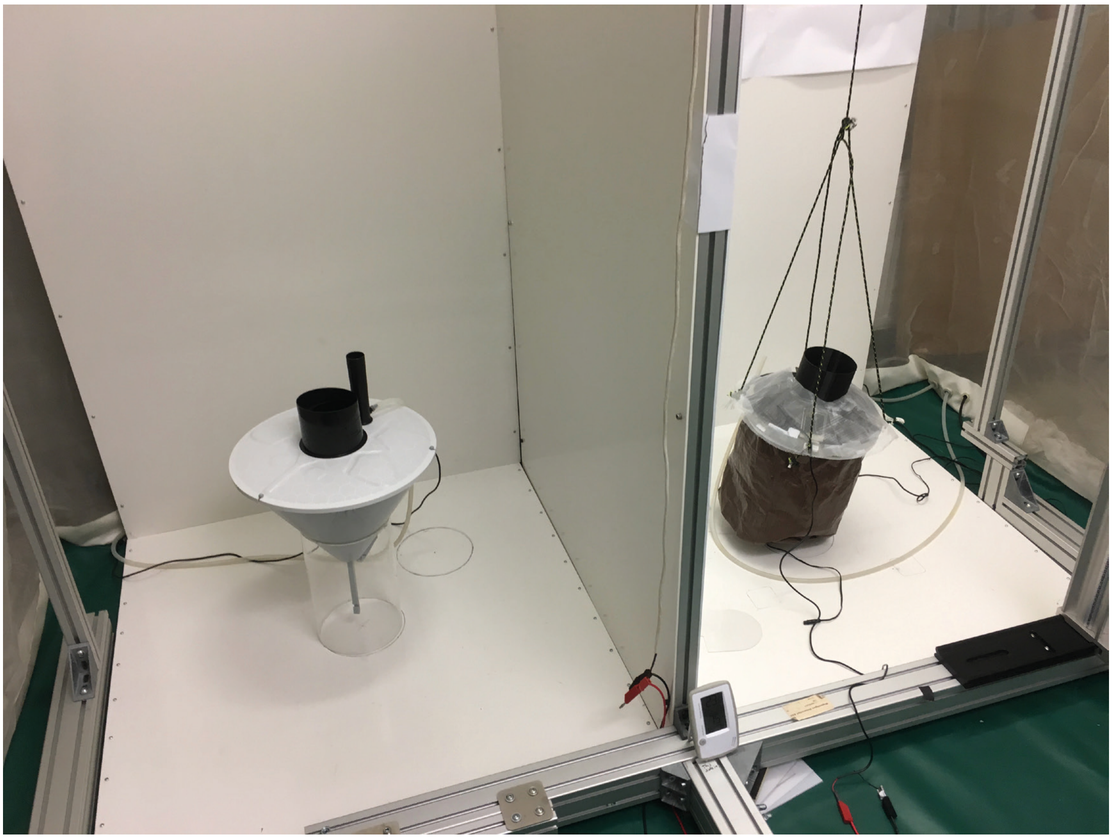


Figure 72. Dual-choice lab experiments were randomised and executed at the WUR climate room.

Dual-choice lab testing details:

Number of replicates	*5*
Number of successful replicates:	*4*
Average temperature:	*23.6° C*
Average humidity:	*73.5%*
Mosquito species:	*An. gambiae*
s.s.	
Mosquitoes released per replicate:	*50*
Total mosquitoes released:	*200*
Total mosquitoes captured:	*42*
M-Tego II:	*30*
Suna:	*12*

Expert opinions

A brochure, comparable to the 'executive summary' at the beginning of this thesis, was send to several people involved with mass trapping to ask about their opinion on the following three subjects:

- Is the feature set relevant and satisfying?
- Is the design up to the task? Will it survive in Africa?
- Is the pricing attractive for 'what you get'

Alexandra Hiscox, PhD

Sander Koenraadt, PhD

Alexandra Hiscox, PhD is a medical entomologist specialising in mosquito biology and novel malaria control interventions. She was one of the principal scientists behind the Rusinga island project. She mentioned that the catch container and small design look very convenient, but desired the ability of using the trap upside down, citing sampling of different mosquito species as reason. Other mosquito species, such as *An. arabiensis*, might react better to a hanging trap. The pricing and convenience seemed to make it an attractive trap. The combination of design and so far gathered proof came across as valid and trustworthy as well.

"Overall, you've sold me on the M-Tego trap. Where can I place my order?!"

Sander Koenraadt, PhD is a researcher at WUR and specialised in insect-transmitted pathogens and (biological) vector control.

"When I look at the design, it looks generally rigid and I trust it can be used under African conditions. The price-quality ratio looks excellent, because of the addition of heat in this trap, a higher effectiveness is reached."

He did note that the electricity usage is higher, which leads to higher overall costs. In the brochure, ***trap*** prices are compared, not system prices. When the electricity system is taken into account as well, the M-Tego is 5.3X more cost efficient than the Suna, compared to 9.6X when only the trap is looked at.

Fredros Okumu, PhD

Fredros Okumu, PhD is the director of science at the Ifakara Health Institute in Tanzania. He is also Co-Chair of the WHO Vector Control Working Group on New Tools for Malaria Vector Control.

He remarked the most important thing is now to do multiple field studies, underlining the importance of further research.

"I love it. This is great and we will be happy to provide any further support"

Trap cost-effectiveness

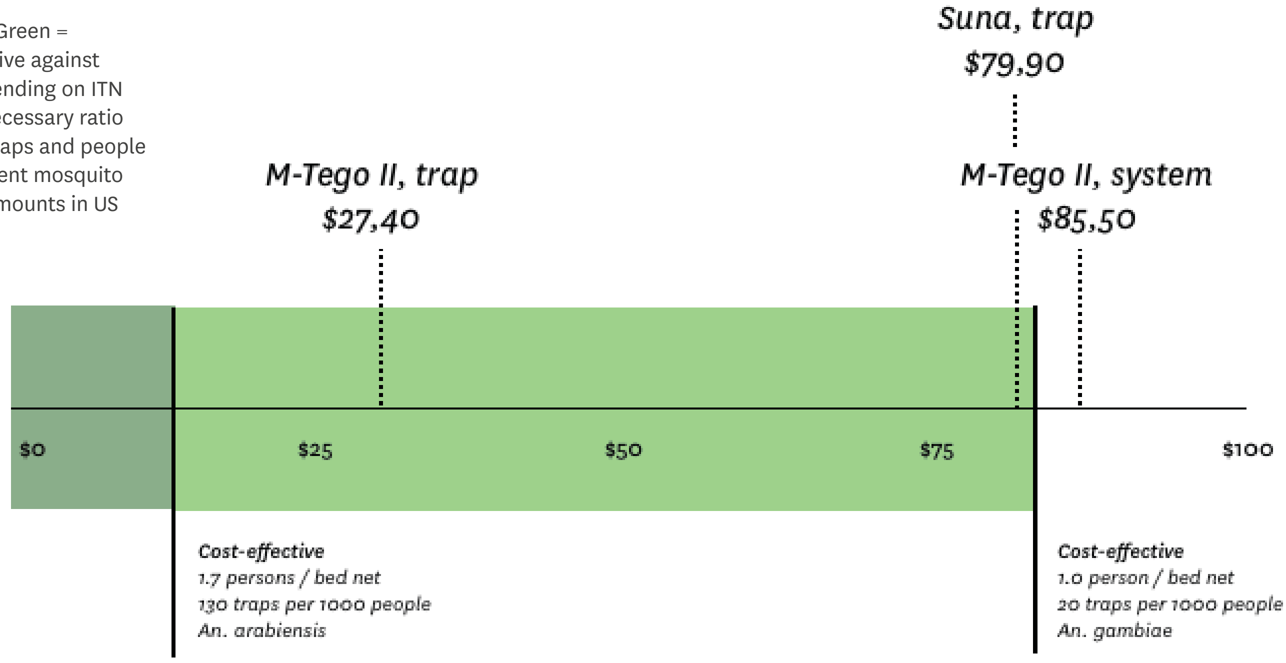
Okumu et al calculated that in order for mosquito traps to compete against ITN deployment, the traps should cost no more than $4,25 to $27,61 per annum, depending on the mosquito species and ITN usage.

Assuming a trap lifespan of three years, the projected maximum cost of a trap will be between $12,75 and $82,83. When looking at a M-Tego II, a complete system including solar panel comes at a price of $85,50. This falls just outside this spectrum, but is a major leap towards making odour-based traps cost effective in comparison to ITNs (figure 73).

However, if this model takes the Suna (a 3X less effective trap) as point of reference, the maximum cost at which a M-Tego will be cost-effective versus a bed net will be higher.

Another point of consideration is that the electricity supply costs are more than half the system costs. If the trap is taken to a system where electricity is already in place, the trap falls around the middle of the spectrum.

Figure 73. Green = cost-effective against ITN's, depending on ITN use, the necessary ratio between traps and people and prevalent mosquito species. Amounts in US dollars



Business model

It is proposed that soon, a company is founded. The aim of this company should be to design the traps, outsource manufacturing, and sell the traps. In this chapter a proposal is made for a sustainable business strategy, based on sales of a second product to the western market, and partnerships. The mission of the company should be to introduce as many traps to communities where malaria is prevalent.

The goals of the proposed company are:

- Design, and outsource production of, a cost-effective trap
- Sell the trap to research institutions, governments and NGOs
- Work together with partners on distribution and end-of-life
- Be self-sustainable and independent of malaria funding

47. Nielsen (2015). The sustainability imperative.

IP AND BIOGENTS

The original Suna trap was designed and build by a German company called Biogents. They have a long reputation of researching and building expensive traps that are suitable for surveillance and research, but not for long-term usage in malaria eradication projects. Therefore, Biogents might not be a suitable product owner of the design of a cost-efficient trap.

Biogents holds several patents that might be infringed by the concept of M-Tego and consequently, M-Tego II. This makes market introduction of science-based traps difficult, as it may induce legal action. The market for IVM project-based traps is less controlled and may be more easily entered without potential retribution.

Ideally, a mutually beneficial partnership is entered. An agreement where Biogents invests their patents and possibly, resources, in return for a share of the startup.

Securing revenue

Malaria projects are limited in scope and effect, and highly depending on donor funding. Malaria eradication funding quickly stopped in the 60s: donors quit programs, governments shifted their priorities. It disappeared from the international agenda for four decades! It is therefore risky to suspend a products business model exclusively on donors funding IVM projects. There are opportunities for a more robust business model, with revenue streams not depending on politically inspired agendas. In a new business model, it also might become possible to distribute the trap while bypassing governments and NGOs.

There are ways of getting a product or service to a BoP market without cost for the end user. For example brands like Lifestraw, who donate modified editions of their products to BoP markets. Other companies, like Dopper, the bottle brand, donates 5% of their revenue to clean water initiatives (figure 74).

It is not a coincidence that these brands are emerging worldwide. A 2015 Nielsen study[47] found that 66% of global consumers are willing to pay more for a product or service if their values align with their own, up from 50% in 2013. Millennials and generation Z (those born after 2000) in particular are more willing to spend money on products if they support a sustainable cause.

Figure 74. Three main philanthropical business models. Note that these *companies also focus deeply on environmental sustainability, a factor that appeals to consumers.

Sells	Donates	Examples
Product A	Money to projects	Dopper*
Product A	Product A	Lifestraw, Waka Waka*, Warby Parker
Product A	Product B	Waka Waka, Biolite*

Figure 75. The Xiaomi mosquito repellent. It retails for around $16 with the promise of 90 days mosquito repellent functioning.

48. marketwatch (2018) Mosquito Repellent Market Global Industry Analysis 2018 - 2025

DEMAND IN WESTERN COUNTRIES

Because a business sustained through (indirect) donations is unstable, some companies depend on sales in western countries for distribution of their products in Africa. Western consumers are more likely to spend money on non-essential goods. Another consideration is that people in western countries already spend money on mosquito-prevention means, like repellent, candles and electronic devices (figure 75) dedicated to keeping mosquitoes away.

Amazon.com sells multiple 'mosquito repellent devices', including lanterns, traps, repellents and ultrasonic devices. Common prices range between $17 and $25, with some outliers at $13 for one ultrasonic device and towards $50 for traps aimed at the hospitality industry (figure 76). The mosquito repellent market is expected to grow world-wide 7.7% to 4.8 billion USD[46]. Contributed factors are quoted as rising global temperatures, demand for natural products at a higher price point, and increased awareness. Especially in the western market, high-end natural solutions are growing in popularity.

Given the success of Dopper and similar companies, a company known for social and environmental sustainability might sell their product with a large margin. The basic Dopper sells for €12,50, while a similar water bottle might sell for under €2 at a discount store like Action. A mosquito trap or repellent device, sold by a recognised brand that is known for social and environmental sustainability, might sell for over €30. Given the good cause of malaria control combined with the annoyance of mosquitoes to everyone else, the marketing case for a product like this is strong. There are no companies known to advertise a mosquito repellent or trap in order to give away traps either, so it is a fresh perspective on this market.

Given the difference in demands from the western market and the needs of the African population, a 'buy A, give B' approach will fulfil the needs of most people in both markets. (figure 74). This thesis will not go further into the design of product A, but does recommend the following;

- Create a brand that is transparent in

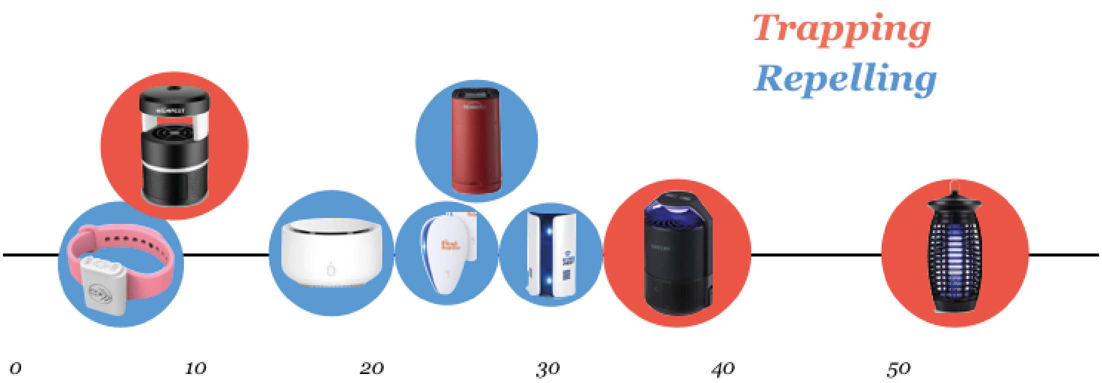


Figure 76. Products on the western market
Product B properties

49. O. Onwujekwe et al: Hypothetical and actual willing- ness to pay for insecticide-treated nets in five Nigerian communities

50. Kramer, K., Mandike, R., Nathan, R., Mohamed, A., Lynch, M., Brown, N., ... & Lengeler, C. (2017). Effectiveness and equity of the Tanzania National Voucher Scheme for mosquito nets over 10 years of implementation.

its vision of social and environmental responsibility

- Tailor product A to the western market and mosquitoes
- Create a product that is highly desirable in terms of aesthetic, but slightly overpriced
- Sell the product in high-end stores and gift shops
- Do storytelling and tell the story of a feel-good product that helps improve many lives. Do not scare people into giving money by showing stereotypical imagery of poor African communities, instead create a win-win situation in which the western market, African communities (and the company) all benefit.

Sales on the African market

First of all, it should be noted that sales on the local, African market is unlikely to result in a similar result as that on Rusinga Island (or better) because trapping only affects mosquito populations when enough traps are present. Sales have a strong individualistic character and are therefore not the best way of delivering mass trapping to the African market. Secondly, selling the trap on the free market would reach those who traditionally, do not suffer from malaria as much as the extremely poor, meaning that the measure does not reach those who need it most.

Costs for the resident: impossible or realistic?

There is a gap between user needs and demands. The user needs of malaria prevention and not 'having mosquitoes around' does not translate into a demand for traps. Selling the trap to inhabitants of rural Africa therefore, is unlikely to be successful, even when subsidised. For the user, other products and services have a greater priority. Some of the products and services that people in sub-Saharan Africa are prone to buy, are electricity, phone services, house improvements and entertainment such as radio and television. In the future, when these needs are met, maybe mosquito trapping will become more of a priority. However, since there are other products on the market that fill that need, it is again unlikely that people would prefer trapping over netting or killing them directly with an electronic zapper.

The WHO has had 'spirited debates' about the question if ITNs should be sold or given away to people in sub-Saharan Africa. There are conflicting papers about the influence of price point on user demand in emerging markets: while putting a price tag on a malaria protection tool might deter some interested people, the people that do buy their ITNs, tend to use them better, more effectively, and longer than those who get them for free[49]. The WHO and several other organisations and studies recommend giving away ITNs and other malaria tools for free[50].

However, bednets are also sold on the local markets and a sales model might work for the higher-end of the market if the benefits are clear enough to the end user, electricity is cheap enough, and former primary needs are filled.

Company projects

As a showcase of how traps contribute to a healthier planet and as a showcase of being a social enterprise, it would be recommended to start 'company projects' in which traps are deployed in selected malaria-ridden communities in SSA. Not only would it benefit the image of the company (beneficial for B2B and especially B2C sales) but it could also serve as a location for research into the social impact of mosquito traps, and an constant product evaluation lab.

Future Implementation

The lifetime of a product is the (often limited) time a product is manufactured, sold, improved, marketed and used. The lifetime of the home telephone is nearing its end, that of the telegraph has long gone by, and the smartphone is perhaps at the peak of its lifetime.

The lifetime of the M-Tego in use as vector controller, in the greater scheme of things, is likely brief. At one point in time, when malaria is eradicated, this trap will be a gimmick, a gadget for homeowners annoyed by harmless mosquitoes. Next to that, it might still be used for research purposes.

Up to that time, there are four phases in the lifetime of this product, as discussed in the chapter ‘application’. They are visualised in figure 77 (an overview of when they will be active and how many units they require).

In this chapter, a closer look is given to the future implementation of the M-Tego.

UNIT VOLUME

In the chapter 'applications' a look is taken at the future implementation of mosquito traps. An overview of these three applications (research projects, general research, and malaria projects) can be found in figure 53 on page 76.

In the chapter 'business model' a fourth kind of application is introduced, those are the proposed 'company projects' run by the company itself.

Looking ahead to these future types of implementations, estimates can be made about how many units will be on the market at any given time. These are visualised in figure 77. While initial research projects compromise a first batch of several tens of thousands of required units, the real market is behind that moment, when the WHO approves usage of mosquito traps for malaria control programmes. From this moment, potential millions of mosquito traps might be deployed in Africa.

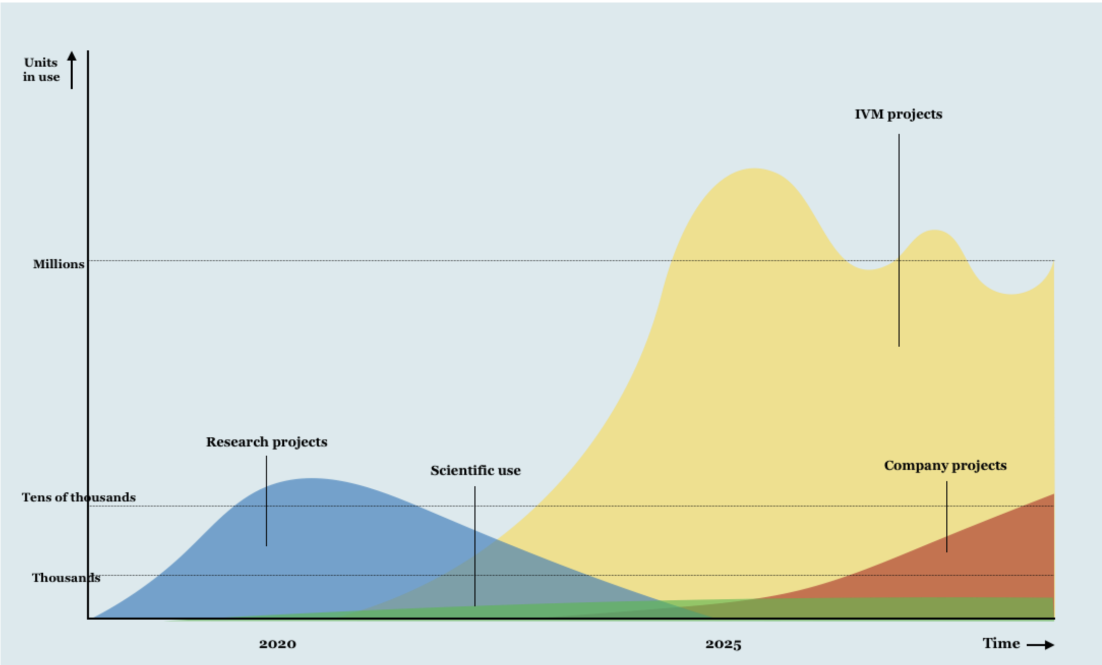


Figure 77. Projection of mosquito trap deployment over different phases.

Distribution and repair system

'The last mile' is a common term for the distance between a last distribution centre and the households that are attempted to reach. In rural Africa, this distance is often large and difficult to cross using standard models for distribution. This distribution doesn't happens only once: 3-6 months after initial distribution, the odour bait for the trap loses its odour and has to be replaced. Although the odour strips are theoretically small enough to be mailed by post, a mailing system is not yet fully in place and reliable.

Next to distribution, a repair system requires the same level of local presence and trust. The network needs to be widespread (preferably multi-national) and in place for at least two years after the end of the project.

In order to cross this last mile, the following demands are important:

- build local networks
- gain trust among local population
- have an effective system for distribution
- have an effective and efficient system for repairs and maintenance

All these points will cost a lot of energy and time to build; trust is not build in one day and employment of local installation and maintenance crews will cost a lot of resources and time. It is therefore better to use an existing network in its place.

POTENTIAL PARTNERS

As reviewed before, these are the demands that a partner must meet:

- Long-term repair system (and storage point of spare parts)
- Distribution
- Potential future business models (e.g. with the partner acting as a channel for traps)

Next to that, for a partnership to succeed, at least the following aspects have to be considered.

The partner needs to be trustworthy, of both the local population and the company. It should be free of corruption and scandals. It should have the channels for distribution, preferably multi-national. At the same time, it is preferred that local people are employed, who have the technical insight to repair traps where necessary.

All of these points are to ensure that the local population trusts and understands the local distribution and repair system. At the same time, an international network is preferred; the less partners will have to get involved the better.

The following potential partners were identified:

- Governments
- Several NGO's
- Micro-Solar companies (MSC) as introduced in chapter 'Background'.

In figure 75 an overview is given of three potential classes of partners. As can be seen, the MSC are the only potential partner in place that can deal with the complexity of distribution and maintenance of traps in the bigger part of sub-Saharan Africa.

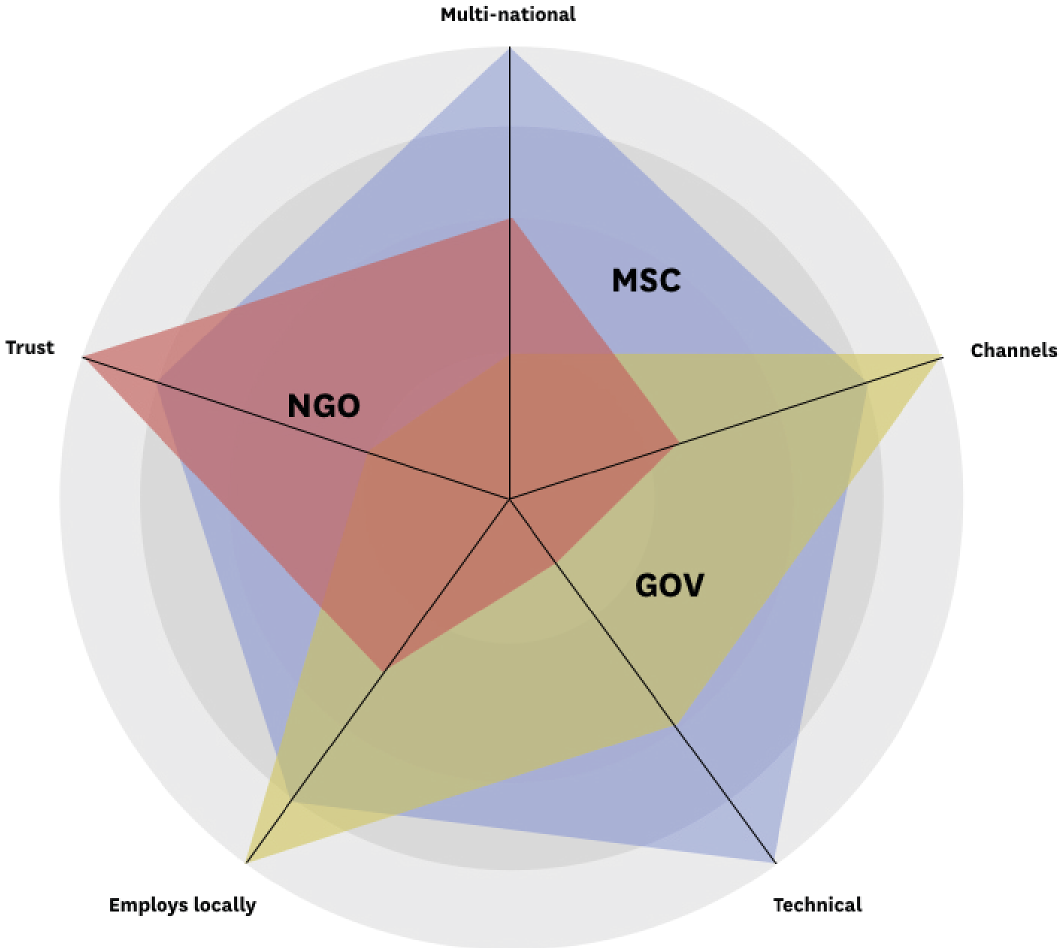


Figure 74. Visual comparison of potential partnerships based on requirements.

Type	GOVERNMENT	NGO	MSC
Countries active	1	2-5	10-60
Channels	Yes	Limited	Network of retailers
Trust	No	Yes	Yes
Employs locally	Yes	Partly	Yes
Technical insight	No	No	Yes
Additional benefits	Might also be buyer of systems	Might also be buyer of systems	Seller of energy components for system, remote monitoring

Figure 75. Comparison of potential partnerships based on requirements.

Partnerships with Micro-Solar companies

Because Micro-solar companies have all the networks in place they are a viable partner for distribution and repairs. They also provide the system elements that are required for trap functioning; the solar panel, controller, and battery.

When the benefit of the trap has been proven, the startup could reach out to these micro-grid solar companies and convince them of the benefit of combining the future trap market in their product-service system.

SKETCH OF A DEAL

In any project, a buyer, such as a government or NGO, will approach the *company* with a project summary. Based on the summary, the *company* will offer the services of the MSC as optional, but much recommended. Following the purchase of the traps the buyer and MSC can discuss distribution of the systems. If a buyer accepts the additional products (solar panels, controllers and batteries) and services (installation, maintenance, storage of spare parts) of the MSC, those parties can further discuss details and pricing based on system needs and geographical challenges. If the buyer of the traps does not want the products and services of the MSC, that party will have to make system arrangements themselves.

A package deal will be beneficial to all parties, since:

- It outsources troublesome distribution to a party familiar with the local market
- It introduces new customers to the MSC products and services
- It greatly aids longer lifetime of the traps

Preference is given to the rollout of traps in confined areas and entire communities at once since this will maximise the effect on mosquito population reduction. This is why individual sales by a MSC may be possible in the future, but not preferred.

ADDITIONAL BENEFITS

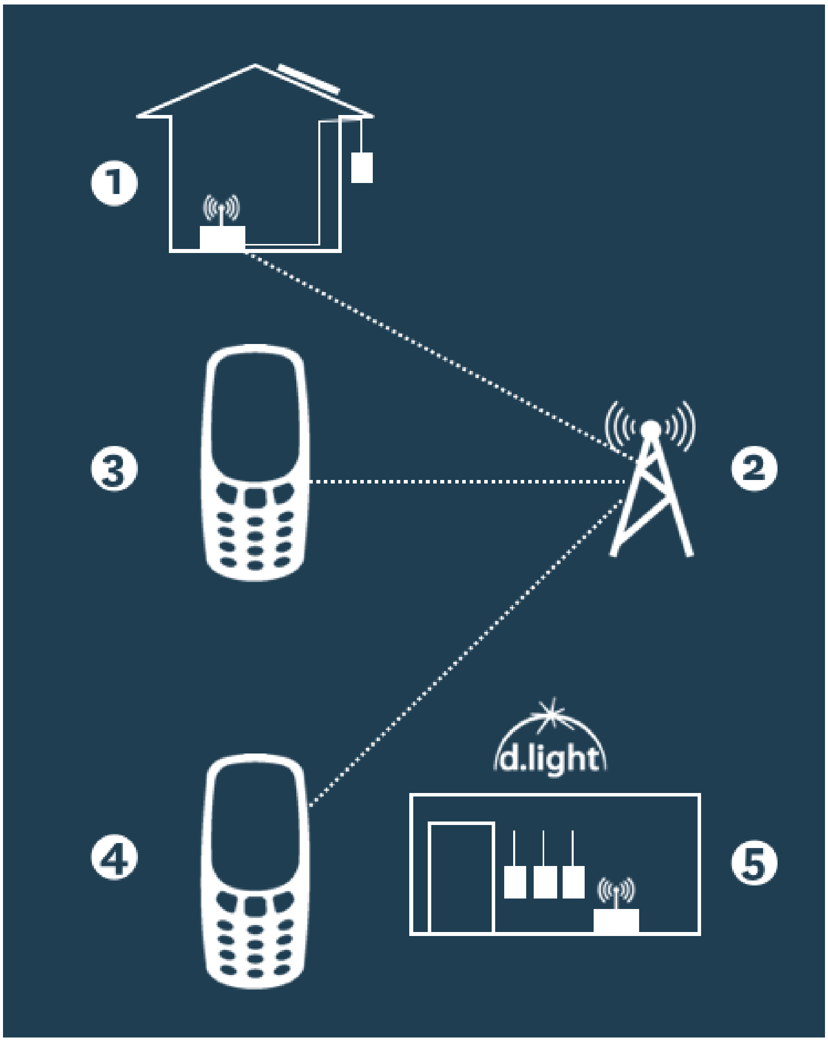
Remote troubleshooting
Next to distribution of just the trap, collaborating with an MSC will also mean using the solar systems some of them have been developing for years. Using their expertise will mean a leap ahead of re-inventing the solar wheel.

Currently, some of the systems designed by MSCs feature an sms-text system, that allows remote, over-the-air switching off or on electricity, if for example the inhabitant hasn’t paid the electricity bill. A similar system could be applied for remote monitoring over a cellular (2G) network.

If the system controller (1) notices that the trap isn’t connected or functioning properly, a text could be send to the user notifying them of the breakage and prompting them to make an appointment with the MSC for further inspection or repair (2, 3). If then nothing changes, the MSC can be notified (4), prompting a technician to be send to the household. The MSC retail channel (5) could serve as a storage for spare parts in an area where many traps are installed.

Circular economy
A MSC as local partner also means collection of broken M-Tego’s is possible, and they all end up in the same place. This makes a circular economy (re-use of materials) possible and profitable. A user can quickly be provided with a new trap, and usable parts can be mined from broken M-Tego’s.

Figure 76. Troubleshooting through an MSC network prevents unnoticed or long-term broken traps.



Vision of an integrated system

There is one more thing that a MSC partnership can be beneficial to. If the partnerships proves to be beneficial to both parties and there is enough prospect for future growth, it can be considered to integrate technology from both companies. Together, the controller, battery/solar system can be redesigned to better meet the needs of the M-Tego. This is a vision for future partnership in development, not a proposal.

PITFALLS OF SEPARATED SMOT FUNCTIONALITY

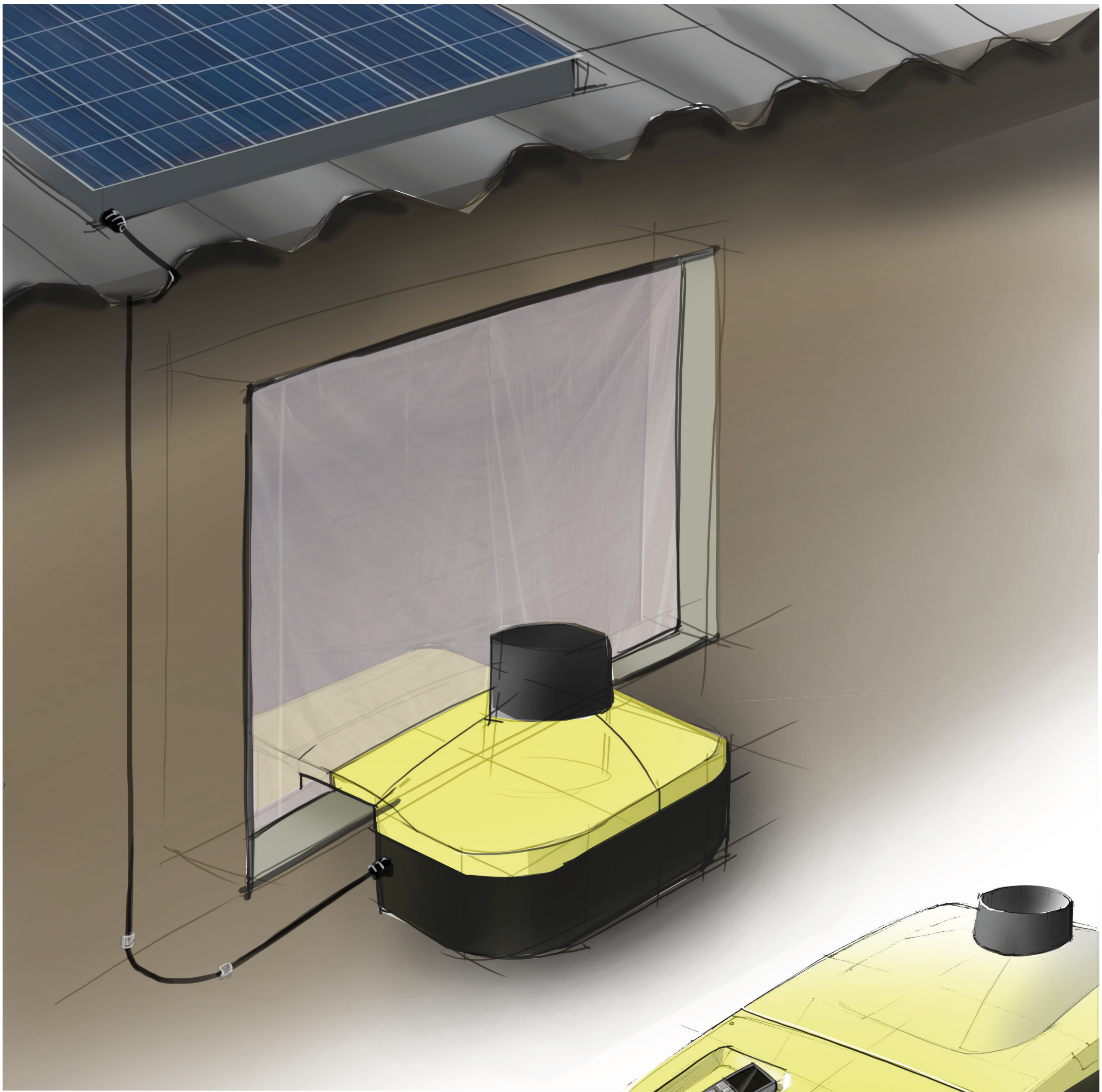
Modular design is a wonderful thing if applied in the right products, like Lego. But image there is one Lego brick that is able to eradicate malaria, and it lies dusty under your bed somewhere while you play with the other bricks... Likewise, it is not a desired effect that the mosquito trap, being one brick, is not maintained while the other features, like the lights and phone charging, are well-liked, well-maintained and well-used. In the chapter 'applications' we've seen that the willingness to maintain anti-malaria products is greatly depending on awareness and proper education.

To prevent users from seeing the trap as 'just a part' of their newly gained electrical system, it could be considered to integrate the trap, battery and solar controller into one product, therefore making the lights and USB charging 'dependent' of the trap and vice versa. By bringing the trap in close physical proximity to these features, it gains more attention from the users.

INTEGRATION OF THE SYSTEM

"Imagine every time you charge your phone, or switch on a light, there you see something, or hear something that reminds you of the mosquito trap, humming softly in the background"

This is a vision for a future trap where functionality with the Micro-Solar company is integrated in such as way, that service and different products offerings blend into one.



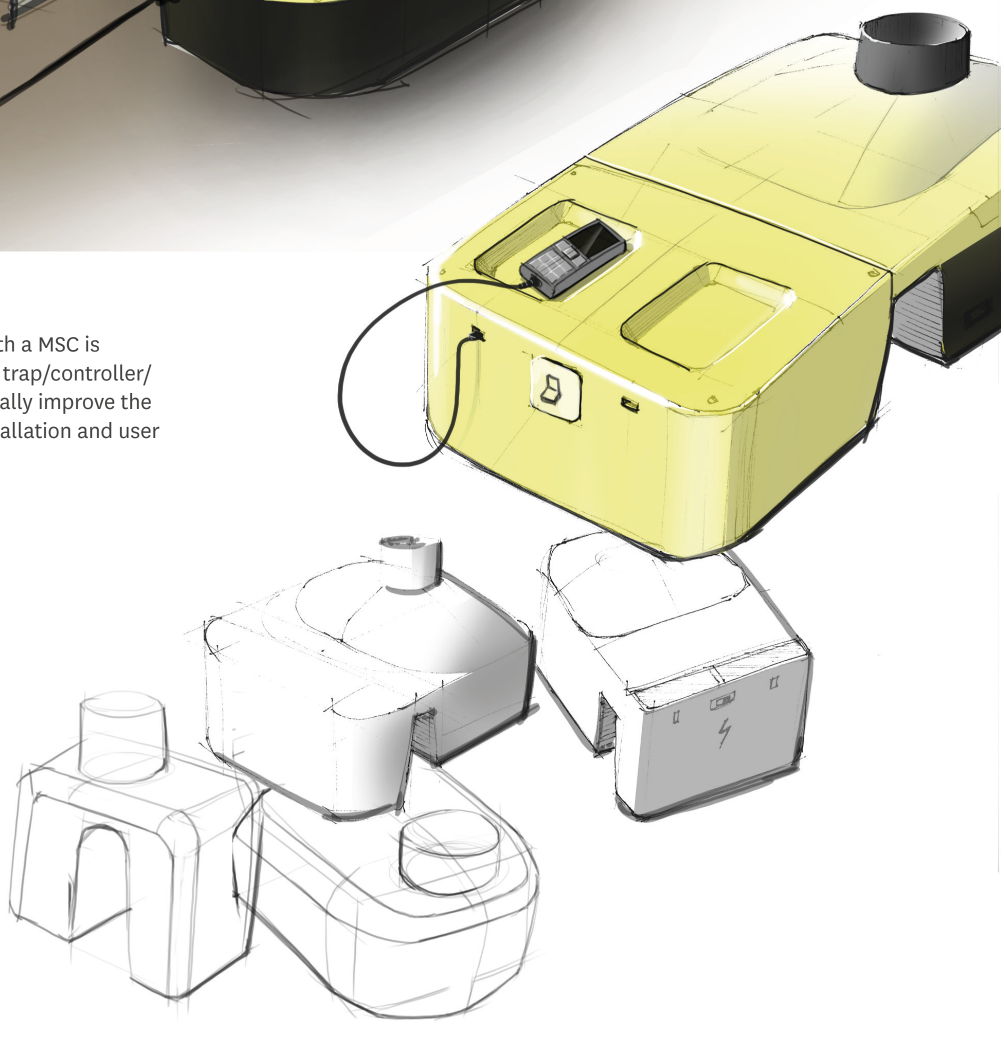


Figure 77. If collaboration with a MSC is taken further, a co-designed trap/controller/battery system could drastically improve the user experience, ease of installation and user connection to the trap.

Concluding

A LOOK AT THE FULL IMPLEMENTATION MODEL (FIGURE 78)

Chapter 'Business model', p. 98

The company (startup) will be central in all future undertakings where mass trapping is involved. First, by sales to field trials (in the period 2020-2022), later through IVM and other malaria projects and company projects: depending on demand and the WHO approval process.

Chapter 'Future implementation', p. 102

A MSC company or an alliance of these companies will be responsible for handling repairs, returns and distribution on a local scale.

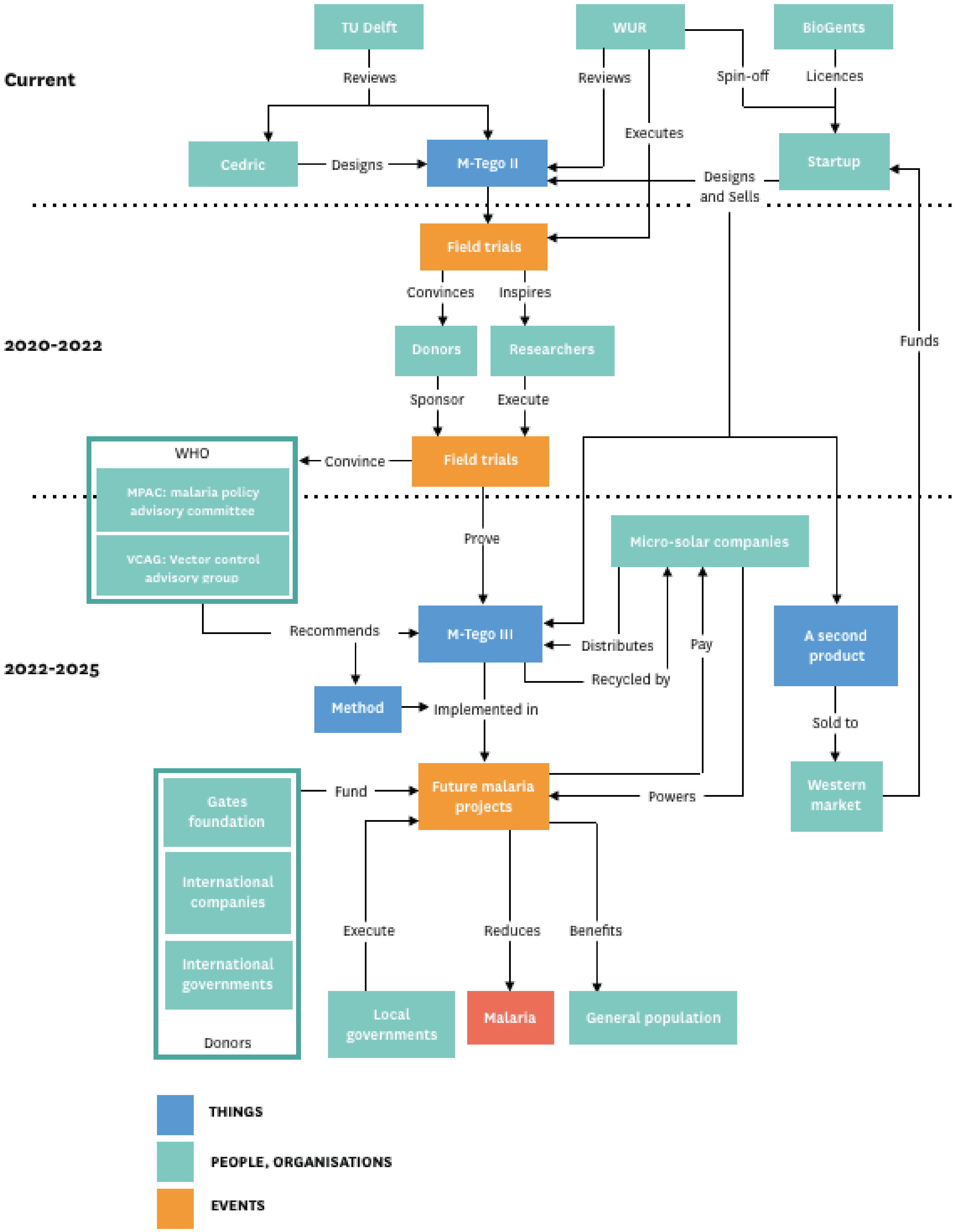
Chapter 'Applications', p. 40

After a phase of testing, the WHO will approve the product class of 'Mosquito traps', triggering national malaria projects in sub-Saharan African countries that utilise mosquito traps.

Chapter 'Final design', p. 80

The trap design as introduced in chapter 'final design' is an elaborated, improved and tested version of the M-Tego concept this project started with and will, with the measures introduced in the second half of this thesis, more likely be sustainable on the African continent.

Figure 78. Full implementation model.



Current
TU Delft
WUR
BioGents
Reviews
Reviews
Spin-off
Licences
Executes
Cedric
Designs
M-Tego II
Startup
Designs and Sells
Field trials
Convinces
Inspires
2020-2022
Donors
Researchers
Funds
Sponsor
Execute
WHO
Convince
Field trials
MPAC: malaria policy advisory committee
VCAG: Vector control advisory group
Prove
Micro-solar companies
Recommends
M-Tego III
Distributes
Pay
A second product
2022-2025
Recycled by
Method
Implemented in
Sold to
Gates foundation
Fund
Future malaria projects
Powers
Western market
International companies
International governments
Execute
Reduces
Benefits
Donors
Local governments
Malaria
General population
THINGS
PEOPLE, ORGANISATIONS
EVENTS

Recommendations

In this chapter, several recommendations are presented. These recommendations might serve as points of reference for the next generation of designers and engineers working on this specific trap, or another BoP device that has similar challenges.

PARTNERSHIPS

Probably the most important notion for future implementation of mosquito traps in Africa has been echoed throughout this thesis: local and reliable partnerships have to be formed that guarantee the sustained success of an intervention.

In the chapter 'Future implementation', partnerships with MSC are proposed as a way of distribution and maintenance scheme for the trap. Should these partnerships not work for whatever reason, other partners are needed for the implementation of the trap in sub-Saharan Africa. This advice is not only directed to the malaria control programme managers in governments and NGOs, but also to the company, should they wish to start their own community outreach.

For the to be founded company, partnerships with the parties involved in upcoming research programmes need to be developed and maintained. If through contracts with the scientific community, the trap is established in the scientific community as the default push/pull and malaria control trap, the company has the chance to prove itself and develop itself further.

ADVANCED ITERATION PROCESSES

It has become clear that the slightest of change in a mosquito trap design can lead to drastically decreased capture rates. Therefore, it would be best future iterations are small and tested continuously. At the same time, a growing list of pro's and cons of each iteration can be compiled. This list can include materials, shapes, dimensions, contrast options and more. This way, the design 'influencers' that are known now can be clarified into true design parameters, allowing future designers to build a more optimal trap.

One of these influencers is now known; the mesh or canopy holes are critical for correct airflow speeds exiting the canopy. If it is too fast, mosquitoes will be scared away.

CONTINUE USER TESTING IN LOCAL CONTEXT

With every future iteration, one important question must be asked: does this design enables long-term sustainability of a project? While much of the sustainability can be attributed to the system in which the trap is deployed, the trap and its usability ultimately is decisive for the daily user experience. This also means that user testing in the local context should be the norm for future development of the trap. It is incredible to realise that the heated wire was at a point where users would grab it, and no one realised it until a user grabbed it.

PROTOTYPING THE PROPOSED SUSTAINABILITY SYSTEM

As a means of testing the proposed system, it is suggested that a small-scale trial is done in a local community over the course of at least a year. The system should be tested on functioning, but also on community acceptance and cost-efficiency.

A last word from the author

This report is the result of a graduation project that took 6 months. It feels like long journey, and at the same time, it feels like the surface of what is necessary has barely been scratched. This project has been challenging to me, and I am thankful it was. A year ago I would have never imagined myself in rural Africa, counting mosquitoes.

Thank you for reading this report. I hope it aids you in further efforts to change the world for the better. If you have any questions or comments, feel free to contact the author.

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“Indifference towards people and the reality in which they live is actually the one and only cardinal sin in design.”

Dieter Rams