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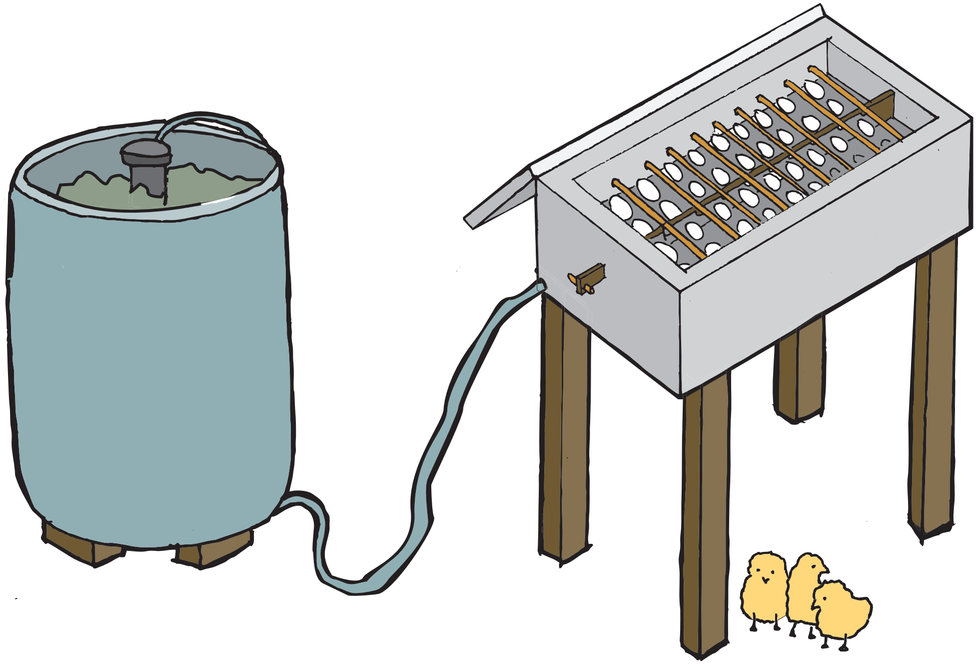
Design of an off-grid egg incubator

Morten Schnack Jørgensen s123748
Synne Sorteberg Skjørten s123450



Design and Innovation
Supervisor: Torben Anker Lenau
In cooperation with Engineers Without Borders

INGENIØRER UDEN GRÆNSER

Technical University of Denmark

DTU

Titelblad

This report is the result of the design process conducted as a bachelor project at Design and Innovation at DTU. The report has been written by

S123450 Synne Synneberg Skjørten

S123748 Morten Schnack Jørgensen

Technical University of Denmark

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0. Preface

0.1. Abstract

The Volta region of Ghana has experienced a lot of agricultural changes in the last 50 years or so. This change has mostly happened in the rural parts of the region along the river Volta. Before the construction of the Akosombo dam, the agricultural activities were blooming, but after, a decline in the agriculture has been seen. The context of which this project is aimed contains several challenges. Some examples are meager sanitation, availability of land and poor infrastructure including no electricity. Our contribution to solve this problem is an off-grid egg incubator. This solves a part of the problem by creating a beforehand not existing agricultural activity of producing chickens on a larger scale without electricity.

The concept is designed to fit the rural context and has been developed with a priority of low cost and local material as well as simple production. The concept is called Vitam Sterkus, which means “life by compost” in Latin. To incubate successfully, some requirements must be met. The eggs need to be held at a constant temperature of 37.8°C and the relative humidity inside the incubator must be between 40-54%. In addition, the eggs breathes hence the need of oxygen and they must be repositioned daily. This is why Vitam Sterkus consist of an incubator module and a compost module. The incubator module has a shelf of chicken mesh and a sledge to turn the eggs. The insulated incubator module is warmed by hot water that runs through a hose in the bottom. The compost module’s task is to generate heat, which it does by decomposing organic waste. The hose is wound around a core in the compost module and the flow is controlled by thermostat.

This project also briefly explores the prospects of the next step before Vitam Sterkus is ready for distribution around the world. First, some technical aspect must be worked out. Second, the concept must be thoroughly tested and validated. Third, the strategy and vision of the implementation must be created.

0.2. Abbreviations

The following abbreviations have been used thought out this report

- DTU Technical University of Denmark
- NGO Non-Governmental Organization
- PDG Product Development Group
- EWB Engineers Without Borders
- DA Development Arena
- WOM Weighted Objective Method

0.3. Acknowledgments

Thanks to

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- **Eddugle Akwetey, EWB** – for sharing the idea and knowledge of the local area
- **Troels Theilby, EWB** – for connecting us to the Product Development Group and making the project possible
- **Jon Spangsvig, EWB** – for sharing information and knowledge of working with NGOs and projects like this
- **Anne Løvenstein, poultry enthusiast** – for the sharing the knowledge and experiences of a poultry enthusiast
- **Flemming Nielsen, Curator of Copenhagen Zoo** – for sharing knowledge and experience from the professional world
- **Brian Elmegaard, Head of Section, Associate Professor ,Section of Thermal Energy** – for providing vital information regarding circulation, thermodynamics and thermostat design
- **Knud Erik Meyer – Associate professor in the Department of Mechanical Engineering Section of Fluid Mechanics, Coastal and Maritime Engineering** – for providing insight in the fluid mechanics of the circulation system
- **Sigrid Elisabeth Bruhn Hemmingsen, Student at Design and Innovation, DTU** – for helping us combine ideas in the ideation phase
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0.4. Introduction to project - context

The Volta River has for many years been the basis of great agriculture and farming in Ghana. The seasonal rise of the river would supply the farmland with essential minerals and nutrients that kept the otherwise dry lands fertile.

The building of Akosombo dam has greatly disrupted flow and the ecosystems in and around the river downstream. A steady decline of agricultural productivity has been seen since the construction. Farmers and anglers have lost their jobs as well as feeding stock and lives due to this. Appendix 4-6

0.5. Problem definition

Research shows that the most environmentally friendly form for meat is chicken. Production of chicken uses less water, food, space and maintenance than any other animal, calculated in calories. To speed up the production of eggs, incubators are used. This is a common practice in many parts of the world, however most incubators require electricity. Places without a reliable source of electricity, for example remote areas of Ghana and other places in Africa, are therefore unable to use this technology.

This project aims to develop an egg incubator that does not rely on electricity, for use in off-grid areas. The development and implementation is not to become an expense to the local community and culture.

0.6. Introduction to project - people

The man behind the idea of an off-grid egg incubator is Eddugle Akwetey. He has grown up in the Volta Region and is son of the regional chief, thus has great knowledge of the problems and possibilities in the region. His idea of an off-grid egg incubator has been on his mind for a long time but he does not have the resources to develop the machine himself.

Eddugle Akwetey, who now lives in Copenhagen, has come into contact with Engineers Without Borders (EWB), a non-profit organization who helps with technical development projects in various countries around the world. They acquired the project by Jon Spangsvig, a member of EWB, as Jon and Eddugle are personal friends. Another participant from EWB is Troels Theilby, who first presented the project to us and provided the connections to Jon and Eddugle Akwetey. Eddugle Akwetey, Jon Spangsvig and Troels Theilby are all menbers of PDG, a subdividion of EWB, who have given the task for this project.

The design team who has completed this project and report consist of Synne Sorteberg Skjørten and Morten Schnack Jørgensen.

Torben Lenau has been the supervisor of this bachelor project and have provided technical knowledge and support throughout the project.

In this report, other names will appear as we have spoken to many people regarding the project. The following is a list with a quick overview of all the people involved.

0.7. Bachelor project process

The process of this project has been similar to many other design processes. Overall, multiple convergences and divergences of the solution space have been the basis of the development process, appendix 7.

As seen in the figure, the overall process is divided into 4 phases; analysis, ideation, concept details and finalizing. A milestone was placed after the analysis and ideation phase, with a report to ensure that we met the timeline and could reflect on the work as the project progressed. In general, the ideation and conceptualization phase consisted of a divergence of ideas and convergence towards the end, as the best solutions was chosen. The finalizing phase consisted of prototyping and technical drawings as well as a workshop regarding future work.

Two timelines were created in the project process. The first timeline was changed as no funding was received to go to Ghana, hence the second timeline was constructed. They can be found respectively on appendix 8 and 9. They show the individual task of each phase as initially planned and will be revised in general in chapter 8.

0.8. Report structure

The report structure is primarily based on the phases in the project process and it is divided into six chapters. The report's main chapters are analysis, ideation, concept detailing and finalizing. The finalizing phase is further divided into three chapters in the report: final concept, prototyping and next step.

Colors of the report

Each chapter includes several methods, results and reflections. Every method is described together with the results. This makes sure that the reader is able to recognize the results of the methods right away and thereby have the right information when proceeding with the chapter. To give a quick overview when reading, the methods are marked with a method marker and the results with a result marker, so that it is easy to distinguish between method and results.

[M] Method marker
[R] Result marker

Method and result markers

At the end of every chapter, the reflections and experiences are summarized to conclude on the methods.

Important to notice that the final concept, the incubator, is divided into two modules; an incubator module and a compost module. The final concept is called Vitam Sterkus - Latin for life by compost.

0.9. Sponsorship application

From the very start of the project, one of the goals was to visit Ghana. It was one of the reasons for choosing the project when going through the possibilities together with EWB. We decided on the project right before Christmas 2014 and started looking for funding as soon as Christmas break was over. EWB does not have a network of people in Ghana, so we would have to find funding of some art in order to make a trip possible. Originally, the hope was to be able to go down two times in shorter periods, one for initial research and one to test our concept later in the project. In order to apply for scholarships and sponsorships from companies, we had to come up with a budget (appendix 10), and an application (appendix 11-12).

Eddugle Akwetey helped with the budget knowing the prices and the people. He would also come with us to Ghana and act as our guide and translator, so our budget had to include three people in total.

0.9.2. Scholarships

A number of possible sources for sponsorship were researched. Including scholarships from various institutions and funds. This proved to be quite challenging. For one, many scholarships require that you apply a year or 6 months in advance, or they have one period per year when they give out money. This meant we missed many possibilities due to time constraints. The second thing is that there simply is not a lot of scholarships for field studies on bachelor level.

0.9.3. Companies and organizations

We contacted companies that does something with chickens or eggs. After some research, it was clear that the chicken hatching companies in Denmark are not very taken with CSR (corporate social responsibility) and they were not very interested funding in the project. We also contacted relevant organizations and NGOs. Some examples were Danhatch, Danæg, Plan Denmark, Ghana Venskabsgrupperne and several others.

0.9.4. Indiegogo

We have also tried crowdfunding on Indiegogo. Here, however, we made some mistakes in not spending enough time on a campaign. One of the most basic mistakes when looking for crowdfunding is “expecting the money to come rolling in”. We shared our campaign on Facebook and with our friends, but as our friends are mostly students with very little money to spare, they were not the right target audience. The result might have been different if we had targeted the right audience and had time to follow up on the campaign.

Overall, we did not end up receiving any funding for the trip. In hindsight, it is clear that choosing an area where a NGO already has a network would be a good strategy if a field study were wanted. Also applying for scholarships at least 6 months prior to the travel might provide better results than what we got.

Without the funding is was still possible to conduct the project as we had a contact person Eddugle Akwetey. He proved to be a valuable link and source of information regarding the context for the project.

0.10. Learning objectives

The learning objectives were approved by the supervisor of the project and will be reflected upon in chapter 8. After the project, we intend to be able to:

- Formulate a scholarship application and apply to relevant funds.
- Investigate and uncover information on chicken production and all its aspects.
- Determine and understand the actors and their silent knowledge as well as the use context and use processes.
- Develop concepts based on the analysis by using tools such as biomimetics and other design practices.
- Carry out tests in order to get “proof of concept”, and thereby determine the effectiveness of a solution.
- Produce boundary objects in the form of sketches and drawings to communicate a message, function or idea regardless of the recipient’s language and background knowledge
- Identify which resources and capabilities that are available in the area where the product is designed.
- Execute a workshop, which develops one or more concepts in cooperation with the local population.
- Validate concepts based on decision tools and empiricism gathered as fieldwork and well as the effectiveness of the concepts.
- Evaluate the project and the tests/experiments performed as well as a perspective to the final concept to other different contexts of use and production conditions.
- Reflect on the project cultural and economic impact on the

country where it is implemented and generally identify pitfalls of projects in developing countries

- Gain an understanding of how to create a sustainable concept that can operate independent of financial support over a longer time perspective.
- Account the final concept utility value according to user group in Ghana and elsewhere in the world.

Analysis

1. Analysis

1.1. Chapter introduction

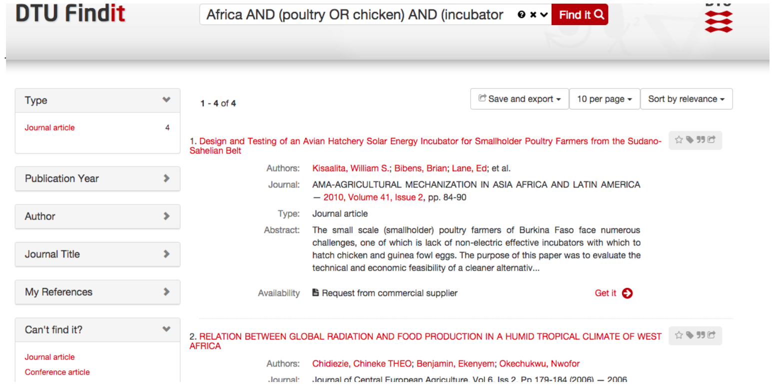
The goal of this project has been to develop an off-grid incubator for rural part of Ghana, more specifically the Volta Region in southeast parts of Ghana. In order to do so properly, information was gathered so the solution works and fits in the context and environment. A thorough analysis has been the base of the design work and discovered, not only where the problem arise from and the context of the challenge, but also the specific requirements and properties of a functional incubator. Along with a lot of research in literature and online sources and databases, several people with different backgrounds and areas of expertise were involved. The people who have contributed to this chapter through the interviews are curator and former animal keeper Flemming Nielsen, poultry hobby enthusiast Anne Løvenstein and the man behind the idea of an off-grid incubator to Ghana as well as local contact Eddugle Akwetey.

This chapter analysis the problem at hand and the context of which the off-grid incubator is developed. It will also go into an analysis of what a chicken egg needs during incubation and explore this through a functional analysis, which end up with a function tree. Last, principles and analogies, both biological and technical, that can handle or solve some of the functional challenges found in the analysis, are explored in a biomimetics inspired method.

M 1.2. Search strategy

When searching for relevant information, be it online in a database or in the local library, it is important to devise a strategy in order to find relevant information. In this project, several online databases have been used, but due to the nature of the project (hatching chickens); a lot of information have also been sourced from independent websites. When searching for information we made sure to use keywords that described the required information well.

The keywords were put together in different search-strings, using the different commands allowed in the different databases/search-engines. An example of a search-string can be seen below. The different results were logged in a document so that we knew which keywords that worked well and provided results and vice versa.



Findit search results

M 1.3. Field trips and interviews

The desired field study trip to Ghana was cancelled due to insufficient funding, so the field studies were limited to Denmark. The field studies in Denmark mainly consisted of two trips to Flemming Nielsen in Copenhagen Zoo, and one to hobby poultry enthusiast Anne Løvenstein (appendix 14). In addition, several meetings with the local contact Eddugle Akwetey was established. Eddugle has spent most of his life in Ghana and therefore has a wide range of relevant information.

Interviews was the main method used to extract and absorb information from the experts in the various areas of expertise on the field trips. The questions asked were primarily open, as not to imply or nudge the answers in a certain direction. In addition, a lot of pictures and notes were taken during the interviews and presentations of the various incubators etc., so the data could be reviewed multiple times, later on in the process.

Field trip to Anne Løvenstein

Another approach to extract knowledge as well as "silent" knowledge of the experts is by asking of a demonstration while they explain the procedure, routines or functions (Bijker 1997). This reveals the knowledge that might be basic for the experts, but new to us. By letting Flemming Nielsen demonstrate the various incubators at zoo, and letting Anne Løvenstein show the routines of her incubation periods we obtained a lot of valuable knowledge.

Demo from Flemming Nielsen

Ⓡ 1.4. Problem elaboration

Due to the construction of dams in the upper part of the Volta River in southern Ghana, the areas and banks along the river has suffered great agricultural damage. Before the dams were constructed, the seasons created a natural rise of water level in the river during raining season, which dredged the surrounding lands. Thus, the minerals and nutrients in the soil were released and brought back into the farmland and another agricultural season could start. Based on the experience of several years of annual flooding, the locals knew how high the tide could get on the banks and the farms and villages was built accordingly. The river also contained a great amount of fish and oysters that local anglers were able to profit from and thereby creating jobs.

Triving agiculture and the Akosombo dam

When the Akosombo dam was constructed (1961-1965), a massive lake was created and the natural behavior of the river was disrupted. After the construction, the water level in the river downstream has almost permanently been low; the river no longer follows the natural cycle of the seasons (Wikipedia 2015). As the dam regulates the flood now, the farmland around it does not receive new nutrients, making it harder to grow crops. During large amounts of rainfall, the dam is opened when the reservoir becomes too large, which leads to extreme flooding in the subsequent rivers.

The creation of the dam also led to the growth of algae and weeds in the river. Because of this, both the fish and oysters in the river have mostly disappeared, and the livelihood of the people is gone. The weeds also provide breeding grounds for venomous snakes and the parasitic worms that bring Bilharzia disease; making is dangerous to swim in the river.

As both living of the river and the land around it is becoming subsequently harder, a new source of income is needed. Most families in the area already have chickens. With a low cost incubator, it would be possible to increase the production of chicken and many families would be able to rely on poultry as a larger part of their diet. **Appendix 15-16**

R 1.5. What is an incubator

The goal of this project is to develop an incubator that will raise the effectivity of the chicken production in rural Ghana. To comprehend the goal, it is important to understand the background and existing solutions to faster chicken production, especially on how it is done in the industrial countries.

An incubator is essentially a machine that provides the eggs the same conditions they receive if they were hatched naturally.

R 1.6. Why is an incubator useful?

Normally the hen needs to brood its eggs from laying them and until they hatch 21 days later. The hen then takes care of its chicks for around 6 weeks before it begins to lay new eggs. This is a long process and it takes a long time between each new litter of chickens. In Ghana today the chicks are not separated from the hen (appendix 15-16), meaning there are around 77 days before the hen starts laying eggs for a new brood.

By using an incubator and removing the eggs when the hen starts brooding them, the hen can start laying new eggs after 10 days (appendix 15-16). As hens do not count the chicks, one hen can be appointed to raise many chicks, letting the other hens go back to laying eggs. Alternatively, the chicks can be raised by hand. Both methods increase the efficiency of the process by a large percentage and allow the owners so sell more chickens and get a higher income.

R 1.7. Context of use

1.7.2. What is a chicken?

A broiler is a domesticated fowl bred with the intention of slaughter. The nutritious meat is an effective and environmentally friendly source of meat. The broiler is commonly known throughout history due to its easy maintenance and farming. Broiler chickens can be raised in large scales, but can also be easily kept by a single person or family. They do not require very extensive care or expensive food and be let to roam free around the property. In many parts of the world, chickens are bred for personal use and is a way to obtain a varied diet and a powerful source of protein.

Chickens and hens

1.7.3. Types of chicken

Incubators can in general hatch every type of egg. Every type of fowl has its own specifications regarding the eggs. Regarding powered hobby incubators, most allow for a decent success rate with a little experience with the type of egg. The eggs from a guinea fowl, a quail or a chicken also need different periods in the incubator, different temperatures and humidity. The chicken most commonly used in the Volta region is in the same family as the European chicken and can be hatched using under the same conditions. As this kind of bird has been largely studied, a lot of knowledge and literature exist around how to best incubate its eggs.

1.7.4. Developing countries

Many developing countries face a controversy regarding industrialized farming and rural incubation. This is also a problem in Ghana. Closer to the cities there are more, often industrialized, farms with more modern technology. The controversy occurs when there is a lack of information flow due to a lack of infrastructure. One part uses advanceed technology and methods for farming, and the other, remains underdeveloped and stuck with manual methods and a low degree of automation, due to the lack of knowledge. This might also result in poor education of the farmers and again lead to poverty. This project could broach the distribution of knowledge and experience concerning incubation of chicken eggs.

Rural Ghana

1.7.5. Ghana

Ghana is a country with great diversity. As seen in other developing countries, there is a large difference between poor and rich. The result of this is a great variation of ways to hatch chicken eggs within the country itself. Even with their own production of chicken, Ghana heavily imports chicken from other countries, leading to a saturated marked in the city regions.

"It is generally known that the unrestricted importation from Europe and America of heavily subsidized poultry meat, which sells cheaper on the local market, has contributed immensely to the depression of broiler chicken production in Ghana" (Atuahene et al. 2010)

The import has led to many chicken farmers to focus on producing eggs for consumption instead of meat, as the prices of imported chicken are very low.

With the larger cities in Ghana separated from the small rural villages, the chicken meat produced by larger and industrialized farmers as well as the imported goods has a hard time reaching the outer, off-grid regions. In these regions, it is often seen that one family produces their own food supply or even trades the food within the communities (Atuahene et al. 2010).

Therefore, a market for local chicken still exists. In addition, local chicken often is of a better quality and the local trading has a potential of boosting the local economy and provide a sustainable solution. Appendix 17-18.

1.7.6. Types of incubators in Ghana - Industrial/ personal use

There is a great difference between industrial production and small-scale incubation in Ghana. This difference is mainly based on the gap of the resources available to communities in poorer regions.

As the situation described above, the lands surrounding Volta has suffered a loss of farming possibilities. Before the dam, these areas were already of limited means, and now they are even more limited. Without any electricity, the incubation is done naturally, and one is dependent on a large quantity of chickens in order to get meat to sell beyond personal use. However, in cities and well-resourced regions with a stable electricity supply, the incubation can be done a lot more effectively. The powered incubator can maintain an accurate temperature and humidity creating the opportunities of large-scale incubators with high capacity.

1.7.7. Challenges in Ghana

There are many sources indicating that poultry production in Ghana has big potential (Adei & Asante 2012; Akunzule & FAO 2014; Atuahene et al. 2010). There are however, many challenges that have to be overcome, in order to get efficient and profitable production. For rural parts of the country, even more challenges arise, with limited access to resources and capital. Another important point is the skill and experience related to keeping poultry, which is vital for success.

Atuahene et al. (2010), points out some important challenges when it comes to poultry in Ghana.

- Availability of land: The best conditions for poultry production requires vast lands and depends on the geology of the region.
- Improvement of health and sanitation: It is useless to develop a super effective incubator if the rise in birds only creates reason for virus and bacterial infections in the poultry.
- Management: In many rural regions, the unskilled farmers are often seen which results in poor management. This also leads to unsustainable companies without capital.

Heav load

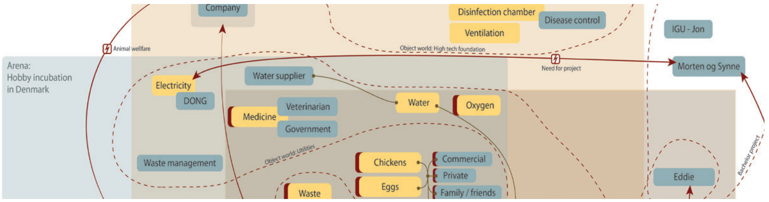
Another large issue to consider is the consequences of the ineffective infrastructure in the poorer regions. Bad roads makes it harder to move around and not many people have cars. The access to modern technology in the outlands is almost nonexistent. This means that the project at hand will have to be based on the available materials in the relevant area and not depend on getting materials brought out.

As for local materials in the Volta region, there are not many of them. There used to be many trees and palm trees in the area, but due to a period of heavily harvesting not many remain today. This has made raw timbre harder to get, however plywood is available. Bamboo is also abundant and may be used as a replacement. A mattress factory in the area makes pieces of mattress an available resource. Used oil barrels and PVC barrels can also be found. As for components, some can be found in the local market, they can however be quite expensive and not of great quality.

M 1.8. Development arena

A DA is the conceptual framework that can summarize the development path and structure the findings of an analysis (Jorgensen & Sorensen 1999). In this project, the DA helped to organized all the connections between the actors and objects that exist on the arenas. This provides a good basis to lay down the correct development path in the right context.

Ⓡ Development arena



The first development arena

The result is a DA (appendix 19) with three sub arenas: Industry: Global, Hobby in Denmark and small scale in Rural Ghana. The three arenas each has a method of incubation, where the complexity and cost varied from arena to arena. Some patterns and possibilities emerged when the arenas was filled with actors and objects. For example, common to all methods of incubation is that there are some resources needed for them to work. These were found by drawing an actor world around the utilities. Other actors and object worlds also emerged between the arenas. Also found on the DA was many controversies, where interests or opinions collide. Some of the controversies were as follows:

- The idea of an off-grid incubator could be hard to sell to areas with prospects of electricity in near future. It would be good if the incubator had strengths or selling points other than being electricity free.
- The village leader might have an interest of best overall welfare in the society, but the individual farmer could react from an interest in personal winning.
- If the incubator works very well, one could imagine a poultry saturated marked which does not generate any more income.

Ⓜ 1.9. Functional analysis

The functional analysis is based on the search in literature and interviews described in precious sections. The search performed for the functional analysis was however, a bit more concrete and precise in order to figure out precisely what requirements the incubator would have to fulfill. The functional analysis is deepened further into details under the definition of functional challenges.

Ⓡ Functional analysis

1.9.2. What does the eggs need?

Precisely what conditions one needs to hatch eggs, is a constant topic for discussion. Production requirements differ from those of hobby breeders. In the hobby breeder community, people use a wide variety of conditions all dependent on what tools/machines is used (appendix 20). It also depends on what hatch rate that is acceptable, as tougher conditions might not lead to every egg hatching. The following conditions are, however, good guides in order to get the most hatched eggs possible:

Air temperature

The air temperature is vital when hatching chicken eggs, and therefore one of the two main success factors. The temperature must be kept at a constant 37.8°C throughout the whole 21 days, and should not vary with more than a quarter degree plus/minus. If the humidity is high enough the temperature might be able to go a bit higher, but generally, it is very important with a constant temperature. Appendix 21-22.

Air humidity

Air humidity is the second main factor to hatch eggs successfully. The humidity should be at 40-54%. The easiest way to see if the humidity is right is to measure the weight loss of the eggs. The eggs should lose 13-15% of their weight during the 21 days of incubation. If the humidity is too high, the eggs will lose too little weight and if it is too low, the weight loss will be too high. It is generally not necessary to weigh the eggs every day. Every other or every five days should suffice.

Ventilation and oxygen supply

As the chicks growing within the eggs need to breathe in oxygen and let out carbon dioxide, proper ventilation of the incubator is important. If the incubator has a ventilator it is important check up on it in order to verify that enough air is circulated. Alternatively, one can open the door of the incubator for 10 min or 5 min twice a day to allow air to be renewed. If this is done, one must ensure that the temperature does not drop too far down while aerating (Meijerhof et al. 2006) Appendix 21-22.

Turning the eggs

Turning the eggs is very important and has a lot to say for the outcome of the hatching. The eggs should be turned at least once a day, but turning them more is only good. One thing to keep in mind when turning the eggs manually is always turning the eggs an odd number of times each day. This ensures that the egg will be laying

Turning mechanism of an incubator

1.9.3. Definition of functional challenges

As the sections above describes different requirements of an incubator, in this section the information will be divided into functional challenges. With divided functional challenges, it is possible to focus the biomimetic search on each function in order to find solutions to each sub challenge.

Overall, during the incubation period, the weight loss is the important factor. This functional challenge already has a great number of solutions when speaking of the documentation and scaling. Digital scales, manual balance scales and so on are well distributed and used. The function of creating the right amount of weight loss for a fertilized egg is the hard part, and when the overall challenge dictates the rule of “off-grid”, the challenge seems to get harder. The sub function of controlling the weight loss of an egg can be further separated into smaller and more feasible functions. There are two main psychometric terms that can affect the weight of the egg: temperature and humidity.

Temperature

The temperature of an incubator is very important, as the temperature is one of the contributor to the vaporization through the shell of the egg. With modern incubators the generation of heat is electric, often a simple heating element or even as elementary as a light bulb. In this case, the generation of heat needs to be done without any electricity and even without modern technology such as high efficient solar cells or wind turbines.

The temperature generation function is required to minimum deliver 38°C as long as the incubator is completely isolated. When taking into account that insulation properties of local materials is far from perfect, the minimum temperature required is for the time being set to 40°C.

Small variations affect the development of the embryo. Also mentioned was the requirement of a stable “outside” or environment temperature in order for the incubator to hold a constant temperature. In this projects given circumstances it will pose a problem, as the nature of the context of use is outside or in a poorly insulated building with great variations of temperature. A clever and simple/low tech solution for the regulation of temperature is needed. This could either be manual or automatic, but again; not electrical. Appendix 21-22.

Adding water for humidity

Humidity

The humidity is the other contributor to the weight loss during the incubation period. This is due to the vaporization from the egg, which depends on the relative humidity, that also depends on the temperature. If the air surrounding the egg contains too much water, the egg will not be able to release any water into it. In the extreme case where the humidity is close to 100%, the egg may be covered with a thin layer of water, which can penetrate thin pores in the shell and in worst case bring bacteria to the embryo. This thin layer of evaporating water can also rapidly cool the egg down.

In the other end, if the humidity is too low, the egg will lose weight too fast. This forces an early development of the embryo and can lead to unsuccessful incubation. To summarize, the weight can be controlled in two ways, by temperature and humidity, both interconnected with each other.

Ventilation

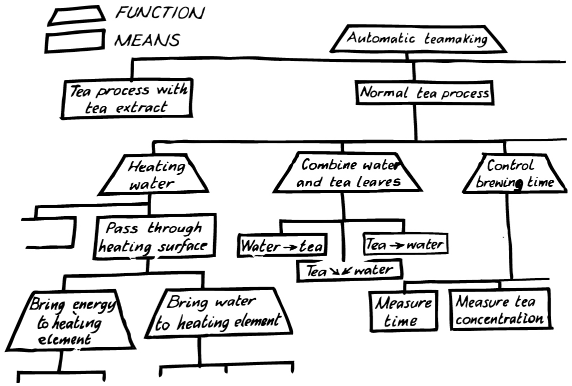
Another sub problem is the ventilation. In professional incubators, the ventilation is done automatically with a fan and/or adding external air. In small scale and portable incubators, the ventilation is done manually. It is necessary to refresh the air inside the incubator in order to change the carbon dioxide filled air out with fresh air full of oxygen.

Turning

The last of the sub functions that will be analyzed is the turning of the egg. This is done manually in most of the smaller machines, but medium and large machines uses an electric motor and some mechanisms. The problem size depends directly on the size of the machine. It is easy and quick to turn 12 or 24 eggs a couple times a day, but when the numbers begins in the hundreds, it will consume a lot of time.

1.10. Function tree

The functional tree is a great way of breaking an object down into functions. Thus, the function tree describes the core of the product. The information obtained in the search and field studies can be organized in different ways. Much of the information simply needs to be presented and kept in mind when developing; other data can advantageously be structured in different ways, one of which, a function-mean tree.

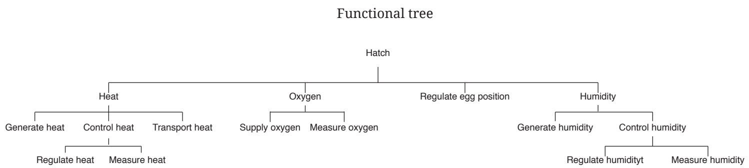


Function tree by Tjalve

In this project, a version of Tjalve's (2003) function-means tree has been used. As the analysis and found information only regards the functions of an incubator and as the off-grid incubator has yet to be developed, the function-means tree was simplified into a functions tree only. By the division of the functions and disregarding any existing means to the functions, the brainstorm on the function tree gets very open. This simplification of the tree makes it resemble the functional decomposition seen in literature (Yen et al. 2011).

Ⓡ Function tree

The incubator needs to perform basic functions within four categories in order for the eggs to hatch. These functions are heat, humidity, oxygen and repositioning of the eggs. These four functions were then divided further until the basic function was described. Appendix 23.



Functional tree for this project

Ⓜ 1.11. Product specification and four-box

A way to organize this information and findings from the functional analysis, two different methods were used, basic specification and four-box method. The different functions from the functional tree were translated into requirements and criteria, for construction, production and operational environment to name a few.

1.11.2. Product specification

The product specification (Andreasen & Hein 1987) is a good tool for making sure that the minimum requirements for a product is taken into consideration. A product specification includes both requirements, things that has to be included, and criteria, things that should be included if possible. When making a product specification one must try to envision all the different scenarios of the product and figure out what the product should be able to do. It is important to find a balance of the number of requirements, as too many may hinder the design process, and too few might mean that the product will not fulfill its expectations.

1.11.3. Four-box

Another way of structuring requirements for the project is a method much used in in biomimetic, the four-box method (Helms & Goel 2013). The four-box method is in some ways a bit simpler to approach and is a good starting point when figuring out what the product should do. It has four categories or boxes: Operational environment, Functions, Specifications and Performance criteria. In order to fill out the four boxes, we answered four questions:

- In which context does the object operate?
- What does the object do?
- What is the object like? (Details about the structure properties and dimensions)
- How well does the object perform?

Ⓡ Product specification and four-box

Our product specification was initially divided into 3 categories: use, production and construction. With the project still in a very early stage only few things were decided, hence the specifications general appearance. Later on, the product specification was expanded to five categories:

- Use
- Safety
- Production
- Construction
- Estheticst

Some of the more essential requirements were the ones concerning the temperature and humidity of the incubator. It was also important to include things like “using local materials”, so that we would keep it in mind throughout the process. This made sure that we did not end on a solution that could not be realized. The newest version of the product specification can be found on appendix 24.

The four-box method describes many of the same requirements and specifications, but is more general and is less strict; the result can be seen in appendix 25.

In general, several parameters and specifications occurred in both methods. Some of the more important details from both methods are listed as follows:

1.11.4. Use

The use of the machine should be simple and be operated by one person. It should be adaptable to different kinds of bird eggs in order to maximize the benefit. In addition, it should be possible to empty out eggshells etc. after use, but not necessarily possible to clean the machine with chemicals.

1.11.5. Safety

The incubator must be safe to and pose no danger to the local society. This is quite important as hospitals or infirmaries are not located nearby.

1.11.6. Production

The machine must be able to be produced by locals and with local materials. It should also be as cheap as possible with a low production time, preferably under one week, even by a non-expert.

1.11.7. Construction

The machine itself has some requirements and criteria, especially when it is developed for rural Ghana. The outside temperatures it has to withstand is 18-35 °C and as minimum endure 6 months of outdoor weather in Ghana. As stated, it has to run without electricity. Preferably, the incubator should be as large as possible, with a high capacity. This is a vital tradeoff between portability and capacity and will be discussed later on.

1.11.8. Aesthetics

The aesthetics are important as they can define or lead to proper usage. One must not be in doubt when trying to open the incubator etc.

1.11.9. Functions

The main functions are also required in pursuance of a useful incubator as described in the four-box. The four main functions are; regulate heat, regulate humidity, turn eggs and provide oxygen.

M 1.12. Analogies and principles - biomimetics

With the proper information and knowledge foundation in place, the next step was to start organizing the information and search for ideas that can solve or handle the challenges at hand. This project uses biomimetic as a way to approach a problem. Biomimetics explores the biological world of principles and analogies that solves the given problems (Helms et al. 2009).

First, the analogies and principles had to be discovered by a structured search.

1.12.2. Analogies and principles research

The general biomimetic and technical search were executed in various databases such as:

- DTU Findit
- Scopus
- Web of Science
- AskNature.org

The search of scientific articles and books with biological analogies was done in a strategic way to make sure that the literature and knowledge was well covered. The search consisted of different search-terms and combinations of these. AskNature has been a big source for our biomimetic research as the site also references scientific articles.

Other ideas and biological analogies used in this project are the results of the project worked on in the *Biomimetics and Bio-Inspired Design* course at DTU January 2015 that Morten was a part of. A large part of the bio search on some of the functions from the course, was material we were able to use in this project.

1.12.3. Brainstorm on functions

Then with the research in mind, we have executed a brainstorm on functions. This included both previously obtained knowledge as well as general knowledge, in order to explore the possible functional principles. To come up with many solutions one does not simply start brainstorming smart ideas. This is at least true most of the time.

We therefore held a small brainstorming session where the focus was the different functions from the function tree. We went over the four categories heat, humidity, oxygen and turning eggs, and tried to think of as well as explore the found principles that could solve or handle the functions.

We used a timer set to five minutes and went over each category. The brainstorm was silent, so there was no talking while we idea generated, but we presented our ideas to each other after each category. The discussion and presentation of the ideas to each other also inspired new ideas. We did it two times around; to be sure, we got down the most principles possible.

Functional brainstorm

1.12.4. Biocards and technocards creation

The next step was creating biocards and technocards, cards that each describes a biological or technical principle. Biocards is a method used frequently in biomimetics, and provides a way to translate a solution found in nature into a functional principle one can use in a technical solution. Technocards are normally not a part of biomimetics, but have been added in addition to biocards. The reason for this is to not only explore the biological world of principles and hereby maybe exclude some solutions, but also embrace the full solutions space.

Ⓡ Analogies and principles - biocards and technocards

A lot of the time, we ended up with direct solutions, rather than principles, but at the end of the session, we were able to sit down and figure out the principles behind the ideas. The brainstorm was especially important for the creation of technocards, as we already knew many principles that could be used. Appendix 26-52.

The following results are arranged in the categories that were established in the functional tree. Within some categories lies sub functions that were explored as well.

1.12.5. Generating heat

The generation of heat without electricity is essential to the project thus explored thoroughly. Several biological analogies has been found as well as some technical ways of generating heat. In general, four major groups of heat generation were explored:

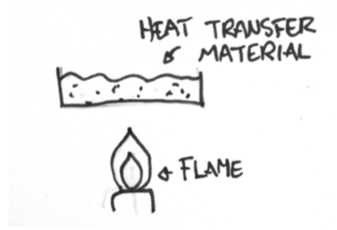
- Chemical - metabolism
- Chemical - combustion
- External - sun
- External - leftover heat

Metabolism

The metabolism way of generating heat is the process from humans, animals and microbes. In this process, a chemical composition is degraded which releases heat. The different analogies and principles of metabolism is found in appendix 28, 29, 32.

Combustion

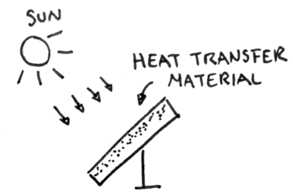
Combustion or fire creates a lot of heat, which easily can be extracted, see appendix 30. This method has been known in many thousands of years. A problem arises as the fire consumes some type and amount of fuel, which needs to be calculated in order to make sure that the solution is sustainable.



Principles from bio and technocards

Sun

The sun generates a lot of heat that can be utilized effectively with a little technical knowhow. The principle is simple, warming up a material that warms up the incubator. Alternatively, one can even let the sun warm up the incubator itself. Appendix 33.



Principles from bio and technocards

Leftover heat

The inhabitants of rural Ghana often use some type of gas fueled stoves and kitchen. This leftover heat can be utilized by heating up stones or other types of heat batteries or used directly. Appendix 31.

1.12.6. Transport of heat

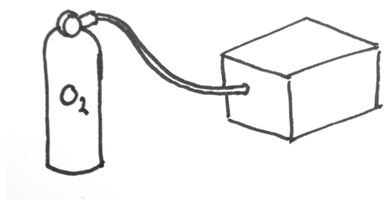
Several suggestions on to how to extract and transport the heat have also been explored. In this project the types of transport has been divided into three major groups; transport by gas, liquid or solid. These types of transportation faces different problems and provides various benefits. For example is gas hard to contain and transport in rural Ghana as the resources and access to plumbing is limited. Appendix 47-49.

1.12.7. Humidity generation

In general, we have divided humidity generation in two ways. Atomization and evaporation. The two groups are basically the same, but the technology required to atomize water might not be available. The atomized water will also evaporate, but more quickly than the methods in the evaporation group. Appendix 34, 35.

1.12.8. Oxidation

Many different oxidation ways were explored. Nature's own way of producing oxygen, through lungs for example, was deemed too complicated for this project. We choose to focus on principles that made use of the oxygen in the air around us, without concentrating it into pure oxygen gas. The challenge lies in exchanging the air outside the incubator with the used air inside, without letting out too much of the heat. This resulted in a couple of technocards, as seen in appendix 41, 45, 46.



Principles from bio and technocards

1.12.9. Turning eggs

The turning of the eggs are divided into 3 groups as well. The three groups are turning by rolling, lift and turn as well as tilting. The eggs only needs to be turned 120 degrees every day. The groups have individually been explored and can be seen in appendix 50-52

Principles from bio and technocards

1.12.10. Regulating heat and humidity

In addition to the generation of heat and humidity, ways to regulate and measure the heat and humidity has been explored. Both simple and technical ways has been examined appendix 26, 27, 36-40, 42-44.

M 1.13. Existing solutions

To fully comprehend the subject and context of incubators in rural environments, a research of existing solutions was executed as a final part of the analysis. The search in literature and on the internet with different search strings gave some results with varying degrees of professionalism.

R Existing solutions

The focus on chicken production today is largely aimed at electric incubators. Not a lot scientific research is being done on alternative power sources and few scientific journals focus on these low tech solutions. There are a few different methods of creating non-electric incubators, but information concerning these is mostly found in discussion forums around the net and it is therefore hard to say precisely what solutions already exists. The following are some of the most common methods. Appendix 53

1.13.2. Solar incubators

One way to heat the incubator is to use the sun as a power source. This can be done by using solar cells to generate electricity and then to drive a heat source or one can use the heat from the sun to warm up water that then warms up the incubator. Solar cells have the advantage that they can be used to drive several mechanisms in the incubator, from the heating to the turning of the eggs. They can also charge batteries, which would solve the problem of having a constant heat source, so that the incubator can run at night and during cloudy days. However, they are expensive to buy and hard to repair if they break down. There are several solar cell incubators on the market today.

Using the sun's energy to heat up a material with good thermal conductivity is another option and quite a few solutions exist here as well. Most solutions use the sun's energy to heat up water, which then circulate the incubator chamber in a sealed tube or chamber. Using water as the heat conductor makes the system more stable in regards to sudden shifts in temperature. Opening the door to the incubator can cause such shifts, but as it takes some time before the water cools down, the system is less affected than if the only the air was transferring the heat. Wax can also be used as a heat transfer medium; however, it needs to be melted in order to be able to flow. When using the energy of the sun directly like this, there is a need for a way of storing heat so that the machine can run during night and in case of cloudy days.

Kerosene incubator

1.13.3. Kerosene incubators

Kerosene incubators are more commonly used in rural environments. In most cases, a kerosene lamp is used to heat up a transfer medium, which then transfers the heat into the incubator. When using this method it is important to make sure the lamp is well ventilated as the fumes from the flame are dangerous for the eggs. Another thing to take into consideration is of course the fuel. A kerosene lamp needs a certain amount of fuel per egg, so isolation is a big factor in how efficient it is to run. One also have to keep in mind that the flame of the lamp might burn with a lower temperature when the fuel is low, so some monitoring is necessary. As transfer medium, both air and water can be used, as long as none of the fumes leak out into the incubator itself. There are quite a few kerosene incubators on the market today and instructions for DIY versions are available.

1.13.4. Eggubator

The Eggubator is an incubator developed by Swapnil Kakote in India. The incubator is non-electric and uses phase changing materials to keep the incubation chamber warm. The exact technology used is not public knowledge, and Kakote has filed for a patent on the method. The Eggubator has won several awards for its innovative solution (Agrawal 2014).

1.14. Reflections on analysis chapter

1.14.2. Function tree

We have used a variation of the function means tree by Tjalve. By only listing the functions in our tree, we gained a detailed understanding of the different problems we would have to solve. The bio and technocards idea generation then provided means for each function and we ended up with a good overview of every way to get a function out of our incubator. By using this method, we ended up with a lot more means of creating a functions than we would have by using normal function means tree.

1.14.3. Using product specification and four-box

The two methods helped us in different ways, but mainly they helped with specifying criteria for the solution and creating an overview of the context of use. Many of the considerations in the specification were things we already knew, but condensing it down to requirements and criteria forces one to find out precisely what the project needs, and how to prioritize. This again makes it easier to reach those goals, since you have them structured and it is easy to go back to the specification and review if the project is heading in a good direction.

The product specification goes a lot more in depth on specific criteria and uses measurable goals. It is a good tool to use for keeping the project on track and not losing sight of the main goals. However, it is not easy to quickly skim it; you have to read the entire thing in order to get the full picture. The four-box method is easier and quicker to create. It is good at painting a picture of the situation, giving some predictions regarding the design situation and context, but does not go as in depth as the product specification. However if you need to quickly present the project to someone else, the four-box method is easy to present and does not require a lot of time in order to get a good understanding of the context.

Our experience is that even though the two methods overlap a bit, one does not exclude the other. The four-box method is a good starting point and after creating it, one might find it easier to create a basic specification, because you now have a clear idea about the context of use.

1.14.4. Principle, analogies, and brainstorm on functions

With experience from earlier research as well as the knowledge gained in this project, we have realized that it is difficult to research technical principles. One reason for this is that there are so many. When you search, you get a plethora of different principles, most of them excessively advanced in relation to what we were looking for. When executing biological principle research, Ask Nature is a great source, but there are no such databases for technical solutions. That might be one of the reasons for why we felt that the biological research went a lot easier.

It was hard to distinguish between solutions and principles in the brainstorm of principles. We combined the brainstorm to include both biological and technical analogies, but it was easy to get suck in on one path. As an idea in the technical area emerged, it inspired new ideas within the same category. This resulted in a strict path of idea generation based on the first idea's mindset. This is discussed further in the next section, as the solution-oriented principles were hard to turn into bio- or technocards.

1.14.5. Biocard vs. technocards

Both of us have some experience with using biocards from earlier projects. They are a good way to separate the principle from nature's solution, and worked well for our nature inspired principles. Technocards were new to both of us and not something we know has been used a lot before. It was a bit difficult to figure out what information to put on the cards. We opted for the categories of *Phenomena* and *Functional principle.* The good thing about biocards is that they make you work through the solution, describing the phenomena, mechanism and then give a way to find the basic principle. When creating technocards, we had a tendency to just write down solutions, and not principles. This is one of the reasons for why we have had some trouble with separating principles from concrete solutions. In hindsight, we realize that we should have spent more time on the technocards, and worked with them a lot more. Instead of having a card that described how a thermostat works, we should have taken out the basic principle behind the thermostat out of that context.

A good thing about having the technocards was that we had a way of combining nature inspired and solutions that are more technical. It gave a common arena for our principles and we did not have to have two separate sessions for idea generation.

For future projects that uses a biomimetic approach and technocards along with it, it is important that the research and brainstorm is done thoroughly in each area and first combined when part-solutions are merged into combinations and that time is taken to make the technocards precise.

1.14.6. Existing solutions

By creating an overview of the existing solutions for non-electric incubators, we have gotten a verification of the need for this project. There are few solar incubators on the market today and even fewer that solve the problem of heating during night. Kerosene incubators need constant monitoring and burn off a lot of fuel making them expensive. Common for most of them is that they use advanced components or material that makes them expensive and hard to build with the resources available in Volta.

1.15. Chapter conclusion

This chapter examines the context of use and the functional challenges of the project. In the Volta region of Ghana the need of an egg incubator is great, and as there is no power it has to be non-electric. To hatch eggs in an incubator some conditions must be in place:

- The temperature must be quite accurate at 37.8°C.
- The relative humidity has to be between 40-54%.
- The eggs needs oxygen and repositioning every day.

This information has lead on to the definition of functional challenges and from there to the findings of several biological and technical inspired principles that could be used in combinations to achieve successful incubation.

Ideation

2. Ideation

2.1. Chapter introduction

With the analysis in place and the information obtained, it was then time to move forward with the design process. This chapter contains the ideation and conceptualization process, and it ends up with a final concept that is ready for detailing.

The approach to the final concept was first a brainstorm on the different biocards and technocard developed in the analysis. As the ideas each solved a functional challenge, they were merged into combinations using a variation of the morphology method. This was something that Sylvester Shuster and Sigrid Hemmingsen helped with in a short "workshop". To conceptualize these combinations, the combinations had to be detailed and proven possible as concepts. Last, the best three concepts were found by a weighted objective method and further elaborated, whereas the best concept was chosen.

Ⓜ 2.2. Ideation with bio and technocards

When all the bio- and technocards were finished, we started with the second round of idea generation. We used the "brain walk" method (Innovation Blogs KU 2015), where we went over each card, and came up with ideas on how to use that principle. We used a timer and had 3 minutes to brainstorm on each card, before moving on to the next one. We did not talk during the session and the cards were in a random order, so that we would not get stuck in one direction. Every kind of solution and idea was allowed.

Ideation

Ⓡ Ideation with bio- and technocards

The result was around five ideas per bio/technocard (appendix 56). There were many different types of solutions amongst the generated ideas. Some of which were pure stupid and some ideas solved problems to other problems that did not concern this project. All in all many ideas were created, and all of them equally important as even the wacky ideas could inspire great solutions later on.

Result of ideation

Ⓜ 2.3. Combinations

To combine all of these ideas into a complete concept, two methods were used. The first method was a variation of the morphology chart, loosely structured. We did this in order to expand the solution frame and let the creativity flow. Afterwards, the structured morphology was executed.

2.3.2. Loose morphology

The reason for choosing a loose morphology was that, we believed that the size and possible solutions would be too great to handle in a traditional morphology chart. The number of ideas in each function and the number of functions would make the chart very large and confusing to handle and manage. Another reason, not to start with a traditional morphology was that we wanted to inspire new and creative solutions. Using a looser form of the method and an expansion of the solution frame breed some new and crazy ideas that might not have showed up in the more streamlined traditional version of the method.

The loose morphology was carried out by hanging all of the bio- and technocards in loose principle categories and picking solutions/ideas, one solution per function required.

As the part-solutions were picked quite randomly and not necessarily fit together. This in turn inspired new and innovative ideas. We did also try to make some solutions that we thought would work well, just based on our current knowledge of the solutions.

Fellow students helping

Other new and inspiring results came when we invited two fellow students, Sylvester N. R Schuster and Sigrid E. B. Hemmingsen, to pick random ideas, one from each needed function. We told them to pick the ideas that seemed awesome without the information that the ideas should be combined. This gave an odd edge to the combinations, some of which we definitely would not have combined.

2.3.3. Loose morphology

The result of the loose morphology was combinations of the ideas generated in the brain walk. Some of these combinations are logically stupid and would not work in reality, but derived small elements that could prove useful. This gave new thoughts on how to combine some ideas, which seemed not combinable. The results is found amongst the combinations in.

2.3.4. Sorting ideas and simplification

After making some combinations, we started to wonder if it was necessary to take all of the most stupid ideas further in the morphology process. Wacky ideas were then sorted in this process as they have served their purpose at this point of being an inspiration to idea development. To simplify further, a quick research was done and the analysis were looked over once again. As the brainstorm already was focused on the different functions, the ideas were categorized already from the start. This made it easy to sort them afterwards.

2.3.5. Sorting ideas

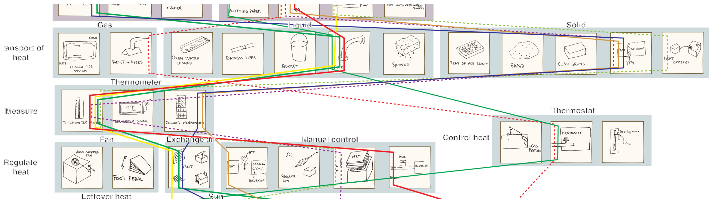
Many of our concepts included ways to automatically let moisture out of the incubator, which often proved to be very complicated. It turned out that it was very unlikely that we ever would need to let moisture out of the incubator due to the humid air in Ghana, and if that were the case, it would not need to be automatic. This resulted in the “regulate humidity” category being left out, and we were free from dealing with a complicated principle.

The ideas that were unrealistic and just plain stupid were sorted out. Appendix 57

Sorted ideas

2.3.6. Morphology

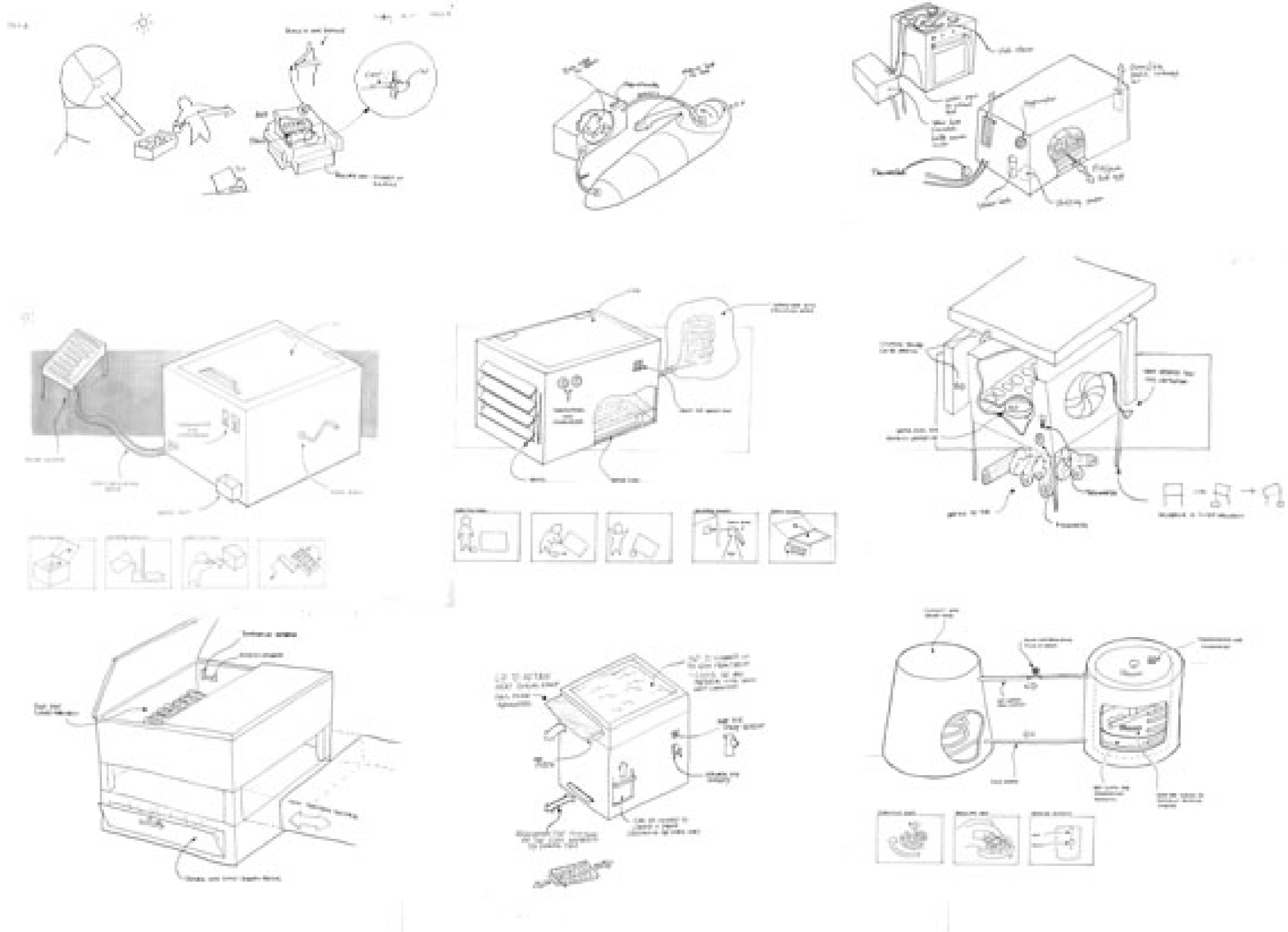
After the loose morphology, it was clear that we needed to structure some of our findings and ideas. We therefore opted to create a more traditional morphology chart. All of the already created solutions was inserted into a morphology chart and lines were connected to create an overview.



Morphology

2.3.7. Morphology

The result was a traditional morphology chart with all the concepts organized. With this, it was clear to see how the ideas were combined and whether or not all of the solutions were used. Several of the ideas were not used at all and some ideas were exclusively used. It was clear to see a repetition of solutions even in the different categories. For example, the regulation of heat, humidity and oxygen has the same solution; open hatch. This allowed the combination of some bio-/technocards and some solutions in order to organize the ideas properly. The morphology chart can be found in appendix 58.



R Combinations

The outcome of this insertion of combinations, from the loose morphology to the regular, was an immense chart with many complicated strings. Moving from the loose morphology to the regular morphology involved some simplifying of the functions (see sorting ideas above). As a result, the combinations had to adapt in order to fit in to the new "categories". This revision of the combinations helped working them through with more details than earlier. The product of this was nine combinations that are briefly described as follows:

- Combination 1: Some sort of stone heating mirror/paraboloid that heat stones/heat batteries transported by person to incubator. Temperature is regulated by insulation, humidity and air is regulated by automatic vents and the machine can be tilted. Appendix 61.
- Combination 2: Human body heat transferred to incubator as well as humid air. Humidity measured by color strip, temperature measured by hand. Eggs turned by chicken inside. Appendix 62.
- Combination 3: Leftover heat from stove is stored in tank of hot water that by thermostat can control the heat in incubator. Blotting paper provides humidity and manual vents can quickly exchange air. Eggs turned by push pull grid. Appendix 63.
- Combination 4: Water heated by solar panel and kept in tank for night heat. Incubator ventilated by lid, humidity provided by evaporating water. Eggs turned by turn handle and tray structure. Appendix 64.
- Combination 5: Heat transferred from hot compost pile to incubator by pipes, and regulated with valve or thermostat. Humidity is generated by spray in hole and measured by hygrometer. Machine can tilt to turn eggs. Appendix 65.
- Combination 6: Incubator heated by fire from below and regulated by varying insulation thickness. Ventilated by fan and a bowl of water inside evaporates into humidity. The whole machine can tilt on stands. Appendix 66.
- Combination 7: A combined incubator and oven to heat. The transfer material between the hot oven and incubator can be pulled in and out to regulate the heat. The eggs are rolled manually and the temperature and humidity is measured inside. Appendix 67.
- Combination 8: Water on top of incubator will provide heat and can be insulated during night automatically. Temperature regulated by manual vent and humidity is sprayed inside through a hole. Appendix 68.
- Combination 9: Compost heated incubator with a valve to control the flow of heat transfer material. Eggs rolled by turning handle on top. Temperature measured by thermometer and humidity measured by hair length. Wet cloth can be applied to generate humidity. Appendix 69.

M 2.4. Conceptualization of combinations

After creating the combinations, we figured out how the combinations would work, and how the user would use them. This is called conceptualization as the ideas expand from one idea, to the two dimensional design concept. It describes the two dimensions in a concept as an "idea with" and an "idea in". The "idea with" specify the socio-technical aspect of the concept. The socio-technical part of an idea often related to whom the concept creates value, how to use the concept etc. The "idea in" is the technical part of the concept, with a description of parts and features. In this section the idea in and the idea with each concept has been developed, and brought each combination to a concept level. (Hansen 2002)

Ⓡ Conceptualization of combinations

The combinations already describes the "idea in". The following is a brief description of the combinations "idea with" and will henceforth be called concepts. Common for them all is the general "idea with" the incubator. The idea with an incubator is that, by increasing the incubation rate and thereby the chicken production in rural Ghana, inhabitant's life value will increase as a result of more food and income.

Concept 1	stones as batteries - easy to control heat free energy - cost efficient
Concept 2	humidity and heat generation combined - easy control
Concept 3	use already generated heat - cost efficient, water tank gives constant heat- easy control.
Concept 4	solar pales gives constant heat - simple to control free heat - cost efficient
Concept 5	constant heat - esimple to control uses "waste" as fuel - sustainable
Concept 6	fire - reliable.
Concept 7	heat transfer material- precise temperature control. fire - reliable.
Concept 8	free energy - cost efficient automatic - less work and attention needed
Concept 9	constant heat - simple to control uses "waste" as fuel - sustainable

The conceptualization made it clearer what worked and where the flaws lay. Some unanswered questions emerged and we would need to figure out how to deal with these in order for the combinations to become proper concepts. All of the questions; will it work, how does that work, can this handle the limitations and so on, emerged and had to be explored.

Ⓜ 2.5. Proof of concept

By doing proof of concept, we looked for anything that would verify/contradict our assumptions, but did not make in depth calculations. This was mostly due to the reason that as it was still early in the project, we did not have dimensions and other details, and calculating without specific numbers is difficult. The proof of concepts were conducted in different ways, but primarily verified by research in literature. Other methods were also used such as quick experiments and tests; these are described in the prototyping chapter.

Ⓡ Proof of concept

2.5.2. Oxygen consumption

According to the article of "Gas exchange in avian embryos and hatchlings" by Mortola (2009) , the embryo uses different amounts of oxygen throughout the period of incubation. The average consumption of one egg is approximately 0.5L/day. This calls for some type of oxygenation. The simplest way to do it is by opening the lid a couple of minutes a day, preferably multiple times of shorter periods. The shortest period the lid need to be opened is defined by the shape and fluid mechanics of the incubator and its opening. This minimum opening time can first be estimated in the detailing of the chosen concept. It was decided that the oxygen will be regulated with the opening of lid.

2.5.3. Heat capacity

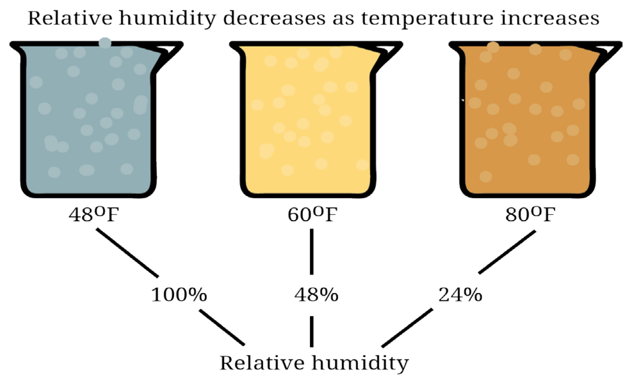
With periodic heat, generation it is be important to find a way to store the heat/energy in some type of "battery". This can be done by using the extra energy to warm a material. This materials heat capacity will define how much energy can be stored and thus how long the energy can last. Vital reflections are; is there enough, let us say solar energy, to capture during day or would the dimensions of the construction exceed the capabilities of the inhabitants and limitations of materials.

The heat capacity is different from material to material, and one of the best materials to use would be water. When fluid (above 0°C) the heat capacity of water is 4.18 J/g-K, which means that; in order to rise the temperature of 1 gram of water with one degree, it takes 4.17 J. The heat capacity of water are one of the highest heat capacities found in nature (Wikipedia 2015). This is why it is appropriate to use if accessible.

Another option is using a phase changing material in order to store or transfer heat. This does however require advanced knowledge on the specific materials, which we do not have. It is therefore decided that due to the period of the project, we will not look further into this possibility.

2.5.4. Humidity generation, is that needed?

The eggs need a humidity of 40-54% during most of the incubation period. During the last days before hatching, the humidity should be considerably higher at around 70-85%. Relative humidity is dependent on temperature; warmer air can hold a lot more water than colder air. In Denmark if you heat the outside air up to 37.8°C in order to use in the incubator, the air will be very dry and the need for humidity generation is large. In Ghana, the outside air is generally warmer but the relative humidity is still at 70-85%, thus it is clear that the need for generating humidity is less in Denmark than in Ghana. As seen in the calculations below, heating the Ghana air to incubator temperature will at most not reach more than 48% humidity, so in order to keep the desired 40-54% and a method of generating humidity is needed in the colder months. We can also see that a way to lessen the humidity most likely will not be required.



Relative humidity (Utah State University 2015)

Calculations

The following calculations are based on average measurements. The temperature in Ghana in this example are close to maximum temperature.

- 6.5°C and 79% humidity becomes 11.51% at 37.8°C (McNoldy 2015) in Denmark (DMI 2015).
- 32°C and 67% becomes 48.56 % at 37.8°C in Ghana (Timeanddate.com 2015)

2.5.5. Circulation of water, self-circulation

The question here is whether a hot and cold closed loop system can circulate without any type of pump. According to Knud Erik Meyer, this is possible if the system has a height difference, due to the density of hot and cold water (The Engineering Toolbox 2015a)

2.5.6. Vegetation and compost in Ghana, is it to dry?

“Moisture is very important for compost requirements, but not wetness. Balance is important here … not too much water or too little. In hot weather, it is important to keep the compost moist. When there is rain, protect the compost to prevent nutrients from leaching out and away.” (Organic Garden 2015)

If the compost is too wet (>60%), the process will become anaerobic and most likely start to smell. If the compost is to dry (<30%), the microbes will not thrive, and the composting will be a lot less effective. Below 15% humidity, the composition stops (TheCompostGardener.com 2015). If the compost is too dry, one can add water to reach the right humidity. As the Volta River is available as a source of water, the humidity of the compost should not be a problem.

2.5.7. Compost, is it sanitary?

As long as there is no meat or dairy products in the compost heap, there should not be a problem with sanitation and composting. If meat is thrown in the compost, it can bring pathogens such as e-coli. In the warmth of the compost, those pathogens will thrive. Meat will also bring a lot more vermin than ordinary composing material. In order to avoid harboring diseases, it would be best to avoid meat and dairy products.

Another problem might be odors. Meat especially will develop a strong smell, if not treated with care, but plant matter will also develop odors if there is not enough oxygen present (Organic Garden 2015). Turning or ventilating the compost is therefore important in order to avoid bad smell.

The only real problem with sanitation is if the compost attract vermin (AffaldPlus 2009). Rats and other pests can bring diseases and should be avoided as much as possible. There are, however, many ways to stop vermin from getting to the compost, for example using a container. We therefore conclude that if meat and dairy is avoided, composing is sanitary enough for use together with an incubator.

2.5.8. Is it possible to turn/ventilate compost pile with pipes in it?

There are several challenges when using a compost heap with metal pipes in. First, how do one flip the pile frequently? With pipes in the heap to extract heat, there is a challenge with turning the pile. Another challenge with water pipes in a compost pile is degeneration of the pipes. Metal in a compost pile will rust quickly, which means that the pipes should be surface treated. Both of these problems will be classified as solvable or acceptable, as water hoses might be accessible.

2.5.9. How large does a compost heap have to be in order to work?

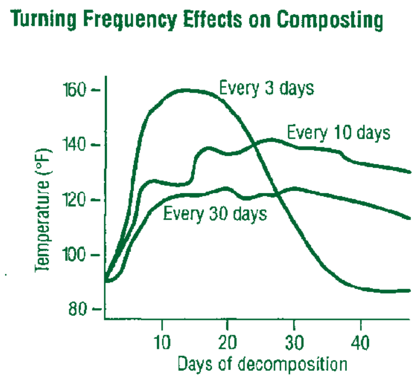
The compost heap needs to be at least 7 cubic feet, in order to work properly and generate heat. (Organic Garden 2015).

2.5.10. Can hairs be used to create a hydrometer?

Yes, absolutely. If hydrometers prove too difficult/expensive to use, looking into creating our own hydrometer is a possibility. They are, however, quite fragile so this should be taken into consideration (Williams & USTODAY.com 2005; Science Buddies 2012)

2.5.11. Will a compost heap produce enough heat?

According to the Practical handbook of Compost Engineering (Haug 1993) different types of compost piles will have different heat curves in a heat/days diagram.



Temperature curve compost (Urban Composting 2014)

From the diagram we can see that the composts produce the needed heat over the needed number of days. The compost pile as a heat source is therefore a valid suggestion.

M 2.6. Sketching

With the concepts found in the combinations and the conceptualization of said, it was then time to sketch the concepts and thereby visualize them. With the broader understanding of the principles, it was also possible to get some of the details in place.

Sketching is a great way to do visual prototyping. With this method, one is forced to think of connections, details etc. that hitherto was unthought-of.

Sketching

R Sketching

Drawing the concept made us have to think about how all the part solutions would work together and the proof of concept phase gave us an understanding of whether or not it would work. Often we realized that some ideas would not work together, or they could be combined into one. The different level of complexity also showed when the concepts were made into whole solutions rather than just a collection of part-solutions. Sketching also made it a lot easier to discuss the different concepts, and the more detailed the sketch, the easier it became to understand each other's thoughts behind choosing different part-solutions.

M 2.7. Choosing concepts

The choice of the three final concepts was a result of a Weighted Object Method (WOM) (Nigel Cross 2008). This method works with points within a number of categories that are weighted against each other. The importance of the category and the points given, was based on our obtained knowledge and reasoned assumptions.

R Choosing concepts

The product of the conceptualization was the nine concepts that in this section will be boiled down to three final concepts. Of these three concepts, one will be chosen in cooperation with Torben Lenau and Eddugle Akwetey as base for the final phase of this project - detailing concept.

When weighing the categories, some design tradeoffs arose that we had to take into consideration. One of the important tradeoffs was the one regarding portability and capacity: to have a portable machine or to have a high capacity. The result of this discussion is that; it would be great to have a portable machine, but it is more important to have a working machine. By working, it is meant that it needs to hold the minimum the amount of eggs detailed in the four-box method; 50 eggs.

With this in mind, we had to explore the possibilities for each of the concepts on how portable it is compared to how many eggs it could hold. It was found that all of the concepts could be scaled egg wise but not all of them were portable. This examination of the concepts therefore resulted in the ignoring of size/capacity as a parameter in the WOM. The portable parameter was still not as important as others, but could then be given values. Likewise, the common scalability was not an important parameter because all of the solutions are equal scalable, and was therefore be excluded in the process.

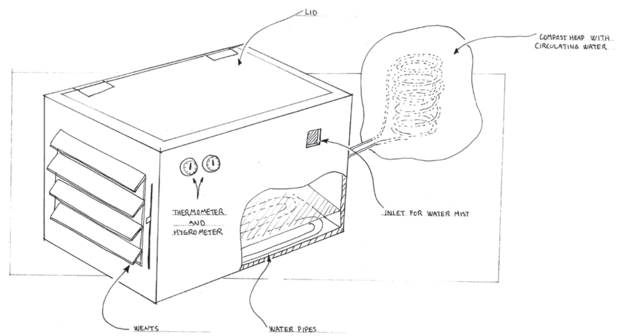
Production time and cost is another tradeoff we had to keep in mind. Ideally, we would want a short production time as well as a low cost. However, as the intended users do not have many financial resources, we chose to weight a low cost higher than the time it takes to construct. As a result, cost was weighted higher in the WOM.

The WOM summarized the concept generation and produced a score for each concepts. Some of the parameters from the product specification had to be excluded as the example above shows regarding size. Other excluded parameters were lifetime and cleaning, as these depend much on the detailing of the concept, and could thus not be estimated. The result of the WOM appendix 59 was three concepts that should be compared and chosen from. The winning concepts was concept 5, second place concept 4 and third place concept 9, respectively appendix 65, 64 and 69.

2.7.2. Three concepts

The three final concepts that got the highest scores in WOM are described in this section.

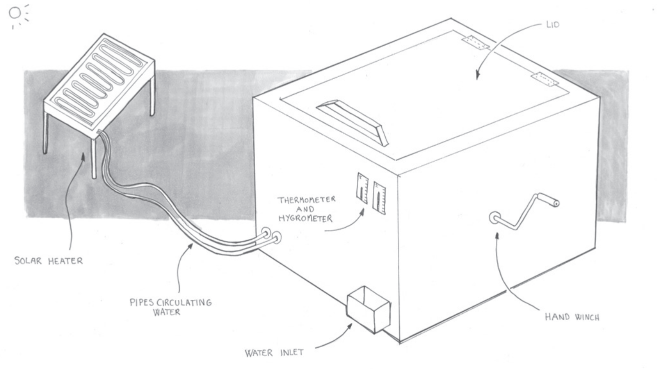
Concept 5



Concept 5

This concept relies on simplicity. It has a natural way of producing heat; a compost pile with water hoses in. The temperature will be regulated by vents and measured by thermometer. The humidity is controlled by a hygrometer and spray bottle, but could in poor places be substituted with wet cloth. The whole machine can be tilted with an appropriate size of stone or other object that ensures the turning of eggs. The machine is all controlled manually, both temperature and humidity regulation as well as tilting. This increases the simplicity of the machine and keeps the cost to a minimum.

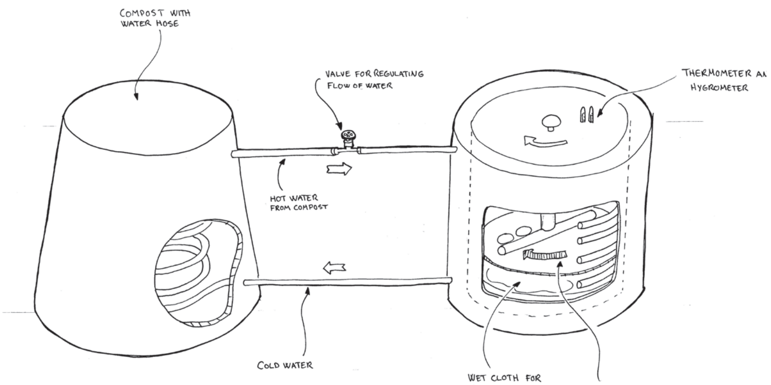
Concept 4



Concept 4

This machine is also simple to use and control. It utilizes the sun's energy by extracting it through water hoses that absorb the energy. This hot water is first transported into a tank, which contains a large amount of hot water. This is done in order to keep the incubator hot during night. The hot water is then used to heat up the incubator as needed. The way the eggs are turned inside the incubator is by a handle that turns a grid-like egg tray inside. A small container hold water in the bottom of the incubator in order to provide the needed humidity.

Concept 9



Concept 9

This concept utilizes the natural flow of hot and cold water through an elevated system to transport the hot water from a hot compost pile to the incubator. It uses a valve to control the amount and flow of hot water to control and regulate the inner temperature, measured by thermometer. It uses hair as a humidity sensor, but could easily be switched out with a hygrometer if accessible. To generate humidity, a wet cloth is simply put in the incubator, and the hot air will evaporate the water. The eggs are turned by rolling, which is done with a handle in the top lid.

2.7.3. Comparison

By comparing the concepts, it is seen that the main difference between concept 4 and concept 5 and 9 is the heating method. As shown in the morphology chart, the compost piles will generate constant heat throughout day and night over a longer period, whereas the sun only provides heat during day. The solution of sun-heated water is then required to be accompanied by an extra solution - storage of heat.

The rest of the differences lies in the small part-solutions. These part solutions are very independent from each other and could therefore be used separate of each other. The three final concepts are therefore very different, but since this is mostly due to the many part solutions, they could also be combined in several different ways. With the same heat source in concept 5 and concept 9, the only difference lies in the extra features. This means that the winning concept may not have the best part-solutions, but it definitely had the most of the best. This is why the concept is far from complete at this point, and could be improved by integrating elements from the other concepts.

The radar chart illustrates the different solutions on the various parameters, (appendix 60). The radar chart shows that the winning concept, concept 5, might be improved in easy operation and portability to reach greater success. Similar could the other concepts be improved with this chart.

2.7.4. Choice of final concept

The chosen concept is a combination of concept 5 and 9. Since the only difference on the two concepts are features independent from the design it did not make sense to choose one over the other, but rather decide on the compost as a heat source. The compost pile generates a constant heat that ensures a stable temperature inside the incubator. The rest of the features and specifics are handled in the next chapter - the detailing of the concept.

2.8. Reflections on Ideation chapter

2.8.2. Ideation process

After the first half of the brain walk with the bio/technocards, we realized how tiring it is constantly to try to come up with as many new ideas as possible, on a time limit. In order to get through the session, we had to take a couple of breaks. We were surprised of how many different ideas we were able to come up with even though it was just the two of us. All in all the method was an effective way of getting all the small thoughts we had on how to solve the different functions, down on paper. It also allowed for many new thoughts, and since we were not discussing the ideas as we wrote them down, it was possible to idea generate on each other's ideas unhindered by what the real intention behind the idea really was. We also realized that some bio-/technocards covered more than one function, for example does a thermostat both measure and regulate heat as the function tree describes.

2.8.3. Combinations reflections

A realization of the transfer from loose morphology to regular morphology is the lack of use of some ideas, as well as scrapped ideas. We expected, that this way of organizing this part of the design process, first with a loose morphology and then arrange the solutions in a chart, would give more inspiring solutions. Instead, by using the loose morphology, we lost the overview over the ideas and did not end up exploring the whole solution space. It was clear to see some favorites amongst the ideas as they were used multiple times. The regular morphology helped us gain insight on this problem and it is something worth thinking about in future projects.

On the upside of this process, the loose morphology gave interesting results, as we estimated that when the combinations of post-its did not depend on each other and were not fixed, it produced innovative ideas. However, if you are not aware of the possibility of combining several solutions from same function valuable ideas could be lost. An example of this could be that solar panel and combustion does not exclude one another and could therefore be used as a combination from day to night.

2.8.4. Proof of concept

The proof of concept was an important part of this process and gave a lot of insight in the ideas that we were unsure about. It validated many of the ideas we had used to create concepts and gave an estimate of how good an idea was. The proof of concepts could have changed many things if we had found problems with our idea. An example of this could be the compost heat generation. If compost did not produce enough heat, something we had assumed it would, one of the main concepts would have fallen through. Luckily, most of our assumptions were correct, and some things turned out to be better than expected.

The proof of concept is a great but time-consuming method of verifying ideas and combinations. One could argue that it would have been better to do a proof of concept after the final concept have been chosen in order to save time.

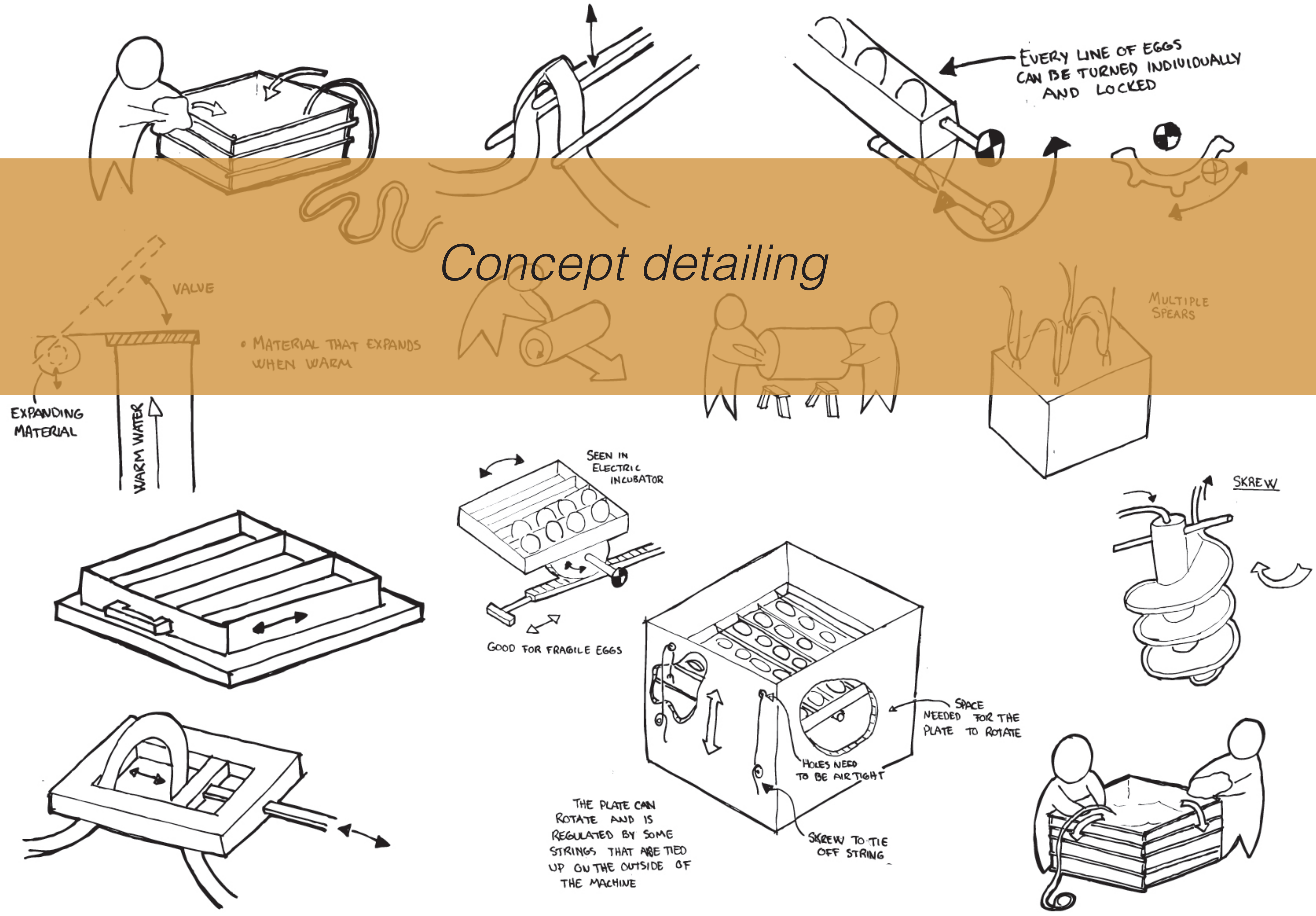
2.8.5. Sketching reflections

Sketching has been a vital tool in this part of the project. We have used it to idea generate, and since it is a lot easier to explain an idea with a simple sketch rather than words, it has been a valuable way to communicate our ideas. When returning to ideas that have been left alone for a while, it is also a lot easier to remember what the idea was about.

2.9. Chapter conclusion

The ideation chapter explores the possible combinations of the principles found in the analysis. These combinations are the result of brainstorming methods on the biocards and technocards followed by variations of morphology methods. The nine combination were conceptualized and the foundations of the concepts were proved or disproved. The three best concepts were then examined closer and one final concept were chosen for further work.

Concept detailing



3. Concept detailing

3.1. Chapter introduction

With the final concept chosen in the last chapter, it was time to detail the concept. The choice landed on the compost-heated incubator, where hoses are used to transport hot water from the compost pile to the incubator. In the following chapter, the rest of the choices regarding the details of the incubator are described.

Ⓜ 3.2. Concept detailing

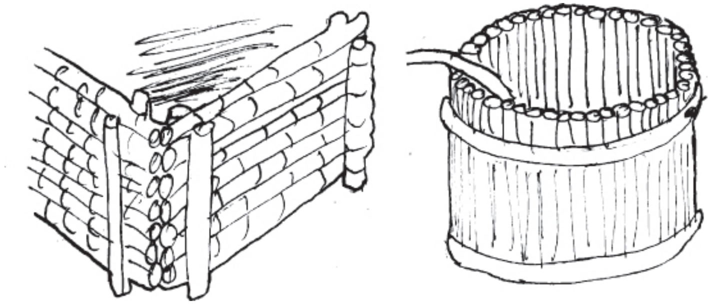
The methods used to detail the different functions has mainly been quick brainstorms with inspiration from already existing ideas. In order to choose the best solution, the positive and negative sides as well as different scenarios of each solution has quickly been discussed. In most cases the best solution was not too difficult to land on, based on our previous and obtained knowledge in this project.

Ⓡ Concept detailing

3.2.2. Compost module

General design

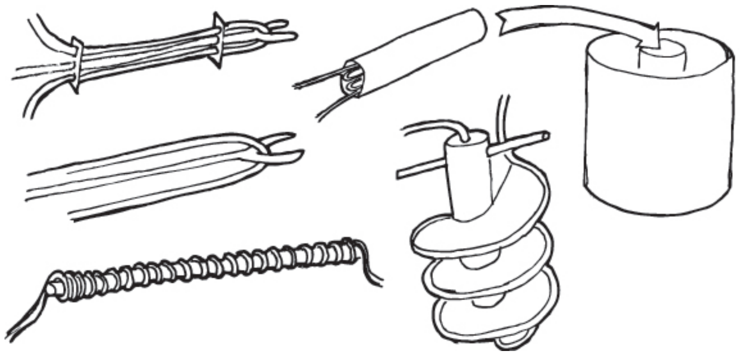
The general shape of the compost pile can be designed in many different ways. Cylindrical, squares, hexagons and other shapes were on the drawing table. (Appendix 72, 73). The shape of the compost pile can determine how efficient the extraction of heat could be and in general, how much heat that dissipates. All of these considerations had to be taken into account when not only sketching and brainstorming the hose design, but also when examining the process of the flipping of the pile and so on.



General design consideration

Hose design

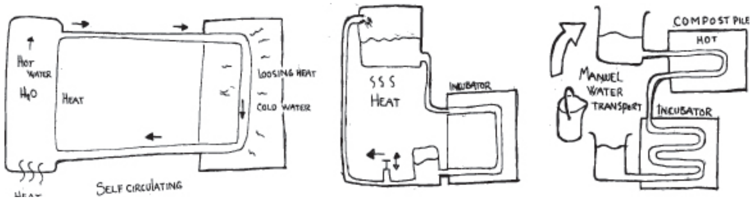
The way to extract heat from the pile can vary, depending on the general shape. It was tried to sketch several solutions that did not depend on the shape, so the final choice of hose design and general shape would be the best individual solutions. Nevertheless, with that goal in mind, it is hard to overlook the shape as a driver of the hose design. The result of the hose design brainstorm was several appendices that explored the possibilities. They can be seen in appendix 74-75. A specific hose design was at this point not chosen.



Hose designs

Water circulation

One of the features that welcomed an automatic solution was the circulation of water. The circulation had, at first, manual, semi-automatic and fully automatic suggestions. However, after meeting Torben Lenau, it was concluded a fully automatic solution would be the best solution. One solution that Knud Erik Meyer was especially happy with was the self-circulating solution. This solution had an advantage compared to the other pumping solutions, as it needs no mechanical parts of any type. The principle is purely based on the fluid mechanics properties of water in a closed loop. Avoiding mechanical parts also means avoiding parts that can break, especially in a dry dusty environment such at the Volta region. Appendix 76



Circulation systems

Choice of design - Compost module

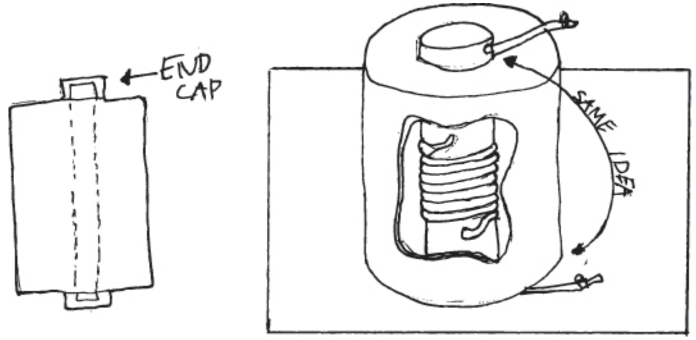
At this point, the general shape of the compost module was narrowed down to a simple box or a cylinder, as the construction is easier with these shapes, the heat extraction is possible with both and the materials needed to build them are accessible. The storyboard illustrates the different approaches to flipping the pile with regards to a barrel design and a box design. The storyboards (appendix 77) shows that with a box shaped compost module the flipping of the pile requires a lot of manual labor and could pose ergonomic problems. The flipping of the barrel compost module is easier, as one can simply roll the barrel a couple of times. The flipping requires little labor itself, however, getting the module back in upright stand or back on frame is hard, as the minimum size of 200 L is quite heavy.

The chosen design is a PVC barrel compost design, as PVC barrels are commonly available and the time and labor required to flip the pile is far less than with box designed compost module. The chosen circulation system ended up being the self-circulating system, and the hose a core with the hose coiled around.

Flipping compost

Attachment of hose (fixation)

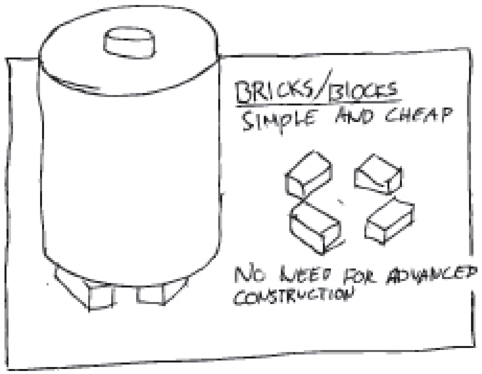
With the choice of the barrel shape, the way that the hose is attached inside the compost pile is important, making sure that the turning and flipping of the compost pile does not harm the hose or construction in general. Different structures and ideas to a hose design are shown in appendix 78, and the chosen structure is a centered PVC tubing with hose wrapped around tightly. The PVC pipe attaches to the bottom and top of the compost pile barrel.



Choice of design

Lift from ground

The compost pile needs to be lifted from the ground, especially with a part of the center pipe sticking out as shown on appendix 79. Several solutions could elevate the compost barrel from the ground, some ideas more advanced than others. The chosen idea is simply to put the barrel on bricks or blocks, to raise the compost barrel just enough so that the core does not touch the ground.

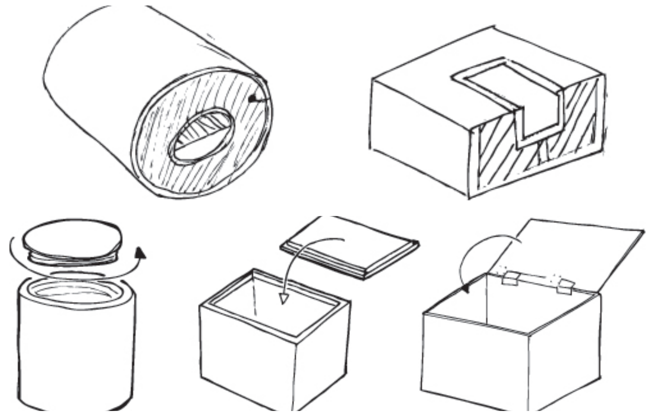


Lift from ground

3.2.3. Incubator module

General design

The final shape depends largely on the available materials and parts, as the incubator needs to be made locally and the incubator must be built locally. As with the compost module design, several shapes were examined. A box within a box with insulation between the boxes could be a great solution, however, more solutions was explored to fully examine the possibilities. Another solution inspired by the compost module could be a PVC barrel. The most significant reason not to use a barrel is that it is tricky to get it insulated properly without losing a lot of size. At this point in the process, the barrel was not precluded as it might hold some strengths in other details. Square solutions and other materials were explored in appendix 80.



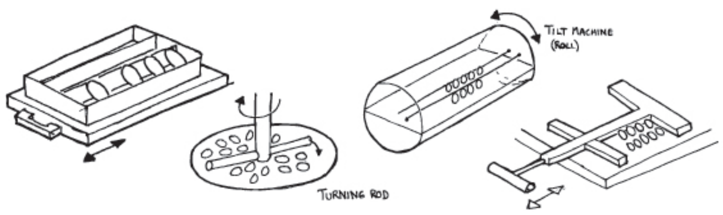
General incubator shape and lid design

Lid design

To ensure a closed box with proper insulation capabilities, a lid must be designed. The design of the lid depends on the design of the incubator. If the incubator end up being a barrel, a circular screw lid is a possibility. If the incubator ends up as a box, the lid can be of a more traditional type. Common for them all is the seal that has to be accurate in order not to leak heat (appendix 81). The final lid design was chosen according to the final shape of the incubator as well as the simplicity of the construction.

Repositioning of eggs

It is important to distribute the heat from the water hose evenly throughout the incubator, so every egg reaches the same temperature. To make sure of this, the eggs lay on a fine meshed chicken net that allows flow of air through but still has enough friction for the eggs to roll when pushed. Many suggestions on the design of the sledge have been created in order to find the best and most simple design. The suggestions can be found on appendix 82-83. Important to is the difficulty of using multiple layers of eggs and the turning of eggs when laying on a circular surface. When the inner eggs, closest to center, has been turned the right amount, the outer eggs have turned too much.



Positioning of eggs

Choice of design - Incubator module

With the challenging dilemma of size requirements vs. amount of insulation, the PVC barrels is hard to use as the incubator module. No matter which orientation the barrels is fixed, it demands a more complex solution than a box within a box. As found in repositioning of eggs, a barrel design proposes a few challenges with regard to turning the eggs if the barrel stand upright. With a barrel that lies down, it is hard to reach the bottom of the module if one uses the ordinary lid. A lid on the curved part of the barrel is hard to insulate properly. The chosen design was a box within a box due to its simplicity. It can be built with easily available materials and can be scaled as needed.

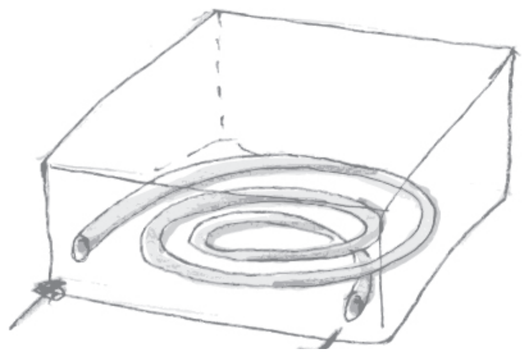
The square design

Size

The size of the incubator was established based on the requirements regarding egg amount. A standard, medium sized chicken egg is approximately 57 mm high and 44.5 mm (HowStuffWorks 2015) through its widest part. This creates some minimum size requirements in order fulfill the product specification goal of 50 eggs. If the eggs are spread out in one layer, with a 10 mm distance between them and some extra space for a sledge, it is summed up to an inner box size of 400 x 800 x 200 mm.

Hose design in incubator

The length and design of the hose inside the incubator is crucial to make sure the temperature is distributed equally. The temperature of the water will undoubtedly be highest at first and decrease as the water flows. The calculations of the hose length inside the incubator are based on the calculations of the insulation. The provided heat from the water hose should be equal to the heat transfer through the incubator walls. Different layouts for the hose have to be considered in order to find a configuration that distributes heat evenly. It can be found in appendix 84.



Hose design

Thermostat

The most critical need of the eggs during incubation is the temperature of the incubator. This calls for a precise solution, and preferably an automatic solution. By looking at the WOM and the combinations in the WOM, it was clear to that the best solution to control the heat is by using thermostat; a valve controlled by the inside temperature of the incubator. To ensure this possibilities of cheap and simple thermostats have been explored. Systems in air-cooled as well as water cooled car, simple hose clip valves and the opportunity of buying a thermostat are all examined in thermostat. The result of this small brainstorm ended in the selection of a Danfoss RAVV thermostat with a Danfoss RAV10 valve to control the hot water flow of the hose if accessible. The thermostats temperature range is 27-57°C and the maximum water flow of the valve is 1.2 m^3/hr. The price of this thermostat and valve is in total: 1300 kr. This is quite expensive to a family in rural Ghana hence other solutions was explored.

A regular thermostat to a household radiator has normally a temperature range between 5 and 26°C. One can imagine that this thermostat could be “hacked” in order to work within the required temperature range. This is still an unconfirmed hack that needs to be further developed. It should be possible according to Brien Elmegaard, but needs further detailing. In that case, the price of the thermostat and valve could be reduced. Appendix 85.

Insulation

The insulation of the incubator is likewise important to settle upon. With an estimate of the heat created by the compost pile, the insulation thickness is calculated according to the type of insulation. Several suggestions of insulation material are explored and validated by Eddugle. The following list shows the best candidates:

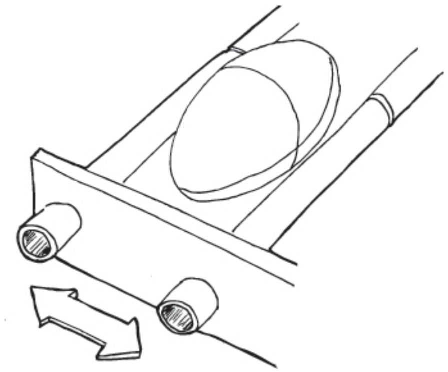
Type	Material	Lambda [W/m^2K]	Phi [W]
Sawdust	Wood	0,08	11,5
Foam mattress	Polyurethane	0,039	5,6
Styrofoam	Polystyrene	0,033	4,7

(The Engineering Toolbox 2015b)

Simple calculations find that with an insulation thickness of 100 mm, the total heat transfer of the materials lays below 12W. The choice of insulation material is sawdust due to its availability almost everywhere. The downside is that other materials such as foam mattress and styrofoam are approximately twice as good as sawdust. However, this is acceptable as an insulation thickness of 100mm is plenty. Appendix 86.

Specific repositioning of eggs

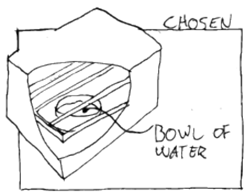
With the above standing details in place, the sledge which turns the eggs was developed. The size and shape of the incubator calls for a rectangular design. The prototyping of different sledge design gave interesting results as the size of the grid dictates the friction when rolling. By this small test, it is found that if the grid size of the sledge is too large, the eggs will diverge from the desired path. This leads to eggs that turn differently. In addition, too small a grid would not allow the air to flow freely around the whole egg. The specific ways to create a grid to push the eggs can be found on appendix 87.



Specific positioning of eggs

Generation of humidity

There are many specific ways to generate humidity, some easier than others. The number of times the lid is opened should be minimized as the heat dissipates every time, however, with a solution leading water from the outside in, there is a problem of sealing and visually seeing what happens. The final choice of humidity generation ended up being a bowl of water in the bottom of the incubator module. Appendix 88.



Generation of humidity

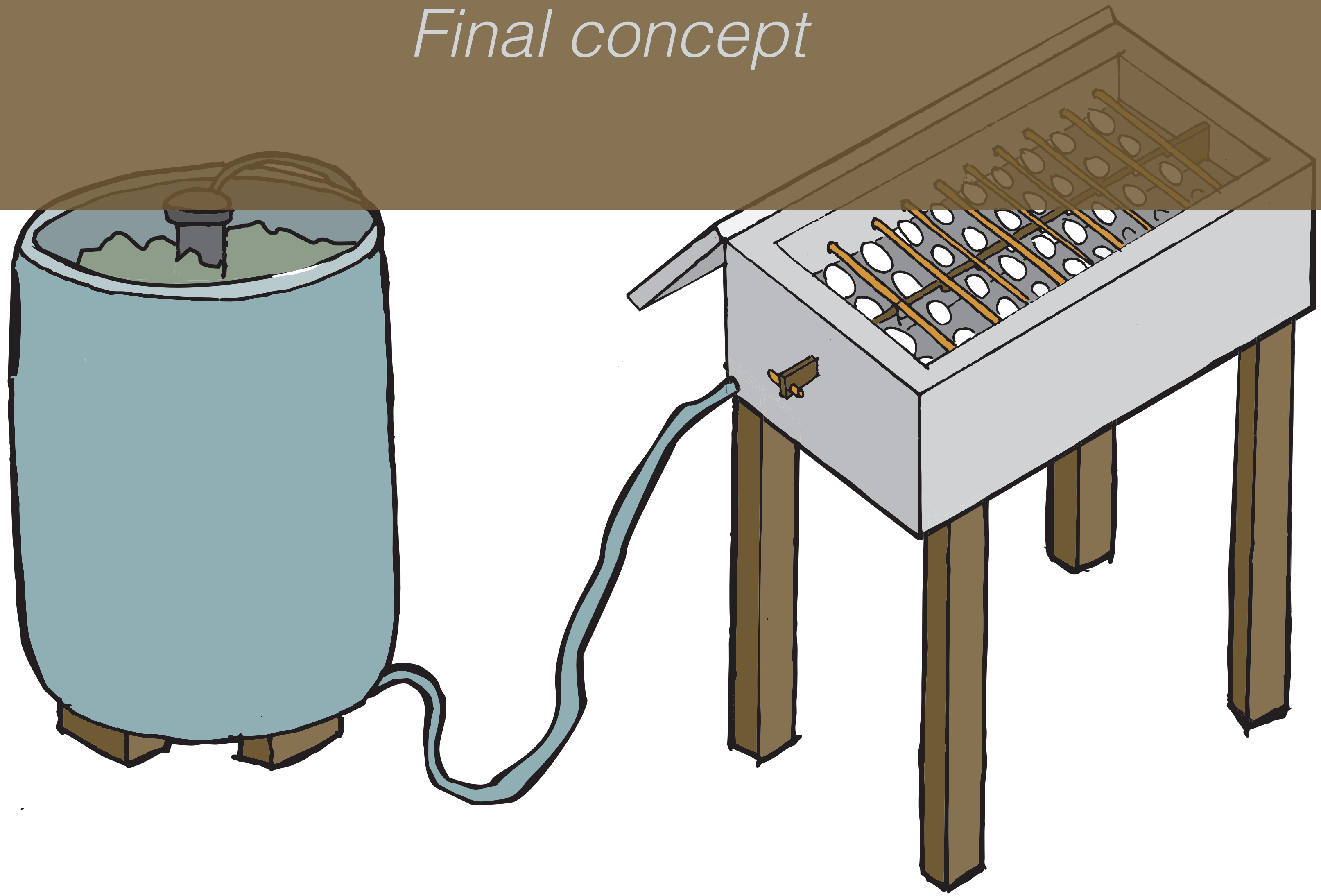
3.3. Reflections on chapter

This chapter has consisted of multiple quick brainstorms that has led to the specification of many incubator details. The quick brainstorms and examinations of every function could have been more extensive, but with the deadline, we had to shorten the process. The small brainstorms provided fast results and with this, it was possible to progress quickly. This might exclude the best results, as the whole solution space might not be explored. This was a tradeoff we needed to decide upon due to time constraint, as the goal of the project was to approach a functional prototype.

3.4. Chapter conclusion

This chapter explores the details of the concept by examining every function and finding the best solution with short brainstorms. The result of this detailing is the final concept with only a few unexplored details such as sealing of lid or calculating the fluid mechanics of the hose. These unfinished details will need to be explored later on, after the bachelor project is handed in. The plan for implementation and recommendations of further work can be found in chapter 6.

Final concept



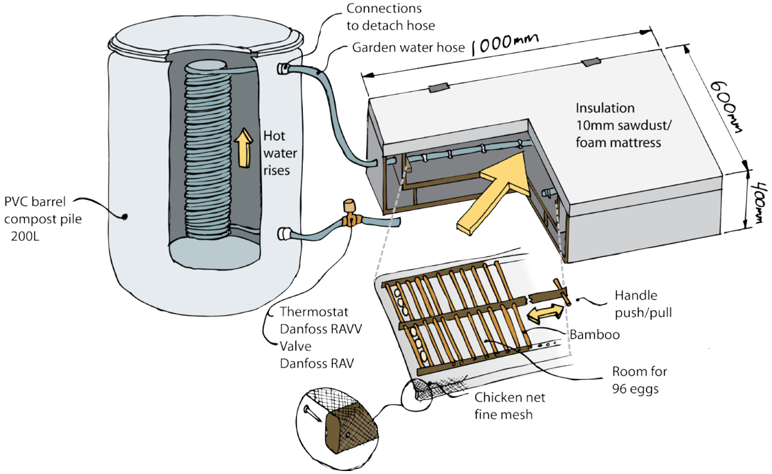
4. Final concept

4.1. Chapter introduction

The final concept is called Vitam Sterkus or "life by compost" in Latin. It consists of a incubator module and a compost module. The compost module is where the heat generation takes place and the eggs are hatched in the incubator module. Water is used as a heat transport material to transfer heat from the compost to the eggs. It is controlled by a thermostat and have a thermometer and a hygrometer for keeping an eye on temperature and humidity. The following chapter describes the details and key features of Vitam Sterkus.

4.2. The idea with and the idea in

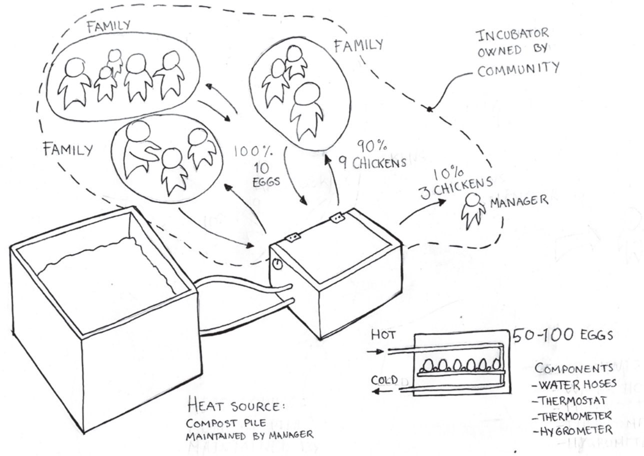
The ideas with Vitam Sterkus are (appendix 90)



The idea with the incubator

- An incubator that creates value through a new source of food and protein as well as a new possible way of creating income.
- An incubator that is sustainable in that it uses local resources and gives something back to the local community, chickens and nutritious soil.
- An incubator that makes use of a constant heat source in order to make a simple apparatus that anyone with a bit of introduction can run by without assistance.
- An incubator that creates unity in the local community. It is built and run as a community incubator.

The ideas in Vitam Sterkus are (appendix 91)



The idea in the incubator

- A machine that increases the efficiency of chicken production.
- A low complexity, cost efficient construction.
- An incubator that uses water as a heat transport material, compost as a heat source and generates humidity by evaporating water.
- An incubator built with local materials, flexible to what is locally available.

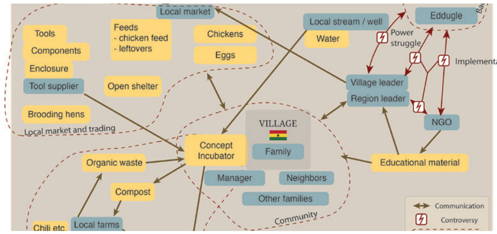
4.3. Development arena 2.0

The development arena from the analysis showed the structure and connections between the actors and objects as they were before an off-grid solution were implemented. With the new development arena, we tried to imagine how Vitam Sterkus performs in the arena and how the relations will translate. Appendix 92.

The idea of a community owned incubator gives incentive to cherish and care for the incubator, thus making sure it lasts longer. As seen on the arena, this community will exchange information within, which provides a base of knowledge and experience. This will lead to more experienced managers of the incubator, which provides basis for better incubation.

The community will also exchange information and material with local farms as the incubator generates nutrient soil as a by-product. Also needed to run the incubator is organic waste that conveniently could come from said farms.

The actual implementation process is hard to define with only the obtained knowledge hence the implementation controversies as seen in the figure. This, it is explored with the expertise from the EWB by the workshop in Chapter 6.



The new development arena

4.4. The compost module

4.4.2. Design and materials

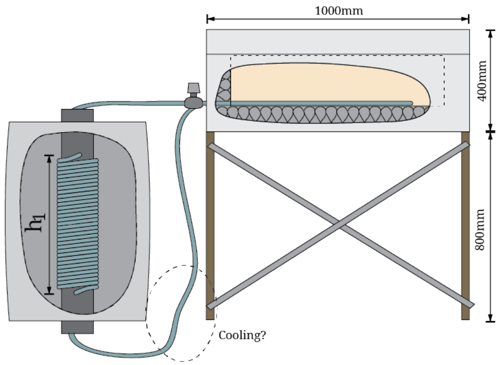
The final design features a PVC barrel for keeping the compost. The barrel needs to be 200 L or more in order for the compost to develop correctly and produce enough heat. There are no requirements for the PVC barrel other than the volume and that it needs to be closed. The barrel has holes in its sides in order to let oxygen into the compost. The holes can be created with a drill or cut out with a sharp tool. In this project, a 200 L blue PVC barrel with a height of 930 mm and a diameter of 580 mm is used.

To extract the heat from the compost module a hose is run down through the barrel. For fastening the hose inside the barrel, a PVC pipe is used as a core. The hose is wound tightly around the pipe that runs through the entire barrel. The project uses a pipe of 100 mm in diameter and 1000 mm length; however, pipes a bit smaller or larger would also work. The hose is threaded through the core in both ends and led to the outside of the barrel. Both ends of the pipe are sealed shut with an end piece in order to seal the air, and therefore also the heat inside, and keep the core in place. It is also possible to fill the core with an insulation material such as sawdust.

The compost module it lifted from the ground with bricks so that the core and the hose coming out of it is free from the ground.

4.4.3. Circulation System

The circulation system is made up of a set of hoses. With the hose going from the compost module to the incubator module, height difference is created and together with the difference in temperature, circulation is created. The two modules are connected by the hoses with the thermostat. Where the hoses meet there is a small plastic pipe that both ends of the pipe is threaded and clamped onto. They can be connected and disconnected by opening the clamps. Appendix 93.



The circulation system

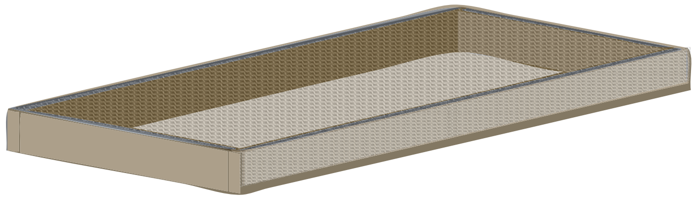
4.5. The incubator module

4.5.2. Design and materials

The outer material of the incubator needs to be sturdy and easy to build hence made out of plywood. It is a common material all over the world, often quite cheap and easy to cut into different shapes and sizes. The incubator is constructed as a rectangular box within a larger box, with isolation material in between. The recommended insulation material will be sawdust, as it is another easily available material, but the incubator is made so that using other materials is possible as well. The insulation thickness is 100 mm when using sawdust.

4.5.3. Shelf for the eggs

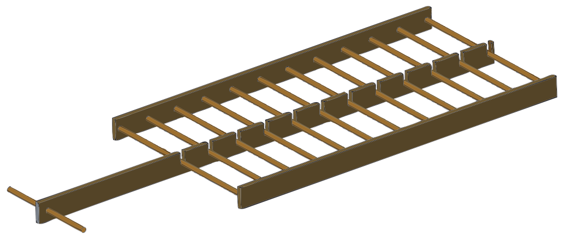
The eggs lay on a shelf of chicken mesh, so that the warm air can reach them all the way around. A fine mesh is used in order to give minimum resistance when changing position of the eggs. The net is attached to a frame and is positioned 100 mm over the bottom inside the incubator. The self can be removed when the incubator is being cleaned.



The shelf for the eggs

4.5.4. Repositioning of the eggs

A sledge is used for varying the position of the eggs. This allows for turning all the eggs at the same time without having to open the incubator. The sledge can be adapted to different egg sizes and markings on the handle indicate how far to pull/push. The eggs should be turned two notches every day, making the egg turn 180 degrees. Even though the sledge is designed to turn all eggs the same amount, it is recommended that one double-check this when aerating the incubator, as some eggs might not turn as well as others. When the first 19 days are over, the handle of the sledge can be removed and the sledge can be taken out in preparation for hatching. The hole for the handle is then sealed with a plug. The chosen design is a grid of bamboo and wooden lists with a handle in on the middle list. The grid is 2 x 11 mm and each slot can hold three eggs, which sums up to 66 eggs in total when calculating with the average eggs size (HowStuffWorks 2015). This number may vary, depending on the chicken.



The sledge

4.5.5. Heat source

The heat comes from the hoses running from the compost module to the bottom of the incubator. With assumptions of minimum 40°C water in the hose, the length is calculated to approximately 1.5 m; hence, the hose only needs to run in a U pattern to distribute the heat evenly. A thermostat is needed in order to control the flow of warm water and achieve a correct temperature inside the incubator. Either the thermostat is a Danfoss RAVV with a Danfoss RAV10 valve if available and affordable or a normal radiator thermostat customized to work at a higher temperature. In order to measure and keep track of the temperature, a thermometer is installed in the incubator. With the thermometer, one can make sure that the valve functions correctly. The thermometer used need to be precise with minimum intervals of 0.1°C.

4.5.6. Humidity source

As the humidity of the air in Ghana when heated to 37.8°C is close to the 40-54% needed, not a lot of humidity generation is needed. This is therefore done in the simple way of a bowl of water in the bottom of the incubator. The hot air will make the water evaporate. A hygrometer is installed so that the humidity can be measured and the bowl is filled as needed, using a small hose and a funnel in order to avoid spilling on the eggs.

A scale can be used to measure the weight of the eggs every 3 days in order to make sure they lose weight, as they should. This requires extra work as and a precise set of scales, but will give an indication of if the humidity and temperature are in the correct range.

4.6. The whole system

4.6.2. Placement

The incubator needs an outside temperature that is as stable as possible. The incubator should therefore be placed in the shade, and if possible inside a shed or closure. If placed in the sun the incubator may overheat, killing the eggs.

4.6.3. Ergonomics

In order to maintain an even temperature outside the entire incubator, it needs to be raised up from the ground. A height of 700 mm from the ground to the bottom of the incubator module will also ensure a good ergonomic working height(Cuffaro & Zaksenberg 2013). The building instructions provide a guide to making simple legs, but using a table or a similar construction would also work.

4.6.4. Construction

Vitam Sterkus is designed so that is can be built without complex tools or materials. The needed parts/materials can be seen in appendix 94

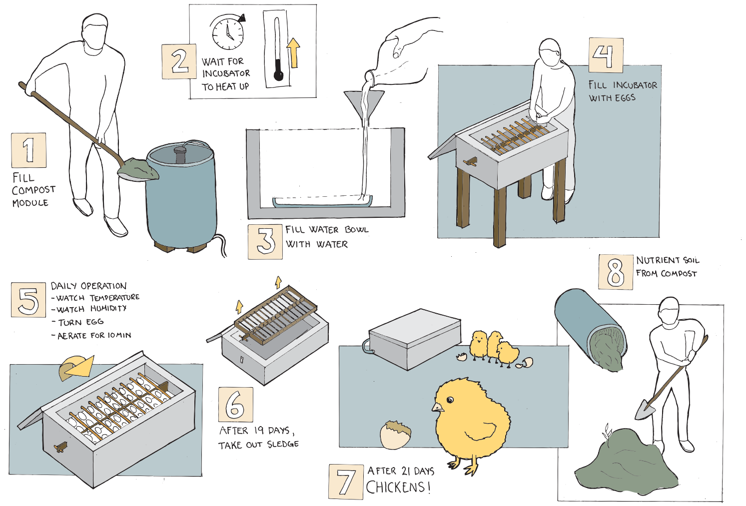
In order to build the compost module, the PVC barrel needs to be modified. Holes with a diameter of 5-15 mm should be cut in the sides, as well as hole of 100 mm in the bottom and on the lid of the barrel for mounting the core. Two holes of 20 mm is needed in both ends of the core for the hose to thread through. If an isolated core is wanted, the insulation is added after threading the hose. Appendix 95.

Then building the incubator module, the outer box is constructed first. The bottom is insulated and the support structure build before the inner box is constructed and the sides insulated. Appendix 96.

The mesh frame and the sledge is built separately and then placed into the incubator. When building the sledge, it can be customized to a specific egg size. The handle of the sledge should have notches showing how far to push/pull the sledge to make the eggs roll 90 degrees.

4.6.5. Operation

The start up procedure and daily operation contains several steps. The figure below illustrates the activities. The cycle of operating the incubator can be divided into 9 steps. Appendix 97



Storyboard of operation

1. The first thing to do is getting the compost module up and working. Organic material should be collected and the compost barrel filled up. Before filling the barrel, the core with the hose needs to be in place.

2. When the organic material starts degrading the compost will start to heat up. Depending on the organic material, this will take about 2-3 days (Trautmann 1996). The incubator should then start to heat up, and is ready when reaching 37.8°C.

3. When the incubator is warm, the water compartment is filled in order to generate the right humidity.

4. When both the temperature and the humidity are at the correct values, the eggs can be added. It is important to make sure that the eggs can roll freely in the sledge, so they can be turned correctly.

5. For 19 days, the incubator needs to have the right temperature and humidity. The temperature is regulated by the thermostat, but checking the thermometer occasionally is recommended to make sure everything is going all right. If the humidity begins to drop, more water should be added to the water compartment. The eggs need oxygen and the incubator module should be aerated for two times 5 minutes every day. This is done by opening the lid. The position of the eggs needs to be regulated a minimum of three times per day, and if more always an uneven number of times. Notches on the sledge handle shows the manager how far the eggs have been turned.

6. After 19 days, the sledge should be removed from the incubator module as the chickens are preparing to hatch and need to lay still.

7. After 21 days, the chickens will hatch.

8. After the compost stops delivering enough heat, the organic material has turned into nutritious soil that can be used to plant crops. The compost module can then be emptied for soil in preparation for a new round. To be able to run the incubations without days in between it is recommended to start a secondary compost module a few days before the first is emptied. This ensures that a new incubation period can begin just after one is ended.

9. Clean the incubator module and do maintenance of the system if needed.

4.6.6. Maintenance

Compost

There are a number of criteria for keeping a good compost. The rate of decomposition needs to be controlled in order to have the right heat output. The microbes in the compost needs oxygen in order to break down the organic material. This is provided by the holes in the PVC barrel, as well as regularly disconnecting the compost module and rolling the barrel a few meters so that the material inside will mix.

Turning the compost

It is important that the compost will be mixed regularly. When turning the compost, the temperature is likely to peak. However, if the compost reaches temperatures above 65°C, many of the microbes in the compost will die (Trautmann 1996). This can be solved by removing the end caps from the core, which will cool down the compost.

Moisture is another important factor. The moisture level in the compost needs to be about 40-60 %. To check compost moisture level, one can use the hand squeeze method (Compostjunkie 2015). Water is added if more moisture is needed.

Incubator

When the chickens are hatched, the incubator needs cleaning. The mesh frame can be taken out together with the water compartment so that the inside of the incubator can be emptied.

As 37.8°C is a good temperature for bacteria, the water in circulation system should be kept as clean as possible. It will also need to be changed out once a while. While doing this it is recommended to let water flow through the entire system to flush out any dirt or substances that could clog the hoses.

4.6.7. Price

The price is hard to determine, as the local price of the material is difficult to find. With this in mind, it is possible to make an estimate of the price, if the incubator should be produced locally in Denmark. The cost is estimated by prices from a Danish construction store. The full calculation can be found on appendix 98.

Estimate of cost in Denmark: 2436.49 DKK.

This estimate should be taken with a grain of salt, as the materials in the calculation are brand new. In addition, some parts, such as screws and cable ties are only available in large quantities. The three most expensive parts on the list; Danfoss thermostat, Danfoss valve and the plywood, pose 3/4 of the total expenses. The outer layer of plywood could be replaced with boards or other wood residues available. The thermostat could also be replaced with a cheaper version if the hack is possible.

4.6.8. Comparison of product specification

Overall, the criteria in the product specification are mostly met in this design. The comparison can be found on appendix 99.

- Under “use”, the product specification stated that is should be portable. This however, was not prioritized as much when creating the concepts and the final solution is semi portable in that one can move the parts fairly easy when separated, but not when the incubator is running.
- As we have not been able to visit Ghana to see what tools that

are available, it is hard to say if the incubator can be built in one week. It can be done with the tools here in Denmark, but might take a bit longer in Ghana. It should however not be more than a couple of weeks.

- A low cost incubator has been in focus through the whole process and it is our belief that the final concept is as low cost as possible when wanting precise results.
- It is difficult to consider the lifetime of the incubator, since we are not certain of the effect the high humidity and temperature will have on the wood. This is something that should be tested and if the result is bad, sealing the inside could be considered. The incubator requires some maintenance in order to keep the compost running and the circulation system and incubator free for bacteria. It only needs to happen after every cycle or two, the time used for this is not extensive and we conclude that it is reasonable.
- The humidity is regulated by the amount of water that can evaporate, and this is done manually. It might not be the most precise way of regulation, but as the humidity in the target area is not far off the wanted level, this seems a reasonable compromise for a lower complexity.

4.7. Chapter conclusion

This chapter describes the final concept in total. It describes how the Vitam Sterkus is divided into two modules, a compost module and an incubator module. They are connected with a hose that transports the heat from the compost module to the incubator module that is controlled by a thermostat. The next chapters regards the prototyping and the further work that is done or needs to be done in order to have the last details of a complete and fully functional solution.


Prototyping

5. Prototyping

5.1. Chapter introduction

In this chapter, the prototyping is used to test the concept concerning the construction and functions. It is an important step to take when finalizing a concept. When creating a tangible model one can experience the minor problems and challenges that can occur during the construction. The prototyping of the final concept has led up to a few realizations as the concept is fully worked through.

Ⓜ 5.2. Prototyping

Prototyping is itself a method to reveal flaws in the design or simply unthought-of aspects of the concept. We used the prototyping to comprehend every aspect of the technical solutions and how they are interconnected. One solution that needed to be prototyped was the transition of the hose from the outside of the compost module inner pipe, the core, to the inside of the core. The best transition could be modelled in a 3D modelling program but it is hard to imagine or simulate the natural bend of a garden hose with the given conditions.

Another of the experiment in this chapter was executed to verify the principle of self-circulation. The experimental setup can be seen in appendix 102, which consist of a heated water tank and a cooled water tank with a water filled hose between. Different variation was tried out with different height adjustments on the experiment to find the best suitable height.

Another of prototypes that lead to a design conclusion is a sledge prototype. The test of prototypes was executed with a couple of eggs and pieces cardboard in different variations.

Ⓡ Prototyping

5.2.2. Bending hose

The result of the prototyping was solutions to problems that we initially not knew existed. One of which is the transition of the hose mentioned in the method. Initially, it was not given much thought, but by prototyping, it was seen that the hose would bend with a too high angle that lead to much too much resistance. A couple of prototypes showed the best length and direction of the transition hole in the coil. Appendix 103.

Bending hose prototyping

5.2.3. Circulation prototyping

The circulation prototype showed in general that the circulation principle worked. It was possible to see that there was a flow through the system. However, it was not possible record the circulation visually (on film) as first intended. The original idea was to put particles in the water as markers, but they seemed to clog the hoses, hence no visual results. Appendix 104.

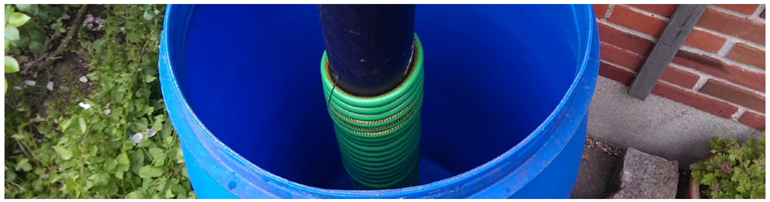
Another way, and the way that this test proved useful, was by detecting the heat in the hose circulating. By grapping the outside of the hose with a hand, one could feel a hot and cold part of the hose, just as expected. This proved the principle of self-circulation, even with a high friction hose. We recommend that further tests and prototypes of the water circulation should be executed, as there is room for improvement.

Circulation prototyping

5.2.4. Barrel prototyping

During construction of the barrel, several observations were done. The holes to the core in the bottom and on the top of the barrel are hard to fit while at the same time achieving a good seal. It was therefore necessary to use a pipe of softer PVC, rather than the hard and brittle PVC that was intended. Luckily, both hard and soft PVC were available when prototyping the compost module. This led to the recommendation of using a softer PVC pipe if accessible.

With the tight holes around the core, it is also quite hard to push and fit the core in the bottom hole. One needs to be physically inside the barrel with the core to get a proper working position and be able to push it through. If the hole were loose, fitting the core would be easy; however, this might result in dissipation of heat or loss of compost material. This operation is however still possible and one must remember that it is a one time job, and not a recurring event. In addition, to prevent the core from leaving the hole, it has to be secured with cable ties or similar in the bottom.



Barrel prototyping

The last important realization of the compost module prototyping was the difficultness of filling the barrel with compost. In itself, it is not hard to fill the barrel with compost, but when the core sticks out of the top, it gets harder. One has to manage the pitchfork, or whatever tool accessible, with compost material and fill the barrels through a relative small opening. This is however, acceptable as the filling of the compost pile is periodically. Appendix 105.

Prototype of the core

5.2.5. Sledge design

The sledge could be shaped in many different ways. This prototypes session revealed some important challenges to keep in mind. One of which, and the most important realization of this prototype was the gap between the eggs and the sledge. If the gap is too big, the eggs might roll in wrong direction. The gap has to be accurate to prevent this so the sledge has to be dimensioned by the average local eggs size. Appendix 106.

The sledge prototype

5.2.6. Further prototyping

Due to time constraints, the incubator has not been fully prototyped at the date of writing this report. The plan is to build the incubator module and connect it to the compost module in order to have a full prototype of the entire concept. It will probably not be able to hatch eggs, as there is still the question on calibrating the circulation flow, but one should be able to understand how it all works and get a feeling for size and shape. This phase is scheduled to take place right after this report is handed in and be finished before the presentation.

5.3. Reflections on chapter

The prototyping has proved very useful for the project. Even though we thought that we had most of the details figured out, there was several things we realized while actually building, like how filling the compost module was more difficult than expected and that the angle of the where the hose exit the PVC pipe has to be as small as possible. Prototyping has also given some verifications, for example that the sledge principle worked and that the circulation of water was possible.

5.4. Chapter conclusion

The prototyping has revealed many flaws and details that has to be implemented in the further work. With the deadline approaching, the prototyping had some time constraints and had to be pushed towards the final deadline after hand in of the report. The prototypes that were made in this chapter provided important realizations to minor details such as the correct way to bend a hose and the proper dimensions of the sledge depends on the local eggs size.

Next step

6. Next step

6.1. Chapter introduction

This chapter concerns the activities that needs to be done before the project can be used as intended in real life. It is based on the results of two methods and a workshop that explores how approach to the next steps of the process. The chapter also mentions some of the technical details that need to be worked out.

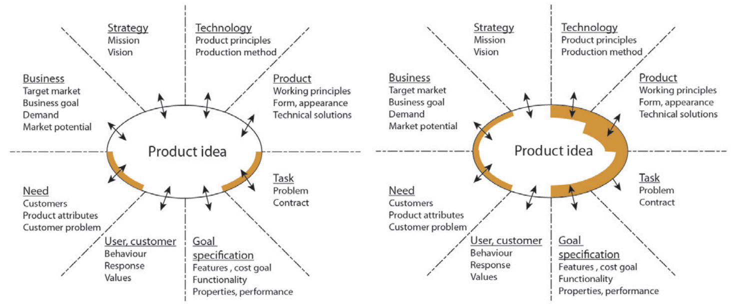
M 6.2. The eight product dimensions

The product idea model is a way to describe the eight product dimensions of the concept that is developed in this project (Hansen 2005). Often, the method is used to describe a situation and show the room for improvement, but in this chapter, it will also be used to describe the development of the project to fully understand the process so far, and thereby provide a better grasp of the next step of the process. The eight dimensions are:

- Strategy
- Technology
- Product
- Task
- Goal specification
- User, costumer
- Needs
- Business

R The eight product dimensions

At project start, we got a task of developing an off-grid egg incubator. This task or problem was based on the basic need of food and income as the Akosombo Dam has reduced the agriculture in the Volta region of Ghana. The project start is illustrated in the left side of the eight product dimensions figure, as seen below (appendix 108). The right side of the figure illustrates the point where the bachelor ends and how far each aspect has been explored and described. In the project, the market potential and the demand has briefly been examined. The task has been elaborated with goal specification and basic specification. Functional principles were developed and the product has taken shape.

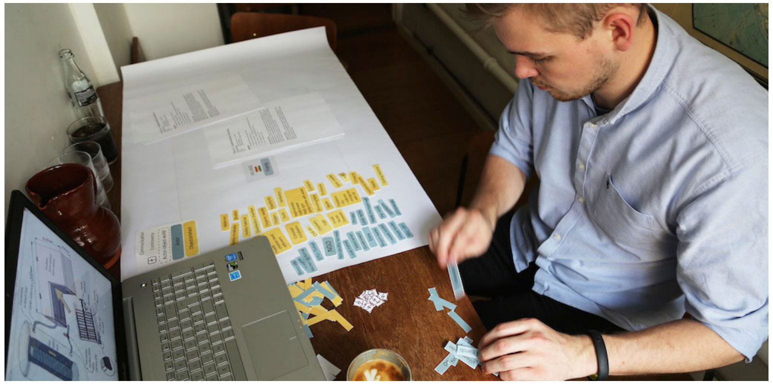


The eight product dimensions

With this in mind, the figure also illustrates the room for improvement. The strategy and vision of the implementation has yet to be found. This lead to the workshop in the next section, which briefly explores the strategy of the implementation process. With this project, the user and customer dimension has been difficult to determine, as the only contact with a local, has been with Eddugle Akwetey, son of regional chief. In addition, to keep in mind is the prospects of implementation in other countries that has similar problems but different users. Implementation in each country requires a user analysis and a tailored implementation plan.

M 6.3. Workshop - plan for implementation

The other method that was used to explore the next step was a workshop with the idea holder Eddugle Akwetey and two members of EWB, Troels Theilby and Jon Spangsvig. A participatory workshop is a great way to extract knowledge from the experts. The goal of the workshop was to create a "to do" list of the implementation and talk about some of the general challenges of implementation. In the workshop, Synne and Morten were the "game masters" and mainly facilitated the workshop and leading the discussions along with questions etc. Appendix 109-110.



Morten preparing the workshop

The workshop had six steps on the agenda:

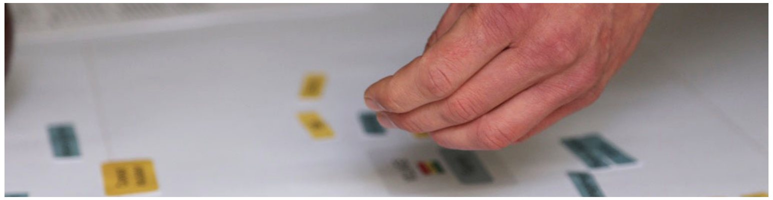
1. Presentation of project and context
2. Presentation of concept
3. Workshop: Arena game - The path to a successful implementation
4. Compare arenas - significant differences
5. List of implementation
6. List of five challenges

First, the project and context was presented. It was presented regardless of any participants already obtained knowledge of the project in order to have a common starting conditions of all workshops participants. The concept was then briefly described. The main part of the workshop consisted of a "game" where Eddugle Akwetey, Troels Theilby and Jon Spangsvig was asked to try and create a DA and discuss all the controversies and possibilities. This part was the foundation of the next three steps of the workshop. Step 4 was to compare our DA with the one created by the participants, and discuss the dissimilarities between. Step 5 and 6 was to summarize the workshop in a list of implementation goals/tasks and a list of approximately five challenges that needs to be handled.

The workshop in progress

R Workshop - plan for implementation

The arena game ended up being a good platform for sparking discussion and getting the participants to share opinions etc. (appendix 111). It did not take long before they began to put pieces on the arena and talk about what could be challenging and who had more or less influence and power. The participants did not approach the arena in the same systematic manner as we had when creating our version, but rather started with some of the most important actors and went from there (appendix 112). A lot of time was spent talking about the hierarchy and tribalism in Ghana and discuss how it would help and hinder the implementation.



Creating the development arena

The steps for implementation were also discussed, and different possibilities for realization of the project came up. There are three phases that needs to be completed in order for the project to become reality in Ghana or any country with similar climate. 1. Finishing of the technical aspect, 2. Testing and validation and 3. Strategy and distribution. Appendix 113, 114.

6.3.2. Phase 1. Finishing the technical aspect

Two options were discussed for finishing the technical parts of the project (precise calculations on the thermostat and circulation). One solution would be to pitch it as challenge for the engineers in EWB all around the world. Many of these engineers have experience with technical solutions in projects like this and using them is a resource would be logical. The other option would be to get some students involved (appendix 116). EWB have some contact with the mechanical students at DTU Ballerup. Figuring out the thermostat and circulation might be a great project for them. This option would probably produce results faster, as the most of engineers in EWB work on a voluntary basis.

6.3.3. Phase 2. Testing and validation

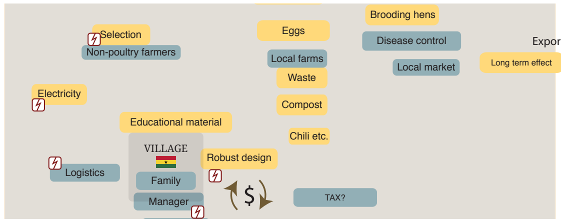
After the technical parts are solved, a test phase is needed. There are some different options for this. Testing in Volta, Ghana would be logical as Eddugle Akwetey will vouch for the project and help with the implementation. As he has a lot of influence in the area, many of the possible problems with getting the system around the incubator to work would disappear. However as EWB does not have a network in Ghana, some work has to be done before the testing phase can begin.

6.3.4. Phase 3. Strategy and distribution

One option that was discussed is making a "package solution" that can be handed over to local NGOs that want to use the project. The package would include a strategy for implementation, building manual and guidelines on how to make the incubator running. It would be up to the NGO to get in contact with the local people and figure out who should manage the incubator, as this will be different from place to place. This would mean that EWB would be responsible for creating the "package", while local NGOs would implement and follow up on the project. This would hopefully result in every project being followed more closely as well as customized to the relevant situation, which could result in a better outcome from each project.

6.3.5. Challenges

From the development arena created by the participants it was clear to see that there was five major challenges that could arise with implementation of the incubator. Appendix 115.



Development arena from the workshop

Choosing the manager

As the manager has a very essential role of the daily operation of the incubator, choosing the right person for this job could prove to be very important. There is a controversy in choosing the most qualified person for the job over the person people think is should be appointed (in the case where they are not the same person). The manager has a lot of responsibility but one can imagine that if the position is attractive that people try to get appointed even though they might not be a good choice. In Ghana, there is a strong tribalism and it would most likely be up to the chief to appoint the manager. In Volta, Eddugle Akwetey would help with this decision. A democratic strategy for choosing a manager would probably have to be developed if the incubator is to be used other places.

Robust design

The incubator needs to be thief and idiot proof. With the incubator full of eggs, it has a lot of value and some way of securing the eggs would therefore be a good idea. The incubator should also be tested as much as possible so that it will be hard to use it wrongly. It would be a failure if for example the lid was difficult to seal when closing, as this could easily result in all the eggs dying. It should also be easy to control the incubator without having to read a pile of instructions as not everyone in the target area has a proper education, and people's ability to read might vary.

Logistics

The overall logistics of getting the project out to people, gathering materials and transporting eggs and chickens is another challenge to be worked out. The infrastructure in rural Ghana is not very developed. The roads are difficult to drive and there are few options for public transport. This might prove to be a problem it one needs to get materials from some distance away. This can also make it more difficult to transport eggs and chickens around from buying and selling them.

Ecosystem

A completely new ecosystem will grow up around the incubator. One might want to get an agreement with some local farms in order to trade organic material and soil. The manager will in some ways have to adapt his or her schedule in order to fit in managing the incubator, however as this does not take up a lot of time it should be possible to do twice a day and still do other work at the same time. There needs to be an agreement on what happens if something goes wrong with the incubator and how to "pay" the manager. There might be a need for medicine and a veterinarian for the birds and a plan for what to do if there suddenly are too many chickens. The more different actors involved, the more possible controversies appear and some sort of plan is needed. This will need be figured out further when the first testing starts.

Electricity

Lastly, there is the question of what happens if the target regions get electricity? Eddugle is certain that this will not happen in the nearest future, and when it does electricity in Ghana is very unstable so an electric incubator would prove difficult anyway. However, it is an important thing to take into consideration. As the incubator has other strengths than being non-electric, sustainable and cheap being two of them, one can hope that would be attractive regardless of the access to electricity.

6.4. Detail for further work

At this point, the concept is in general finished. There are however, a lot of details that needs to be calculated or examined in order to have a fully functional machine that can live up to the product specifications. The workshop and the concept-detailing chapter left some unfinished challenges. These needs to be taken care of as mentioned in first phase of further work.

The sealing of the lid is quite important is the heat might escape if not sealed correct. If the wood warps, the sealing will not perform as intended. The wood might warp even more than naturally if it is exposed to warm humid air. This leads onto another detail that need considerations; sealing of wood from moisture and rot. To be able to reach the goal of an incubator that lasts more than 6 month, it might be necessary to seal the inside to prevent the inner box to rot.

Two more technical details that needs to be figured out is the thermostat and the water circulation system. It is earlier suggested that the thermostat could be made as a "hack" to a regular thermostat. This has to be explored further in order to have a low cost incubator. Furthermore, the thermostat and valve has be calibrated so that it matches the specifications of the flow within the hose. The calculations of the flow specifications is the second technical detail that needs to be handled. The best dimensions of the hose, length and diameter as well as the friction and other loss must be calculated.

6.5. Reflections on chapter

6.5.2. The eight product dimensions

The eight product dimensions really help with mapping out all the different aspects of the design process that need to be completed in order for a product to launch successfully. For us, it has been a good method for figuring out what needs to happen after our project is over in order for the incubator to become something "real".

6.5.3. Workshop

The participants did not use the arena in the same systematic way as we have used it. This might be due to a very short introduction, and the participants not being familiar with the method. They did need a reminder to write their thoughts down, but overall got hang of the concept quickly. Their development arena ended up being simple, but resulted in five areas of interest, or challenges.

We did however, get what we wanted out of the workshop, as the purpose was more getting a discussion going than making a perfect development arena.

6.6. Chapter conclusion

The conclusion of this chapter will summarize the final recommendation to EWB and the next step. The recommendations are divided into three steps. First step consist of the finishing the technical details. The technical details that needs to be worked out are:

- Sealing of lid to prevent dissipating heat
- Sealing of the inside of the incubator to prevent mold
- Calibration of the thermostat and circulation system in general

Second step includes the testing and validation of the concept, both technical and sociotechnical aspects. The following must be tested:

- Full incubation period test in Denmark
- Field testing prototype in Ghana
- Testing the implementation paths and choice of managers

The third step consist of creating a complete package to other NGOs. This package should contain:

- Building plans and part lists
- Manual and operation guide
- Implementation and domestication recommendations
- FAQ and challenges that could arise

Conclusion and reflection

7. Conclusion

This project has developed an off-grid egg incubator for use in rural Ghana.

The final concept, Vitam Sterkus has undergone a long design process. First the problem itself and the context of use has been explored in the analysis chapter. The problem itself has occurred due to the construction of the Akosombo Dam, which affected the natural agricultural environment of the downstream regions in a negative way. Jobs were lost and income reduced, and the lack of electricity in the rural regions proved the need of an off-grid incubator.

In addition to no electricity, rural Ghana proposes other challenges when considering an implementation of an off-grid incubator. Some of these were: availability of land, health and sanitation as well as management.

An incubator creates the same conditions for eggs as natural incubation by a hen. These conditions were turned into requirements:

- The temperature must be quite accurate at 37.8°C.
- The relative humidity has to be between 40-54%.
- The eggs needs oxygen and repositioning every day.

To meet these requirements principles and analogies were explored by a biomimetic approach. The found principles were described in a considerable amount of bio and technocards. The principles covered the found functions: generate heat, generate humidity, supply oxygen and reposition the eggs.

The bio and technocards established the platform of which the ideation could be based upon. A brainstorm created an amount of ideas on each bio and technocard and the ideas were combined and conceptualized into the nine concepts.

To narrow the concepts down to a single concepts for further work, a WOM was used. The three best concepts were further discussed and the final choice of concept was a combination between two of the three finalists. The chosen concept was at that point not final as many consideration regarding the design details has to be selected.

Vitam Sterkus is the product of the design process. It consist of a compost module, which creates heat, and an incubator module that receives the heat by a water filled garden hose. The flow of the hot water is controlled by a thermostat.

It is embedded in the concept that the incubator is driven and owned by a small community. This community will also be a base for sharing knowledge and experience to secure a high success rate. As the compost pile needs organic waste to create heat, it is expected that a symbiosis will rise between the local farms and the community around the incubator, trading nutrient soil for organic waste.

Some prototyping was done during the project. However, in the following period, between the hand-in of the report and the presentation of the project, Vitam Sterkus will be prototyped fully. This will hopefully reveal unthought-of details. Some details have already been uncovered with the prototyping of the compost module etc. The experience and results from this prototyping must be handled post presentation in order to have a fully functional concept.

Besides the finishing of the technical part of Vitam Sterkus, the next step also contains a “to do” list before implementation. Several testing and verification must be done before a package with all the required information can be distributed to other NGOs all over the world.

7.1. Reflection

The reflections of the methods used in this bachelor project can be found in the end of every chapter. This section will reflect over the general design process and discuss the general approach to the design work. A reflection upon the learning objectives is also described in the following, providing an estimate of the knowledge and experience we have acquired during the project.

The overall timeline has been followed however; a few detours and unexpected tasks moved the details and deadlines a bit. The most important detours of the project, was our own idea and perception of the need for a complicated and automated concept. The solution space was expanded to contain automatic solutions to every detail, where we forgot to pause occasionally and ask; is there a need for an automated solution to this functional challenge? For example, in the first brainstorms and search of principles, we tried to explore the idea of automated humidity regulation. Regardless of the need of such automated function. We brainstormed on and developed many solutions to this, only to scrap and sort the ideas when realizing that the need was non-existing. These realizations have been important, as we have learned a lot from them and now know the value of the pauses and questions one needs ask.

A tradeoff that challenged our perfectionism, was the concept detailing process. The phase of concept detailing could be, and should have been if we had more time, expanded to include more methods. The decisions were made quite fast, as the deadline approached, which resulted in an concept with room for improvement. This is not saying that if more time were given, the concept would have been perfect, as no concept is. However, with a few weeks or even a month more detailing we believe that the detailed features of the concept might have been designed differently, as more of the solutions could have been explored.

Another time-consuming detour was the scholarship application. As the timeline was created based on the belief that we could come to Ghana, if not two times then one, we were indulged with the idea seeking funding. Before we knew it, quite a lot of time had been spent on the application and all of a sudden, we had to develop a new plan and work around the fact that the project was based on a trip to Ghana.

Some struggles were also experienced during the writing of this report. From the start, both authors of this project has agreed upon the methods and content of the report, however; the structure of the report has been discussed a lot. Often, a normal scientific report has clear boundaries between the sections, hence the easiness of distinguishing the content. A design process is more loosely structured with methods intertwined, which is why we found it difficultness to compose this design report. Measures could have been taken beforehand by being aware of this challenge when using the methods and noting the exact use of methods. With this struggle, the authors did not have opposite opinions; it was just hard to find the right balance between the division of methods, results and reflections.

Despite of the lack of time to work with every detail as much as we wanted, we are happy with how the project turned out. The project has managed to explore a huge solution space and a solution that has a high chance of working in real life was found. Most of the decisions taken has a good backing and worked to make the incubator work for the given context and for the given target group.

7.2. Learning objectives

The following is a list of the learning objectives with a short reflection on the completion of these:

- Formulate a scholarship application and apply to relevant funds.

The sponsorship application was changed and perfected many times between Christmas 2014 and up to mid-March. It was send out numerous times to a lot of relevant funds and companies. Despite of not getting any funding, we have learned a lot about the process and now have experience with how to apply for scholarships that we can use in the future.

- Investigate and uncover information on chicken production and all its aspects.

Production of chicken was explored in many different ways, all of which methods from earlier courses at DTU were used. These methods, such as “follow the actor” and literature search, all helped uncover the chicken incubation. This goal is only half met as the rest of the chicken production has only briefly been discussed.

- Determine and understand the actors and their silent knowledge as well as the use context and use processes.

Through the analysis, we have found the actors that figures in the world of poultry production. Methods were used to extract the silent knowledge and hereby, fully understand the actions and requirements for successful incubation.

- Develop concepts based on the analysis by using tools such as biomimetics and other design practices.

Both biomimetic and general design procedures have been used to develop several concepts. Some of the methods that resembles were also compared to establish the best practices in the given context and situation.

- Carry out tests in order to get “proof of concept”, and thereby determine the effectiveness of a solution.

In the project, several rounds of proof of concept have been conducted. First, and the quickest way, was by searching literature of the principles that we needed explained or proved. When literature was not enough, we had to develop and prototype solutions ourselves too proof a concept.

- Produce boundary objects in the form of sketches and drawings to communicate a message, function or idea regardless of the recipient’s language and background knowledge.

Sketching is normally a large part of a design process, which also was the case for this project. From the middle of the analysis phase to the very end in the workshop, ideas, solutions, concepts and systems have been sketched to communicate between us selves or to external participants.

- Identify which resources and capabilities that are available in the area where the product is designed.

As we did not have the opportunity to study Ghana ourselves, we interviewed and discussed the context and area with the local contact Eddugle Akwetey. He explained a lot of the resources and available materials in Ghana as well as the social structure and communities in the villages.

- Execute a workshop, which develops one or more concepts in cooperation with the local population.

This learning objective is only partly completed, as we were not able to go to Ghana. However, we used EWB, including Eddugle Akwetey in a workshop to discuss and create a “to do” list of further work. Hereby we accomplished the goal of learning to use an expert in a workshop that regards their area of expertise as the initial goal of the objective was.

- Validate concepts based on decision tools and empiricism gathered as fieldwork and well as the effectiveness of the concepts.

The gathered empiricism was directly used through the product specification and later on in the WOM. The WOM is a great tool we used to range the ideas or concepts created and later on establish which element of the idea that were good and which parts that needs improvement.

- Evaluate the project and the tests/experiments performed as well as a perspective to the final concept to other different contexts of use and production conditions.

A reflection after each chapter evaluates the procedures and methods used. These reflections provided insights into the upsides and downsides of the methods and how they could collaborate. With the limited period, not a lot of technical experiments were conducted, and some will first be finished between the hand in of this report and the presentation of the project.

- Reflect on the project cultural and economic impact on the country where it is implemented and generally identify pitfalls of projects in developing countries

It has been hard to estimate the specific economic and cultural impact as we have not seen similar projects been tried before. Two common pitfalls are projects that do not work without constant economic support as well as products where the recipients do not have any owner feeling towards the product. We are handing the project over with the intention of the incubator should be community owned, and not a product distributed by the NGOs. The only things that the NGOs will help locals with is knowledge and constructions plans, but the community buys and builds the incubator. The further cultural and economic impact is an element to be figured out after the first field tests and try periods.

- Gain an understanding of how to create a sustainable concept that can operate independent of financial support over a longer time perspective.

It is hard to pinpoint the concept of a sustainable solution. We have however tried to find the best implementation through the workshop with EWB. One of the ideas with the incubator is to use local organic waste to create nutrient soil. In addition, it creates life by this principle, hence the name: Vitam Sterkus.

- Account for the final concept's utility value according to user group in Ghana and elsewhere in the world.

Local resources are used and the value from Vitam Sterkus is created by providing a stable income for the community that owns the incubator. A specific price calculation has proved that the incubator is relatively cheap, and by talking to Eddugle and the others from EWB, we have gotten positive feedback on that the incubator really could create some value for the intended users. Precise calculations on how much value would be added have not been made, as there are several details that still need to be figured out before giving a reasonable estimate.

Bibilography

Adei, D. & Asante, B., 2012. The Challenges and Prospects of the Poultry Industry in Dormaa District. *Journal of Science and Technology (Ghana)*, 32(1), pp.104–116. Available at: http://www.ajol.info/index.php/just/article/view/75598 [Accessed February 11, 2015].

AffaldPlus, 2009. *Din Håndbog om Kompost*, Available at: http://www.affaldplus.dk/c/document_library/get_file?uuid=6675d787-3213-406d-88e5-6791fc192e86&groupId=147099.

Agrawal, S., 2014. Electricity-Free Egg Incubator. Available at: http://www.ecoideaz.com/innovative-green-ideas/electricity-free-egg-incubator.

Akunzule, A.N. & FAO, 2014. *Livestock Country Reviews*,

Andreasen, M.M. & Hein, L., 1987. *Integrated product development*, IFS (Publications). Available at: https://books.google.com/books/about/Integrated_product_development.html?id=tZoSAQAAMAAJ&pgis=1 [Accessed June 7, 2015].

Atuahene, C.C., Attoh-Kotoky, V. & Mensah, J. J, 2010. Poultry production in ghana - prospects and challenges. *Ghanaian Journal of Animal Science*, 5(2), pp.93–99. Available at: http://ir.knust.edu.gh/bitstream/123456789/6405/1/pdf.pdf.

Bijker, W.E., 1997. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*, MIT Press. Available at: https://books.google.com/books?id=IsbmwN8-m1cC&pgis=1 [Accessed June 7, 2015].

Compostjunkie, 2015. How to compost. Available at: http://www.compostjunkie.com/how-to-compost.html.

Cuffaro, D. & Zaksenberg, I., 2013. The Industrial Design Reference & Specification Book: Everything Industrial Designers Need to Know Every Day. Available at: http://www.amazon.com/Industrial-Design-Reference-Specification-Book/dp/1592538479/ref=sr_1_1?ie=UTF8&qid=1433704430&sr=8-1&keywords=everything+an+industrial+designer+needs+to+know [Accessed June 7, 2015].

DMI, 2015. Vejret lige nu. Available at: http://www.dmi.dk/vejr/maalinger/vejret-lige-nu/.

Hansen, C.T., 2005. On the content of a product idea. *Engineering Design and the Global Economy*, pp.1 – 14.

Hansen, C.T., 2002. The content and nature of a design concept. *Proceedings Norddesign 2002*, pp.101 – 110.

Haug, R.T., 1993. *The Practical Handbook of Compost Engineering*, CRC Press. Available at: https://books.google.com/books?id=MX_jbemODmAC&pgis=1 [Accessed April 9, 2015].

Helms, M. & Goel, A., 2013. SPECIFYING DESIGN PROBLEMS AND EVALUATING BIOLOGICAL ANALOGUES FOR BIOLOGICALLY INSPIRED ENGINEERING DESIGN. , pp.1–9.

Helms, M., Vattam, S.S. & Goel, A.K., 2009. Biologically inspired design: process and products. *Design Studies*, 30(5), pp.606–622. Available at: http://dx.doi.org/10.1016/j.destud.2009.04.003.

HowStuffWorks, 2015. Egg. Available at: http://animals.howstuffworks.com/animal-facts/egg-info.htm.

Innovation Blogs KU, 2015. Brainwalking. Available at: http://innovation.blogs.ku.dk/metode/brainwalking/.

Jorgensen, U. & Sorensen, O.H., 1999. Arenas of Development - A Space Populated by Actor-worlds, Artefacts, and Surprises. *Technology Analysis & Strategic Management*, 11(3), pp.409–429.

McNoldy, B., 2015. Calculate Temperature, Dewpoint, or Relative Humidity. Available at: http://andrew.rsmas.miami.edu/bmcnoldy/Humidity.html.

Meijerhof, B.R., Specialist, S.T. & During, H.B. V, 2006. Ventilation of incubators , the secrets of carbon dioxide , humidity and finally temperature.

Mortola, J.P., 2009. Gas exchange in avian embryos and hatchlings. *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*, 153(4), pp.359–377. Available at: http://dx.doi.org/10.1016/j.cbpa.2009.02.041.

Nigel Cross, 2008. Engineering Design Methods: Strategies for Product Design, 4th Edition. Available at: http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470519266.html [Accessed June 7, 2015].

Organic Garden, 2015. Compost requirements. Available at: http://www.organicgardeninfo.com/compost-requirements.html.

Science Buddies, 2012. Hairy Science: Measuring Humidity with a Hair Hygrometer. Available at: http://www.scientificamerican.com/article/bring-science-home-hair-hygrometer/.

The Engineering Toolbox, 2015a. Circulating Force in Gravity Heating Systems. Available at: http://www.engineeringtoolbox.com/gravity-heating-systems-d_189.html.

The Engineering Toolbox, 2015b. Thermal Conductivity of some common Materials and Gases. Available at: http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html.

TheCompostGardener.com, 2015. Compost Moisture Levels. Available at: http://www.the-compost-gardener.com/compost-moisture.html.

Timeanddate.com, 2015. Weather in Accra, Ghana. Available at: http://www.timeanddate.com/weather/ghana/accra.

Tjalve, E., 2003. *Systematic Design of industial Products*,

Trautmann, N., 1996. Compost Physics. *Cornell University*. Available at: http://compost.css.cornell.edu/physics.html.

Urban Composting, 2014. Composting Tutorial. Available at: http://www.urban-composting.com/images/turning.gif.

Utah State University, 2015. Temperature-Moisture Relationship. Available at: http://ocw.usu.edu/Forest__Range__and_Wildlife_Sciences/Wildland_Fire_Management_and_Planning/Unit_4__Temperature-Moisture_Relationship_4.html.

Wikipedia, 2015. Akosombo Dam. *Wikipedia*. Available at: http://en.wikipedia.org/wiki/Akosombo_Dam.

Williams, J. & USTODAY.com, 2005. How Humidity is Measured. Available at: http://usatoday30.usatoday.com/weather/whairhyg.htm.

Yen, J. et al., 2011. Biologically Inspired Design: A Tool for Interdisciplinary Education. Available at: http://www.researchgate.net/publication/266224422_Biologically_Inspired_Design_A_Tool_for_Interdisciplinary_Education [Accessed June 7, 2015].