PROTOTYPING, REDESIGN AND PRODUCTION PLAN FOR THE

ANGKOR LIGHT

A solar lantern for the rural population of Cambodia

Martijn Kranen
Industrial Design Engineering
University of Twente
October 2007

Mrs. dr. Angèle Reinders – University of Twente
Ir. Henry de Gooijer – Kamworks
Arjen Luxwolda – Kamworks
Commissioned by Kamworks

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PREFACE

This project really was an eye-opener for me in different ways. As a designer I went to a world completely different from the one I am used to live in and it therefore really required another view on designing. For example efficiency was not a main priority, contrary to the need to produce the product locally (almost) regardless of the amount of extra hours per product added.

Personally I experienced that living in a poor country marks the relativity of the wealth of our Western world. Our hunt for more and better things sometimes intends to overshoot in the materialistic direction. People living in the most sober circumstances with great pleasure and joy point out that belongings are not (always) the way to happiness. Severe poverty on the other hand makes life extreme difficult and having some products to help during the daily activities really can make a difference.

FIGURE 1: CHILDREN FROM THE VILLAGE

My motivation to start this project was to go abroad to a total different country in the first place. Also the ability to contribute to a sustainable product was a big consideration. During the project my view on the best way to help third world countries changed a little. We can and should provide the knowledge to help these people but should not judge the culture of a country from a strictly Western point of view. Trying to understand why people act the way the do really helps in this process and providing education can help them to develop themselves and their country.

FIGURE 2: THE STUDENTS AT KAMWORKS (EXCEPT BAS)

Working with local people and attending a class at the University of Leap was a nice way to get acquainted with the Cambodian culture. At the start I was overwhelmed with the attention given to all western people, everyone was looking at us and in the more rural areas people are even waving and shouting (especially the children). After a while I got used to this phenomenon, but it was nice to see that I was not the only one seeing new things.

I had real fun with the Cambodian employees of Kamworks, with the other students and the kids at the orphanage, who were always smiling. Exploring the country by motorbike revealed a lot of things tourists normally don't see and meeting people who normally don't see tourists. It was a beautiful way to explore Cambodia and its natural and cultural treasures.

I want to thank the following people who helped me to complete this project: Arjen for his help and endless patience while answering a lot of questions. I also want to thank him for the constructive discussions we had about the production process. Henry for his support and critical eye while watching at a distance from the Netherland. Leap for his endless smiles and stories about Cambodia and its people and for showing us around. Sarin and Sita for their help in the workshop and a wonderful insight in the Cambodian way of living. Last but not least I want to thank Angèle Reinders for her support from the Netherland, especially helping to achieve things difficult to arrange at the University.

A special thanks goes to Loes and my family for their support and motivation while being far away from home.

Martijn Kranen

FIGURE 4: LEAP, CAMBODIAN STUDENT, TRANSLATOR AND FRIEND

FIGURE 3: DAILY WASHING OF THE COWS

Summary

Introduction

This report is the result of a bachelor graduation project at the University of Twente commissioned by Kamworks, a small Cambodian company founded by the Dutch charity foundation Pico Sol. The company itself aims at the production and sale of affordable PV products for the rural consumer market in Cambodia. The project covers the prototyping, the redesign and the design of the production plan for a solar lantern.

The problem

Cambodia is a country with limited power resources. About 90% of the Cambodian households have no access to electricity infrastructure for reliable lighting. These people are also very poor and live below the poverty line of less than 1$ per day. Needs like lightning are not obviously catered for, because of this limited power availability. The alternative, using a fuel lamp, is very expensive because of the high fuel price.

Another problem Cambodia faces is the unemployment rate. General wages are low and because of the turbulent history about 60% of the population is 20 years or younger. Job opportunities for this group are very low.

Analysis of the existing lantern

The project started at Kamworks aims to solve a part of both problems described. In association with the Delft University the first version of a solar lantern has been developed, delivering both an affordable lightning solution to the rural population and work opportunities to young Cambodians. This version of the lantern was designed by Stephen Boom in 2005 as a result of a master graduation project. The complete design process was done in the Netherland, exact for a field study of about 6 weeks. The lantern had not been produced and tested locally and exact knowledge of the Cambodian situation was not always available during the design process.

This project started with a global analysis of the situation and the problem. Next the existing prototype of the lantern was reproduced in Cambodia, followed by a general analysis of the result and the production process. Several tests were done with this prototype, including a drop test, a water test and a user test to determine deficiencies of the product.

Redesign of the lantern

Using the requirements formulated by the company and the deficiencies found a redesign was carried out. Every aspect was looked after, but special attention was given to a low price for the product and the possibility to produce it locally. Inquiries were done to obtain the lowest price for components used.

The product was altered to be waterproof, to be more resistible against dropping on the ground and to be easier to produce at Kamworks.

Design of the production plan

The production of a product in Cambodia differs a lot from a situation in the Netherland. Production aspects like availability of machines and labour were examined and potential problems were investigated. Based on the findings the design of the product was altered and a production plan was made. Several tools including moulds and bending aids were designed and tested. An scheme was made to describe the assembly of the total product.

Results

The results of this assignment are a prototype, a complete redesign of the lantern and a production plan including the design of the tools needed.

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1 INTRODUCTION

1.1 BACKGROUND

This report is the result of a bachelor project at the department of Industrial Design Engineering of the University of Twente. It covers the redesign of a solar lantern for the rural population of Cambodia. The project was commissioned by Kamworks, a small solar company in Cambodia.

1.1.1 KAMWORKS

Kamworks is a young Cambodian PV company with Dutch founders. This initiative arises out of Pico Sol, an also Dutch independent charity organization which makes an effort to help the small-scale application of solar energy in third world countries. The company itself aims at affordable PV products for the rural consumer market in Cambodia. About 90 percent of the population of this country has no access to electricity.

The goal of Kamworks is being expressed in their mission statement: "Affordable energy for sustainable development". At the moment the main focus lies on installing so called Solar Home Systems at orphanages, churches, schools etc. These activities will be extended with the production of commercial consumer PV products.

FIGURE 5: THE KAMWORKS BUILDING AT THE ORPHANAGE

Kamworks is located in a village named Sré Ampil, 40 km south-east from Phnom Penh, on the grounds of an orphanage (see Appendix O). One of the problems these orphans come across is finding a job when they are leaving the orphanage. Cambodia is mainly a traditional agricultural society and children usually continue with the business of their parents. Kamworks tries to establish some jobs by employing them to produce sustainable energy products. In this way both the environment and the orphans gain profit.

The University of Twente is an entrepreneurial research university. It offers education and research in areas ranging from public policy studies and applied physics to biomedical technology. The discipline Industrial Design Engineering focuses on the design of mass produced (consumer) products. The bachelor project is the final assignment of three years of the bachelor program.

1.2 Assignment

1.2.1 Background of the problem

At this moment the rural population of Cambodia does not have a solution for affordable permanent indoor lighting. Indoors and in improvised stores under their house people make use of kerosene lamps and lighting powered by generators and batteries. Outdoor lightning solutions only consist of small torches powered by expensive batteries. Although there is a demand for both permanent indoor and movable outdoor lightning no affordable products are available.

With five full hours of sun per day and a balanced distribution over the year, Cambodia is one of the sunniest countries in the world. Because of this fact, the potential for successful solar powered products is very high. To utilise this potential in 2005 Stephen Boom of Delft University of Technology carried out a Master thesis with the goal to design a solar lantern. In October of that year he finished this project resulting in the SOLantern. At the moment a prototype of this lantern is made, but it is not ready yet for mass production.

1.2.2 Assignment description

The goals of this assignment are to redesign the SOLantern to make it useable and affordable for the target group and make it producible in Cambodia. The assignment consists of the analysis of the current design, the redesign of the lantern and the production plan.

At the completion of the assignment a pre-production series of about 20 pieces must be able to be produced using the designed production plan. Next extensive user tests can be performed with these products by the company.

1.2.3 Situation

To get a good idea of the local situation, the end users and the production capabilities the assignment will be carried out in Cambodia. A team of 6 students will be working on different parts of the lantern and its distribution system (see Appendix A for more information).

1.2.4 Framework

The approach that will be followed consists of several parts (Figure 6).

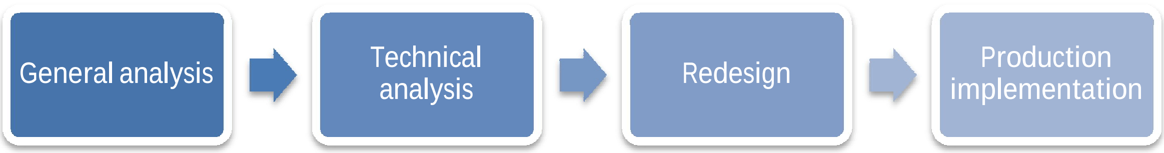


Figure 6: Process of the project

The general analysis consists of reading lecture and papers concerning the lantern, e.g. the reports of Stephen Boom (Boom, 2005) and Mando Rotman (Rotman, 2006). Also the local situation in Cambodia will be explored and the rural population will be questioned about the prototype.

The technical analysis will be done by the local reproduction of the prototype, by performing several tests with this prototype and by the analysis of the competitors. Also an examination about the availability of materials and a cost price analysis will be performed.

After gathering this data a redesign of the lantern will be performed to fulfil the demands.

To produce a pre-production series and a subsequent production of about 400 products the implementation of the production is carried out. This will result in the production of this pre-production series which will be used to perform some final tests.

The timeframe of this assignment will be three months.

1.3 Naming convention

To make a clear difference between the product designed by Stephen and the redesigned one these two versions will be referred to as SOLantern and Angkor Light respectively. The SOLantern is the name originally chosen by Stephen. Angkor Light is the one chosen by Kamworks, reflecting the Cambodian identity of the lantern and is also the name under which the product will be sold.

2 GENERAL ANALYSIS

2.1 INTRODUCTION

Because the project is carried out in a country with huge differences compared to the Netherlands a general analysis about the local situation is carried out. This analysis consists of an exploration of the geographic situation, the language, the market, the energy and lightning situation. At the end of the chapter the SOLantern is introduced and placed into the local situation.

2.2 CAMBODIA

Cambodia is a country in South East Asia, bordered by Thailand on the west and north, Laos at the north and Vietnam at the east. It has a population of almost 15 million people (Population Reference Bureau, 2007) covering an area of 181.035 square km (World Bank, Environment Department, 2004) , this is about 4.5 times the size of the Netherlands. The country is located in the tropics. Cambodia has an average minimum temperature of 23° and an average maximum temperature of 32° with almost no variation during the year (The Weather Channel, 2007).

FIGURE 7: GEOGRAPHIC LOCATION OF CAMBODIA

The country is mainly known to the outside world because of the cruelties of the Khmer Rouge regime in the '70, led by "Brother Number One" Pol Pot. Nowadays the country has still not completely overcome its history, the leaders of the regime have never been prosecuted (Pol Pot died in freedom in 1999) and the soldiers of the regime are still walking around and could be anyone's neighbours without them knowing.

In two weeks after the Khmer Rouge was defeated by the Vietnamese in 1978, next the Khmer Rouge started a guerrilla war which finally ended after the peace settlement in 1991. In 1993 the first democratic elections were held, but even today the country is not really a democracy because corruption and intimidation are every day's business.

Due to the economically and technical recession during and after this period and the lack of financial support of Western countries like neighbouring country Vietnam received, Cambodia is still a low developed country.

2.3 LANGUAGE

The Khmer language is part of the Austro-Asiatic language group, together with e.g. Vietnamese and Mon found in Thailand, Cambodia, Burma, Vietnam and Lao (Gordon, 2005). These languages differ a lot from Western languages in sound and writing. It has a completely different kind of alphabet and several other sounds are used (see Figure 8 for an example of Khmer writing). The English education is developing but at the time almost no one speaks it at a high level making communication with local people very difficult.

ព្រះរាជាណាចក្រកម្ពុជា

FIGURE 8: THE WORD "CAMBODIA" IN KHMER

2.4 Market situation

2.4.1 Corruption

According to the Corruption Perceptions Index Cambodia was ranked 151 out of 163, meaning that it belongs to the 15 most corrupt countries in the world (Transparency International, 2006). Compared to the 9th place of the Netherlands it is obvious that trade is not as straightforward as in western countries. A lot of regulations exists and officers in function don't hesitate to ask more money purely for personal gain to get things aranged. Going higher up in the command chain will get around this problem but is time consuming.

This fact has certain implications for product development and production in Cambodia. A longer period to get the necessary paperwork has to be taken into account and even unpredictable incidental higher costs for licensing and the import of products will be possible. The gouvernment is aware of the corruption problem and is trying to organize things better for foreign companies, especially because this in the interrest of the country. But the same corruption is causing these things to change very slow.

2.4.2 Selling products

Large electronic concerns do not exist in Cambodia, instead little market shops are located in a lot of villages. These shops sell a lot of different products varying from ventilators to gas stoves which make finding a certain product sometimes difficult. Prices for products are always established by bargaining.

Figure 9: A typical Cambodian market shop

A big problem for buyers in general is the unknown quality of a product. A brand name is no guarantee because the Cambodian market is flooded with fake Chinese products copying quality brands. A big challenge is to develop a quality product and convince the people of this fact.

2.5 Electricity in rural Cambodia

In the rural areas of Cambodia electricity is not an obvious presence. Over 85% of the total population of Cambodia lives in rural areas (Institut de Technologie du Cambodge, 2002) and over 85% of the total population suffers of the lack of access to the electricity grid. Together with electricity prices of 16 c/kWh in Phnom Penh and an average of 51 c/kWh in the rural areas Cambodia has one of the lowest electrification rates in Asia and among the highest electricity costs in the world (Economic Consulting Associates, World Bank, 2002).

> *Outside the provincial towns, power supply is rare and meager, with only about 6 percent of Cambodia's rural households having access to electricity supply, and another 3 percent owning some type of individual power generating unit.*
>
> *Of the remaining 91 percent of the rural population, some 55 percent use automobile batteries (costing US$ 2.0-3.5 /kWh) for occasional and limited use, or do without electricity completely (36 percent)*
>
> *World Bank (http://go.worldbank.org/C1KN2PJ7M0)*

The electricity distribution differs from the distance to a city. At the moment only 7 of the biggest cities have access to the national power grid supplying power generated by the national power company Electricité du Cambodge (EDC). It is very unlikely that this company will extend the grid to cover more than 80% of the population because of the high costs and low gain.

The second type of power suppliers are Rural Electricity Enterprises (REEs). Relatively small generators supply power to one or two villages only, making a large grid not necessary. This type of power supply is suitable for rural areas but with the average price of 51 c/kWh very expensive.

The third method consists of car batteries charged by local generator shops, but this is also an expensive solution, up to $3.5 per kWh (Economic Consulting Associates, World Bank, 2002). The batteries are not charged with the right current and with very inefficient diesel generators causing very short battery life, loss of energy and a lot of pollution.

2.6 Solar Energy

At the moment solar energy in Cambodia is a rare phenomenon. Some small NGOs are installing *Solar Home Systems* in small villages, supplying power to one to several small households to let them use some electrical lights and perhaps a small television if affordable. These systems are often paid by foreign countries as a part of an aid project.

Solar Home Systems are an effective way to supply rural villages with electricity. The costs are generally about $1.2/kWh (Kamworks, 2007), mainly because of the high material and installation costs.

Another option is to extend the electricity grid to reach these people. This is even more expensive and the costs also depend on the distance between the existing grid and the area that needs to be covered. Solar energy has no need for a large grid, resulting in the same cost per kW independent at every location with the same amount of radiation (Figure 10).

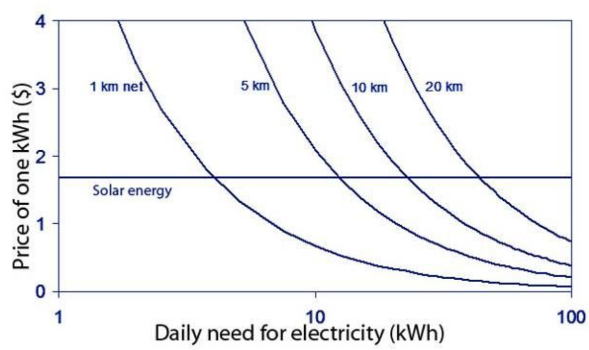


Figure 10: Solar energy costs versus grid extension costs

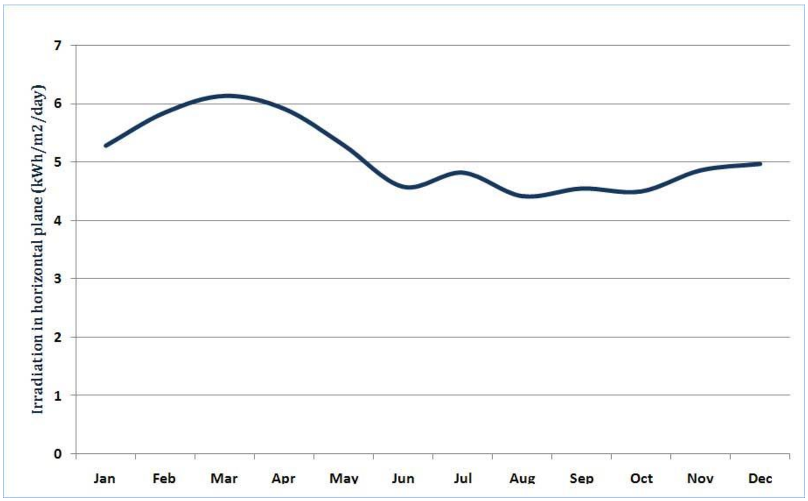


FIGURE 11: MONTHLY AVERAGES INSOLATION IN PHNOM PENH

2.7 LIGHTNING IN RURAL CAMBODIA

Lighting in the rural areas is a matter of improvisation and creative use of available resources. At the moment several kinds of lightning solutions exist.

2.7.1 TRADITIONAL CAMBODIAN LAMP

The first one is the Traditional Cambodian lamp, a simple tin fuel lamp (Figure 12). Kerosene is available throughout the country and is therefore an easy way to get some light. Besides a bad smell this solution has some other disadvantages:

- Little light is produced
- These kinds of lamps are unsafe because the top part becomes too hot and can fall off easily. At that moment a fire can arise.
- The lamp is useless in rainy conditions
- Burning fuel is polluting to the environment

Due to the high fuel price the use of this kind of lighting is expensive. Families using this kind of lighting spend $20-24 per year on fuel (MIT Sloan - GLab team, 2007).

FIGURE 12: TRADITIONAL CAMBODIAN

2.7.2 FLUORESCENT TUBE

Some kind of electric lighting is available. Light bulbs are very energy consuming and are therefore not used. Fluorescent tubes are used instead, but little is known about electricity and its safety aspects and very bad wiring and fixation of these lights is used often. Besides this increase of the risk of short-circuit and fire several other problems with this kind of lightning exist:

- Batteries are used carelessly, with the result of damaged batteries and less capacity
- Batteries are being charged with the inefficient generators. The characteristics of these batteries are not taken into account while charging resulting in overload and heavy wear.

FIGURE 13: A HANGING FLUORESCENT

- The charging process is very polluting because of the very inefficient generators used

2.7.3 Fisherman's light

A lighting product commonly used is the headlight for assistance by fishing or finding frogs and is powered by a small battery. A different purpose is the use as lighting inside a house. In this situation a car battery is used as power supply.

The biggest problem with this headlight is the weak light bulb. User interviews performed by Stephen Boom indicate that the bulb needs to be replaced up to 3 times a day. The fishermen spend about $10 dollar a month on charging of the battery and replacement of the light bulbs.

This product is a multifunctional; by removing the reflector the headlight is transformed into an ambient light usable for indoor lightning. This principle is used in the development of the SOLantern.

FIGURE 14: FISHERMAN'S LIGHT

2.8 The SOLantern

The lantern developed by Stephen is a sustainable solar product aimed at the needs of the rural population.

Because a rechargeable battery and a solar panel are used no extra costs are needed to keep it working. The lantern should replace the two current polluting and inefficient lighting solutions: the traditional Cambodian lamp and the fluorescent tube.

The chosen materials and production methods are supposed to make it possible to produce the lantern in Cambodia. This is not tested yet and no local manufactures are located at this moment.

At this moment only a basic prototype of the design is produced in the Netherlands. Several requirements formulated by Stephen are not evaluated yet.

FIGURE 15: PROTOTYPE OF THE SOLANTERN

2.8.1 Purpose of use

The product can be used inside the house for reading, cooking and talking and outside the house for walking and tasks like finding animals. Several general lightning categories can be determined when these tasks are analysed (Plas, 1998). To fulfil all demanded purposes the product should be able to comply with all these lighting categories (Table 1).

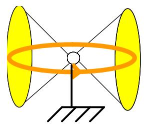
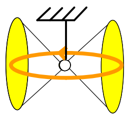
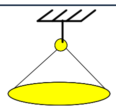
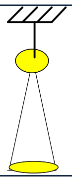
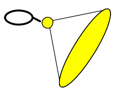
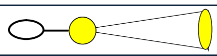
Symbol	Light distribution	Light fixation
	**General lighting** Evenly distributed light around the lamp in horizontal plane	Fixated on the ground
	**General lighting** Evenly distributed light around the lamp in horizontal plane	Fixated at the ceiling
	**General lighting** Big bundle of light from above	Fixated at the ceiling
	**Task light** Bright spot to see more details	Fixated at the ceiling
	**General lighting** Big bundle of light	Mobile possible to carry in one hand.
	**Spot light very bright spot**	Mobile possible to carry in one hand

Table 1: Lightning categories (Boom, 2005)

2.8.2 Target group

The target group defined by Kamworks are:

"Poor people living in rural and developing areas without a reliable access to an electricity grid".

Poor people are those with an income of about $1 per day. The first target market will be Cambodia because of the lack of electricity grid and the huge potential for PV products. About 5 million rural people in Cambodia (1.1 million families) belong to the target group. Monthly expenditures of these families for lighting vary from $1-3 per month (Boom, 2005). The product positioning is illustrated in Figure 16.

2.8.3 SELLING MODEL

At the moment a Master thesis is written by Miriam Reitenbach about the marketing of Kamworks' solar products. Several directions are being explored varying from fixed a market stall to altered tuk-tuks driving between villages to sell the products.

The entrepreneurs selling will also be able to repair products and give information about PV to customers. An educational program made by Jony Heerink providing general knowledge about solar energy and Kamworks' vision is used to train these people (Heerink, 2007).

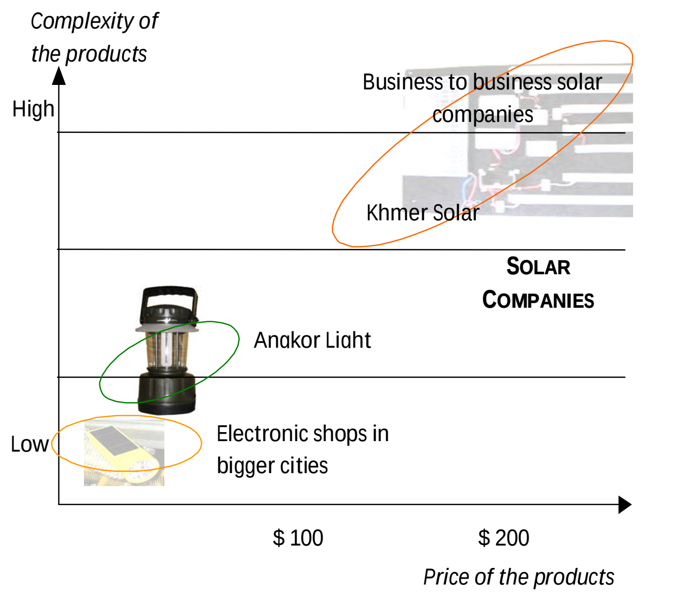


FIGURE 16: POSITIONING OF THE ANGKOR LIGHT BETWEEN THE EXISTING SOLAR PRODUCTS (BOOM, 2005)

2.8.4 SELLING PRICE

The target price of the solar lantern made by Stephen Boom was estimated at $50. Several market researches confirmed this price as the maximum amount of money people are able to spend on this kind of product (MIT Sloan - GLab team, 2007) (Rotman, 2006).

The current price estimated by Stephen is almost $63 (see Table 2), this is higher than the indication of the amount of money the target group can spend on a lantern. Attention should be given to obtain an accurate prediction of the real cost price and the selling price and lowering it. This can be done by enquiring a lot of companies to get the lowest price and comparing alternatives based on price during the redesign process.

Components	Price ($)	Reference
Plastic components	$2,77	Westward.com
Electronics	$7,56	Conrad electronics
Metal components	$0,09	PMB
Screws, Nuts, bolds etc	$1,29	Assumption
CFL	$2,10	Kamworks Chinese supplier
Battery	$2,80	Kamworks Chinese supplier
Subtotal	**$16,61**	
Capital costs (machinery)	$0,53	Assumption
Labor	$0,25	Assumption
Transport, packaging, breakage (15%)	$2,49	Business plan Kamworks
Subtotal	**$3,27**	
Distribution and marketing (14%)	$6,05	Business plan Kamworks
Profit(20%)	$8,64	Business plan Kamworks
Margin retailer(10%)	$4,32	Business plan Kamworks
VAT(10%)	$4,32	Business plan Kamworks
Subtotal	**$23,33**	
Total excl, solar panel	**$43,21**	
Solar panel:	$19,50	Kamworks Chinese supplier
Total:	**$62,71**	

TABLE 2: THE COST BREAKDOWN OF THE SOLANTERN

3 Technical analysis of the SOLantern

3.1 Introduction

After a general analysis of situation presented in the previous chapter a technical analysis of the existing lantern will be carried out. This will be done in the following steps:

- Recommendations from previous reports about the lantern are analyzed, questions are formed based on these recommendations
- The prototype is reproduced locally to:
  - do a user test, a drop test and a water test
  - analyze deficiencies of the product
  - analyze problems in the production process
- Technical analysis of the SOLantern and its functions
- A new competitor analysis is made to determine the strengths and weaknesses of the product
- Answers to these questions, results from these tests and conclusions from the previous chapter are used to determine a list of requirements and wishes for the final product

This list of requirements will be a starting-point of the concept development phase and is used to check if the final product fulfils its needs.

3.2 Recommendations and results out of previous research

Three reports have been written (partially) about the solar lantern. The first one is the initial master-thesis of Steven Boom about the SOLantern, the second is the internship report of Mando Rotman about Product Market Combinations (PMCs) in Cambodian rural areas and the last one is a market research project of the MIT about solar product and the marketing of them. In all of these report recommendations and points of attention are written down for further investigation. A complete list (with answers) can be found in Appendix B .The ones useful for the redesign of the lantern are extracted, put together and sorted by way to acquire the answers.

3.2.1 Report Stephen Boom

The graduation assignment of Boom (Boom, 2005) was to design the SOLantern. His report is a reflection of the design process, including a general analysis of the problem, the technical aspects of the lantern and a small user evaluation at the end. Most of his considerations regarding the design are written down making it a very useful document as a start of the redesign.

A lot of research is done in the Netherland, so very few local available materials are listed. Because this is necessary to know when starting mass production in Cambodia it will be an important part to investigate.

3.2.2 Report Mando Rotman

Extensive field research was carried out by Rotman (Rotman, 2006) to determine possible PMCs for Kamworks in the rural areas. Useful data about people's earnings and willingness to pay where collected.

3.2.3 Report MIT

The research carried out by the Massachusetts Institute of Technology (MIT Sloan - GLab team, 2007) was done to determine

3.3 Reproducing the prototype

One prototype of the lantern is made in the Netherlands by Stephen Boom. No tests with this prototype have been done in Cambodia, only earlier prototypes have been shown to the target group. Bringing the prototype to Cambodia is very difficult and therefore no option. By producing the prototype with local machines advantages and problems will be known and can be taken into account while redesigning the product. For these reasons the prototype is reproduced using local machines and locally available materials.

Because the first prototype was not fully functional and some boundary conditions have been changed, some additions are made:

- a bigger battery is used causing the bottom part to be larger
- a connection to attach the solar panel is made (not implemented in the first prototype)

3.3.1 Available Machinery

Cambodia is a development country and therefore it is not possible to easily get every imaginable machine to produce the product. It is helpful to know which kinds of machines are available at the moment at Kamworks; this can be taken into account in the design process to make the product producible. Kamworks is able to buy some second handed machines when needed. The available machinery at Kamworks is listed in Appendix C .

The power needed is produced by the existing solar panels and an additional generator. The batteries of the solar system have a capacity of 19.2 kWh (1800 Wp), the generator is capable of producing an extra 15 kWh. The vacuum form machine needed about 4.73 kW for heating and another 0.75 kW for all other operations. All other machines used only a fraction of this amount. Because of the high start-up power needed by the vacuum forming machine and high energy use the generator must always be used during production with this machine.

3.3.2 Materials

3.3.2.1 Plastics

During the reproduction period non-transparent polystyrene and acrylic with a thickness of 1.5 mm where available at the company. Transparent acrylic (2 mm) and an acrylic-like material with a thickness of 1 mm were found in Phnom Penh, almost the only place in Cambodia to find these kinds of materials. No other plastics for vacuum forming were available, especially at the short-term.

Some printed overhead sheets were used to make the front panel (the button overlay). This part was put onto the casing using two components glue.

3.3.2.2 Metal

Metal is widely available at local stores, including large sheets and strips. While producing the prototype not all strips with the right width were in stock, so a metal sheet was cut into smaller pieces.

Instead of RVS as material for the handle aluminium was used, because of its availability and nice appeal.

3.3.2.3 Buy parts

Some identical 4.5 Ah batteries were available at the company with the desired voltage and size. The connections were also positioned at the same place as the one used in Booms design so one of these batteries was used.

CFL

The CFL used was a standard 5W light with a E14 connection submitting a bluish light. The lamp holder used was a E14 fitting mounted onto the internal frame with two metal strips and some screws. The original design consisted of a different connection not available in Cambodia.

Knobs

The knobs to attach the handle with the internal frame were taken from the Netherlands, because it was known that they were not available in Cambodia.

3.3.3 The production process

The local production of the prototype is very useful to analyze the difficulties in this process. Not only problems regarding the product itself are discovered, also the complete production environment is tested. The problems experienced are described in the next paragraphs, with a direction in which the solution can probably be found.

3.3.3.1 Vacuum forming

At Kamworks the 3 plastic parts are made using the vacuum form machine. Vacuum forming is a process in which thermoplastic materials are formed on top of a mould through which the air is sucked out of the space between those two. The complete process is explained in Appendix L together with applications for the Angkor Light.

Different materials

Several materials with varying thicknesses are used because PC (the material selected by Boom) was not available. Using these materials revealed some (potential) problems.

In general thinner sheets are formed better than the thicker ones and higher or vertically varying shapes create more variation in the wall thickness. PS and ABS are very easy to thermoform; acrylic and PC on the other hand are more difficult.

Plastic delivery

Thick plastics which are not very pliable like Acrylic were not formed very well using high shapes, because not enough plastic could be delivered in the lower corners (Figure 17). Using sheets with higher thicknesses enlarged this effect.

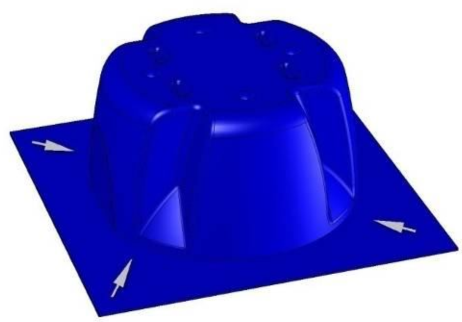


Figure 17: Problems with thick plastic delivery

A solution would probably be a bigger vacuum pump resulting in more suction but this is not feasible given the high costs. Also a bigger sheet and bigger frame could solve this problem but the company will end up with a lot of waste material. Therefore this solution is also not preferable.

Pre-stretch form disappears

The pressure beneath the material is blow up the plastic into a bubble shape. This is necessary to produce an equal wall thickness in the final product. At the moment only one action at a time can be performed, e.g. blowing and ascending the mould is not possible. When the pressure pomp stops working, the plastic shrinks back and the bubble shape is partially lost.

Blowing more air into the mould than desirable to compensate the shrinkage is one solution, but the undesirable side effect is that the plastic will be stretched too much and wall thickness may vary in the final product. A better solution is an adjustment to the machine to make it possible to perform multiple actions at one time.

CHILL MARKS

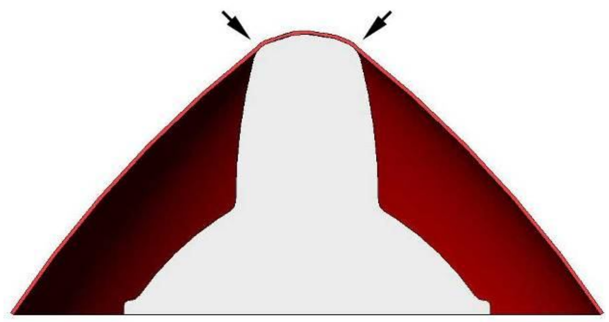


FIGURE 18: CHILL MARKS

After the pre-stretch phase the mould starts ascending. When the mould hits the material only a certain amount will be in touch with it, the remainder will be touching only air (Figure 18). This causes the plastic in touch with the mould to stay at the same place whilst the other part is stretched because the mould keeps ascending. After the vacuum forming step chill marks between the two parts are visible.

The effect described is almost impossible to avoid, although the effect can be minimized by good timing of the pre-stretch and ascend of the mould, a good design of the product and heating up the mould to the plastic temperature.

CRACKS IN THE REFLECTIVE LAYER

Vacuum forming the reflector revealed a serious problem: it is almost impossible to form this part without making cracks in the reflective layer. This is caused by the much higher stiffness of this layer compared to the plastic sheet. More and longer heating and adjusting the pre-stretch height offer no solution to this problem. Once in a while a useful product was made, but this is definitely no workable situation in a production environment.

Only adding a layer after vacuum forming of the part will be an option, e.g. gluing a thin plastic layer on the reflector or by using paint can be a solution.

3.3.3.2 METAL CUTTING, BENDING AND FIXING

Forming the handle was a matter of alternately bending and measuring the aluminium strip. The same process was performed while producing the inner metal frame. Moulds are necessary to produce these parts in large quantities to ensure the right shape.

Rounding the endings of the strip was done with a grindstone; in mass production cutting would be preferred. Drilling and cutting should be done before bending because this requires less complicated alignment tools.

Because no spot welding machine was available the internal frame was put together with bolts. The advantage of this method is the possibility to separate the parts when necessary, a disadvantage is the amount of extra space required and the extra costs.

3.3.3.3 CFL HOLDER

A standard CFL holder was used to attach the lamp, the connection with the frame was made of the same metal. By the use of a standard holder the construction was very solid and reliable and should be seriously considered as a possibility in the final product. Another kind of fitting will be used because the ballast of the lamp will be manufactured in-house, but these holders are available in all possible variations and mountings.

3.3.3.4 FINISHING

PLASTIC PARTS

The difficulty of removing the plastic scrap from the vacuum formed plastic depends on the material used. Polystyrene is easy to cut and to plane away, so is ABS. Acrylic is very difficult to cut and to sand, because it cracks really easy. A solution is to use a high speed grinder making which melts the material. Drilling reveals the same problem, PS and ABS are easy to work with and only a high speed drill can be used in case of acrylic.

Painting the top casing

The top casing needs to be transparent because the lamp needs to shine trough it but the bottom part of it should be coloured, otherwise the battery and internal frame are visible. This is done by painting the plastic on the inside, temporary covering the part that should pass trough the light. Because of the difficult form of this part taping off is very difficult and paint easily flows to places where it should not be.

An easy to use temporary seal should be made or a replacement of the paint should be found.

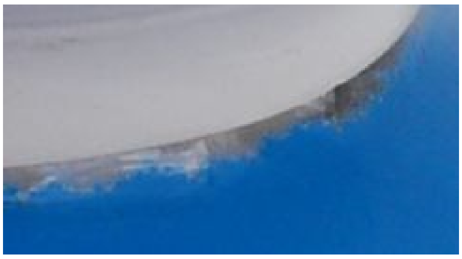


Figure 19: Frayed paint of the top casing

Screw connection to attach the handle

The bolts used to connect the handle with the internal frame were attached to it using an electrode welding machine. The intense heat and the thick electrode caused the metal inside the bolt to melt and to make the screw thread disappear. A tap was needed to reconstruct the thread again which of course is not preferable when producing in large quantities.

Front cover

A silicon foil was intended to be cover the power switch, a thin printed plastic sheet was used instead. Double components glue was used to attach the cover onto the casing, but the power switch could not be used anymore because of the stiffness of the sheet. Attaching only the upper and lower part of the cover solved this problem.

3.3.4 THE FINAL REPRODUCED PROTOTYPE

The result of the reproduction is a completely functional prototype representing the last design made by Boom, with a few minor adjustments to the local production situation.

FIGURE 20: PROTOTYPE IN STANDING AND HANGING POSITION

3.4 Prototype testing

In order to see if the product fulfils its requirements certain tests need to be performed. Each test is preceded by a description of the purpose and an evaluation at the and with any problems discovered.

3.4.1 User test

A very simple user test with the prototype of Boom has been done, therefore only basic information about the lantern at this stage is known. The purpose for this test is to get more insight into the thoughts of rural people about the lantern in general, about how they are able to use it and if they are capable and willing to pay the estimated selling price.

Figure 21: User test at a family home with the prototype

The most important conclusions of the user test are that the lamp is used by people as intended. The function of the lantern with and without the reflector is understood well and things people want to do with it are exactly the intended ones.

Disadvantages mentioned are the bad fixation of the reflector and the weight. Three out of ten people are capable of and willing to pay the price of $50, but only if the quality of the product is very high and it will last long. The other people want to buy the product for a price between $20 and $25, otherwise they cannot it.

The complete questionnaire including literal answers can be found in Appendix G .

3.4.2 Water test

During this test an amount of water with a pressure between 1 and 2 bar is being sprayed over the product at a downwards angle. Also water from the side and from below is sprinkled, simulating rain splashing on the floor. To determine if and where water is coming into the lantern, paper tissues are placed against the casing and on top of the inner parts. A complete test set-up can be found in Appendix I .

Figure 22 : Water test

Unfortunately water is leaking into the casing at the following points:

- The holes used by the connection bolts between the top and the bottom casing
- The holes used by the connection bolts between the bottom casing and the handle
- The little gap between the to ends of the rubber on top of the bottom part

This means that water is coming through every possible hole in the product. The first two problems are very similar; a solution can probably be found in the same direction.

3.4.3 Drop test

The requirement made by Boom concerning the height where the lantern could be dropped from was 50 cm. This value was taken because almost every rural family has some combined tables/couches in their home, which have an average height of the assumed criteria. Because a rural house always has a tamped down earthen floor and this will also be the hardest kind of foundation during outside use of the lantern this kind of surface was add to the criteria.

Results of the test are listed below, a complete report can be found in Appendix H .

- A casing made of acrylic was very brittle and was damaged easily
- PS and ABS have much better impact resistance; partly because they are more flexible
- The damage mostly occurred at the point were the battery touched the casing. This was possible because the upper casing and the frame did not fixate the bottom casing into its original shape during the collision.
- The frame including its connections did not suffer from multiple drops
- PC, although not actually tested, will probably not be strong enough to withstand the same drop test

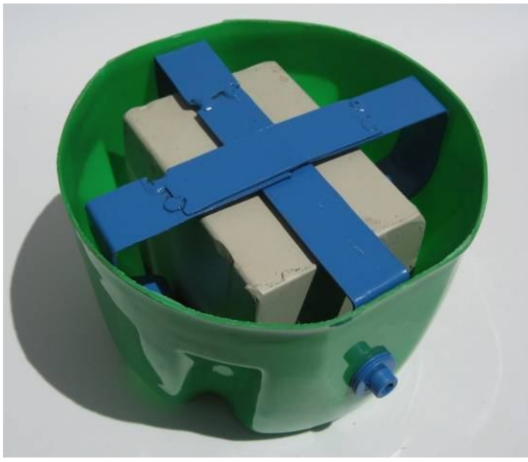


Figure 23: Dummy battery and polystyrene casing

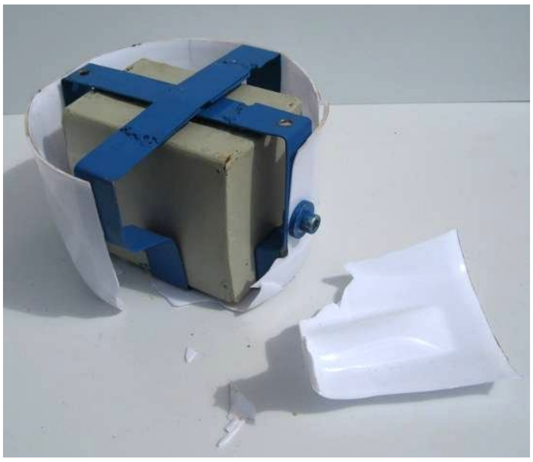


Figure 24: Result using the acrylic casing

3.5 Competitors

Several competing products are on the market, but most of them are not available in Cambodia. An extensive examination of these products was performed by Stephen Boom including a comparison of the strengths and weaknesses. One of the outputs of this research was a collage of the most important ones (Figure 25).

Most of these products have a cheap appearance, feel cheap and are cheap. Some are of a much better quality, are much more expensive and are made for the western (camping) market. The cheap ones cost as less as $10, the expensive ones have typical prices of $10 and more. The characteristics of a stereotypical lantern are (Boom 2005):

- A big plastic handle to carry the product
- Top part with the on/off switch. This part can be opened to replace the light bulb.
- A cap to give the impression that the light reflects downwards.
- (Semi) transparent cap to cover the light bulb inside. Mostly it makes use of fluorescent tubes of 5-7W
- A solid base for lead acid battery or dry cells and electronics. The base can be opened to replace battery.
- An separate solar panel (if included)

Figure 25: Collage of competition (Boom 2005)

Chinese products are famous in Cambodia because of their lack of quality. In accordance with this finding an important conclusion was made about these competitors; to excel above their level a quality product with according look and feel should be made. The new lantern should be able to distinguish itself on appearance and functionality from these stereotypical models with a bad reputation. The risk of (illegal) copies by Chinese manufacturers should be taken in account during the design of the lantern.

Because this investigation took place in 2005 the products currently available could be changed. Also a comparison between these products and the existing Angkor Light is possible to reveal the current advantages and disadvantages.

3.5.1 Comparison

The biggest advantage of the Angkor Light is its light beam shining more than the full lower (or upper) hemisphere (Figure 26). All other products have a cap blocking light at the top side, some of them also have bars to support this cap prevent light to pass in some horizontal directions. The other advantages not seen at any other product are the ability to use a optional reflector to converge the light if necessary and the possibility to turn and fixate the lantern to aim downwards or forwards.

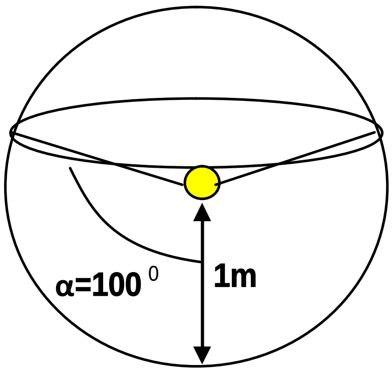


Figure 26: The light distribution around the product in an angle of 110 degrees measured from the vertical axis (lower hemisphere)

FIGURE 29: TYPICAL COMPETING SOLAR LANTERN

FIGURE 29: EXTRA CONNECTION FOR POWER OUTPUT

FIGURE 29: VERY SMALL AND LIGHT WEIGHTED

The most important advantages of competing lanterns are:

- One product featured an extra connection to charge mobile phones or other small devices
- Some lanterns are very light weighted
- The size of some lanterns is very small

If possible these features should be incorporated into the new design.

3.6 STANDARDS

Several standards were used to check and to show the quality of the product. Guaranteed quality is very important in the Cambodian market situation, due to the existence of a lot of (Chinese) products of inferior quality. Together with the existence of known selling points the trust of the consumer can be acquired.

3.6.1 INGRESS PROTECTION RATE

To satisfy the need of checking the level of being water proof the Ingress Protection rate is used. The IP rating defined in international standard IEC 60529 and classifies the level of protection that electrical appliances provide against the intrusion of solid objects or dust, accidental contact, and water. The one used is IP23, standing for the protection against:

FIGURE 30: THE PV GAP MARK

- Objects of 12.5 mm and bigger (fingers or similar objects)
- Water falling as a spray at any angle up to 60° from the vertical (rainwater)

To determine if the product complies with this standard, tests need to be done.

3.6.2 PVGAP AND IEC

PV GAP (Global Approval Program for Photovoltaics) is a not-for-profit international organization, dedicated to the sustained growth of global photovoltaics (PV) markets to meet energy needs world-wide in an environmentally sound manner. Its mission is to promote and encourage the use of internationally accepted standards, quality management processes and organizational training in the design, fabrication, installation, sales and services of PV systems. To this end, it partners with PV related industries, international organizations, testing laboratories, government agencies, financing institutions, non-governmental organizations, and private foundations, in developing and developed countries.

PV GAP co-operates closely with the International Electrotechnical Commission (IEC) in respect of standardization (principally with IEC Technical Committee N° 82, Solar Photovoltaic Energy Systems) and certification (with the IEC Quality Assessment System for Electronic Components, IECQ).

By obtaining a PV GAP mark the product can be distinguished from the bad Chinese product available on the market. The standard consists of several documents called PV Gap Standard Specifications, covering product specifications for the both the electronics and the general design (PV GAP, 2004).

3.7 Changed boundary conditions

Several additions to the lantern have been requested by Kamworks due to problems encountered during the design of the electronics. Implications will be described during the design phase. The alternations are new boundary conditions for the redesigned lantern and consist of:

- A bigger battery with more capacity, 4.5Ah instead of 3Ah
- A CFL with separate ballast
- Different electronics

3.8 List of requirements of the Angkor Light

During the previous design stage performed by Stephen Boom a list of requirements was formulated (Boom, 2005). A lot of these requirements are in line with the findings presented in this chapter. The list is extended with the changed boundary conditions and requirements from the company. A direct reference is added if available.

3.8.1 Production

- Vacuum forming should be used as production technology for the plastic parts
- Final assembly should be in Cambodia

3.8.2 Aesthetics

- The product should have a modern western look and feel (Boom 2005, 2.3.3.1)
- The product style should fit with the mood board made by Stephen Boom (Boom 2005, 3.6.3), the colours should be bright and powerful the Cambodian way (Appendix P)
- The product should express stability (Boom 2005, 2.2.3.1)
- Make people feel proud to own a product like this; Refer to the Cambodian look and feel
- The product should have a quality appeal and consist of plastic parts
- The product should look and feel robust

3.8.3 The product should meet the demands of the PV-GAP

- The on/off switch should withstand cycle of 100000 times
- Charge controller protect from damage from voltage under open circuit conditions
- Protected against damage from reversal polarity conditions of battery and solar panel
- The battery should be protected by a fuse. This may be on the circuit board
- Solar panel connection should withstand minimum of 1000 connection cycles
- The battery capacity (C2) shall not decrease over the testing period more than 10% of the initial battery capacity. C0-C2/ C0 <10%
- The measured days of autonomy shall match or exceed the defined minimum days of autonomy as indicated by the manufacturer
- The lamp shall operate undamaged according to the manufacturer specs. At maximum battery volt and max radiation
- The manufacturer shall specify the daily number of hours the system can service the load under test conditions
- The product should be able to operate during rainy conditions a according to IP23
- The product should be able to withstand the shipping vibration test

3.8.4 Electrical components

Light

- The light bulb should be visible
- The light bulb should be able to be replaced
- The CFL should meet the PV-GAP standard

Battery

- The battery should not make contact with the electric system when stored
- The battery should have a minimum capacity of 2,5 Ah (at 12V)
- After purchase, a fully charged battery should be able to operate the product 3 hours without being recharged in between (Boom 2005, 3.5.4)

- The battery should be protected from direct sunlight
- The user should be able to obtain information when the battery is almost empty
- The user should be able to obtain information about the charging status of the product
- The battery should be able to be replaced
- The battery should meet the PV-GAP standard

Solar panel

- The panel should be able to take inside the house (Boom 2005, 2.2.3.3)
- The panel should be able to be fixated and aimed at the sun
- The product should operate on 12 Volts (Boom 2005, 3.4.1)
- The panel should meet the PV-GAP standard

3.8.5 Other

- The selling price should not exceed the maximum of $50
- The product should be sold as one integrated package containing the solar panel determined in (Boom 2005, 3.4.4), mobile lighting unit and instruction guides

3.8.6 Use

- The product should be able to be carried by the user (Boom 2005, 3.3.2)
- The lighting product should be able to stand on a rough underground like stones and sand and mud (Boom 2005, 3.3.2)
- The lighting product should be able to be hanged (Boom 2005, 2.2.3.1 and 3.3.2)
- The light should shine evenly distributed in an angle of 110 degrees measured from the vertical axis, around the product
- The minimum illumination level should be at least 20 lux at a distance of 1m
- Components that are irreplaceable, like casing and frame, should be able to operate after a fall of 50 cm (walking height and table height) on earth ground (Boom 2005, 3.3.2)

3.8.7 List of preferences

- The product should made be out of local materials which are easy provided
- The production of the product should fit with the main objective to contribute to the development of Cambodia by offering local labour
- Users can easily take the lantern and solar panel to their work (rice field or marketplace)
- The product should be easy to repair
- The product should fit all lighting categories
- The product should have a connection to supply power to other products (e.g. a mobile phone)

3.9 Deficiencies of the product

After analyzing the recommendations, reproducing the prototype and performing a user, a drop and a water test and comparing the results with the requirements several deficiencies of the product can be summarized. Solutions to the problems to meet the requirements will result in the final product presented in chapter 4. The following problems were found:

3.9.1 Casing

- The handle touches the top casing causing scratches
- The knobs used to hold the handle into position are heavily clamped when the handle is turned and damaging the casing (this happens because of the turning in combination with the screw thread)
- One side of the base casing is weaker then the other parts (no frame is behind the plastic)

- The casing is damaged due to the pressure performed by the internal frame during use
- The casing is not watertight, especially at the separation between the two ends of the rubber and the opening for the bolts connecting the top casing with the internal frame
- The casing is not large enough to contain the bigger battery

3.9.2 Electronic components

- Users can easily open the product and access the electronics producing approximately 300V during start-up of the CFL (Hil, 2007)
- Users can easily access the electrodes of the battery and/or detach the battery itself to use it in other ways, causing battery exhaustion and illegitimate warranty claims
- Because the power connector is placed on the circuit board and because it has no supporting frame behind it a lot of torque is applied every time a connector is plugged in. The circuit board might be damaged after time
- The lantern is designed for a CFL including a ballast instead of a CFL with separate ballast
- No interface for the new electronics is available

3.9.3 Production

- The edge of the painted and the transparent area of the top casing is frayed
- The paint comes off at the contact points between the top casing and the base casing

3.9.4 Aesthetics

- The picture of the on/off button is not exactly placed above the button itself
- When the on/off switch is pushed it sometimes does not work because of the stiffness of the plastic in front
- The on/off switch works unnaturally: in an outward position the lantern is turned on, in an inwards position it is turned off
- The light of the lamp shines through the lower casing, revealing the threads and other inner parts giving the product an shabby look
- The colours chosen in the prototype do not reflect the taste of the Cambodian population

3.9.5 Costs

- The price of $62.71 (see Table 2) is much higher than the target price of $50

3.9.6 Other problems

- When the lantern is placed at an downward angle the lantern is not balanced
- The handle is cutting into the users hand, especially when the lantern is placed at an downward angle
- Because there are 4 stability pins at the base casing it is overdetermined and not stable at a bumpy surface
- The reflector does not stay in position when aimed to the front neither turned when aimed backwards

3.10 Conclusions

During the tests and the analysis done with the prototype several deficiencies were found. To fulfil the requirements described in §0 several adjustments to the design, the production process need to be carried out.

Elements that make the Angkor Light unique should work properly; extra attention should be given to these elements in the design process of the final product. Also the cost price need to be more specific and should be reduced to make the product affordable for the target group.

4 Design of the Angkor Light

4.1 Introduction

The previous chapter dealt with several shortcomings of the current product. In the following chapter the solutions to these problems will be presented. Changes to several parts are summarized first followed by solutions to general problems. At last a total cost price calculation is given.

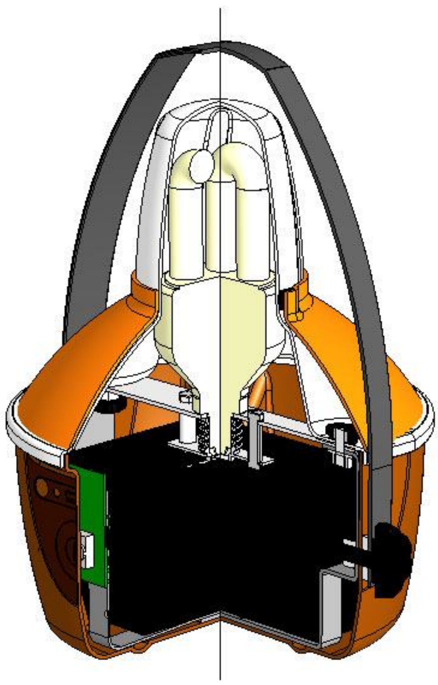


Figure 32: SOLantern

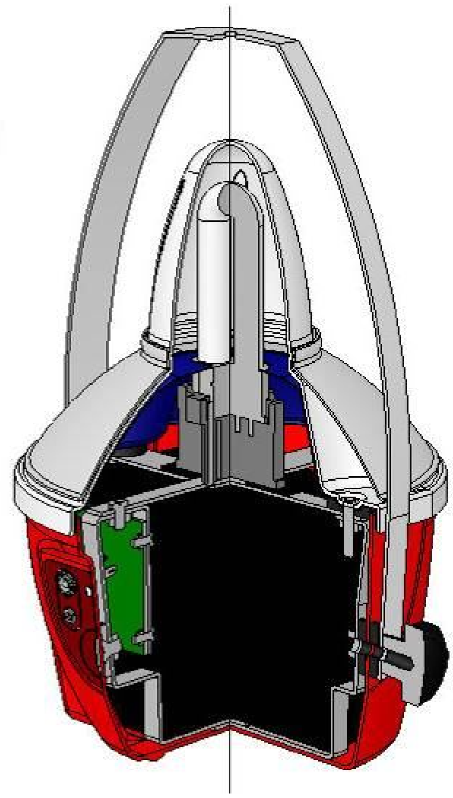


Figure 31: Angkor Light

4.2 General product layout

The products consists of a internal frame wrapping around the battery and serving as a support for the casing and other components. The following order will be used in this chapter (see also Figure 33):

- Casing
  - Reflector
  - Top casing
  - Inner top casing
  - Base casing
- Handle
- Front plate
- Internal components
  - Internal frame
  - Light source
  - Electronics

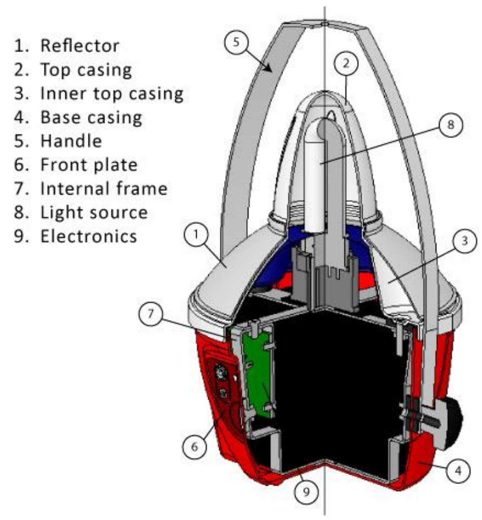


Figure 33: Overview of the Angkor Light

4.3 Reflector

4.3.1 Reflective layer

The material chosen by Boom consists of a plastic PS sheet with a very thin reflective layer glued on top of it. As seen in the previous chapter cracks develop very easy and make this material not really applicable. Gluing a thin reflective layer on top of a plastic sheet will also cause problems; tests revealed that vacuum forming is not possible because the layer is to stiff and will not form when it is glued onto the product afterwards seams will always be visible because it does not shape very well into double curved surfaces.

Reflector colour	Illumination (lux at 1m)
Without reflector	20.2
White plastic (abs)	70.4
Bright silver (spray)	76.5
Silver (can)	148.8
Mirror film	163.5
Chrome (spray)	216.0

Table 3: Reflector coating illumination

Some different brands of reflective paint are available in the neighbourhood of Phnom Penh; two types of spraying paint and one type of paint in a can were found. The chrome spray has much better reflective properties than the other ones; even better than the original reflective layer (see Table 3 for the test results). To prevent the layer from scratches an extra layer of clear paint was added, unfortunately decreasing the extend of reflection with about 40 lux.

Because of the much longer lifetime of the reflector the choice was made to add the clear paint nevertheless.

4.3.2 Fixation

The reflector does not stay in position when placed forwards or backwards. It even falls off when the lantern is turned downwards. This problem is caused by the shape of the reflector and the base casing which are modelled to be able to be released by the mould. The current solution with two rubber strips does not provide enough friction to fixate the reflector.

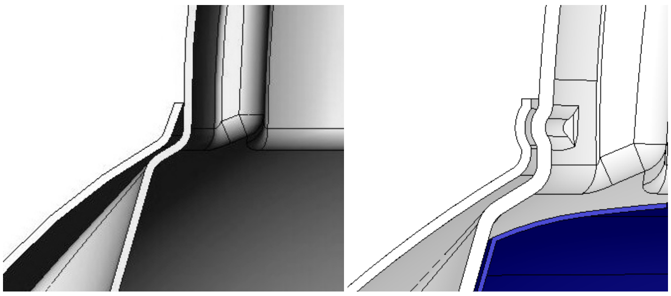


Figure 34: Reflector fixation problem and solution

The reflector must also be able to be placed at the base casing upwards and downwards causing more problems because the connection point of the reflector has a draft and is therefore not symmetrical in de vertical direction. Several options were drafted and tested on usability and makability. The solution chosen consists of a click mechanism with a rim making use of the flexibility of the plastic (Figure 34).

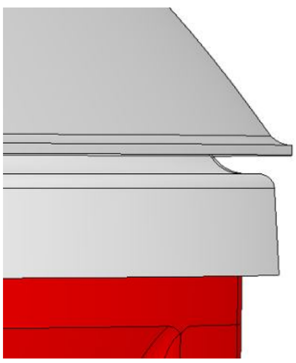


Figure 35: Rim to remove the reflector

4.3.3 Removing of the reflector

By adding a click mechanism to fixate the reflector the force needed to detach it will be higher. Removing the reflector without adjustments is difficult; therefore an extra rim was created (Figure 35). The rim is easy to release from the mould and formed in a regular shape, making the mould not more difficult to produce.

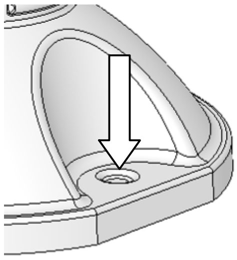


FIGURE 36: CAVITY

4.4 TOP CASING

The addition of the rim to the reflector also implies changes to the top casing (Figure 34). The solution chosen for this part has four separate horizontal rims instead of one big horizontal ring, because this fits better into the design of the existing vertical grooves. Tests with the prototype showed both a complete ring and separate rims provide a good solution to the fixating problem.

Another design consideration was the possibility to use a cavity to lower the screws attaching the upper parts onto the frame (Figure 36). Lowering the screws is optically better, but two big problems were encountered. The first problem was the connection to the internal frame. The cavity is rounded at the bottom side due to problems occurring during vacuum forming while using sharp corners. The rubber ring between the internal frame and the casing had to be shaped according to the cavity; this was not possible using the available material and tools.

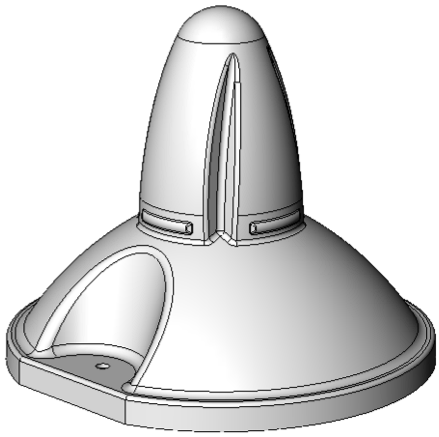


FIGURE 37: TOP CASING

The second problem was the precision required to position the top casing into the inner top casing. In theory the depth of a cavity can be at most 75% of the width of the opening on the surface, excess thinning will occur beyond this depth (Formech International Ltd., 2001). Even shallow cavities will result into a thinner casing, especially at these two points where the top casing connects to the frame this is very unwanted.

The shape of the top casing was altered to make it visually more consistent with the lower part. Making the top casing rounder also has several advantages:

- The chill marks encountered during the production of the prototype will be minimized because the plastic is stretched less at the top (see §3.3.3.1)
- The total shape resembles Angkor Wat better, making it more recognisable as a Cambodian product
- The top of the part will be stronger because there will be less stretching of the plastic making it less thin

4.5 INNER TOP CASING

One problem discovered after the production of the prototype was that the light of the CFL shines trough the base casing revealing a lot of the inner parts. This effect is unwanted because it looks very cheap.

FIGURE 38: INNER TOP CASING

Two more problems encountered were the frayed painting of the top casing and the paint coming off at the contact points with the base casing. Several test where done to obtain a straight paint line, like using paper tape, a removable plug and even some fluids preventing the paint to stick to the plastic. No solution was found making it both possible to produce the product locally and being also a solution usable in a production process.

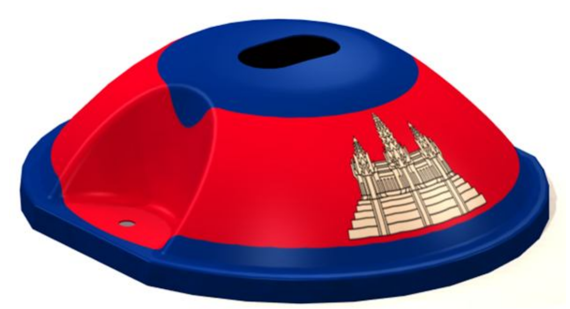


FIGURE 39: EXAMPLE OF A DESIGN

All problems can be solved by using a separate part. This extra layer blocks the light normally shining through the base casing and is used to colour the lantern.

The part can also be painted by artists to make a special collectors item or can be decorated with stickers. The extra costs to produce this part are partially by the lack of a layer of paint and the added quality appeal to the lantern.

4.6 BASE CASING

The total shape is adjusted to the bigger battery which is about 1.5 times higher than the old one and has therefore been rotated 90° to lower the point of gravity and make the lantern more stable. Still it has effect on the height and the required strength of the base casing because of the increased overall weight and volume. The drop tests described in §3.4.3 revealed that PS with a thickness of 1.5 mm was needed, instead of 1 mm in the original design. Vacuum forming test with this material showed that sharp corners and deep cavities could cause problems.

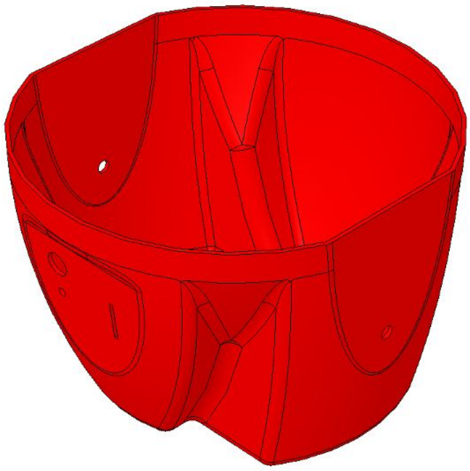


FIGURE 40: BASE CASING WITH HOLES FOR CONNECTIONS

The new design was adjusted to fit the Cambodian style together with the top casing. More curves are used compared to the SOLantern, this was possible because the frame was used to position the battery instead of the casing itself. Rounded corners also facilitate the vacuum forming process and these curves make it less obvious that it is a casing for the rectangular battery. The indentations were kept because they strengthen the casing, identify the front panel and reflect the shape of the top casing.

The number of stability pins has been decreased from four to three, making the connection with the ground not overdetermined anymore. These pins are placed as far as possible to the outside of the product to provide as much stability as possible. Drafts to ease the release of the part from the mould were missing in the original design and were added.

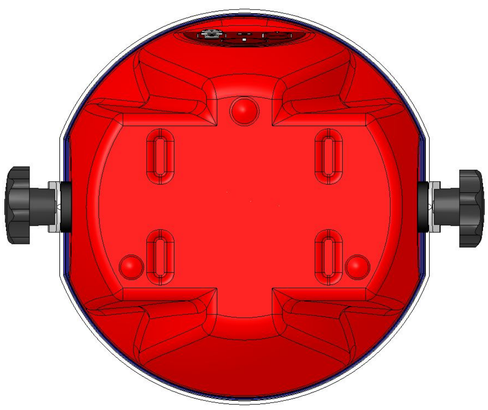


FIGURE 41: BOTTOM LAYOUT WITH STABILITY PINS AND BATTERY SUPPORT NODES

The battery support nodes were kept to absorb the energy of the battery in case the lantern will be dropped onto the ground.

4.7 Handle

4.7.1 Handle fixation

The handle needs to be turned into a certain direction and must be able to be fixated in that position. Heavy clamping of the casing has to be prevented when the handle is turned (see §3.9.1).

Several concepts have been developed to eliminate this problem, all with several advantages and disadvantages. The main considerations are to ability to produce it locally and the expected lifespan. By limiting the rotation to a certain degrees the problem arises that not all lightning function can be fulfilled. After testing of several possibilities the most basic one turned out to be the best: a rubber ring made of an old car tire will fixate the handle in every desirable position without damaging the casing (Figure 42). This material is also very cheap and easy available in rings.

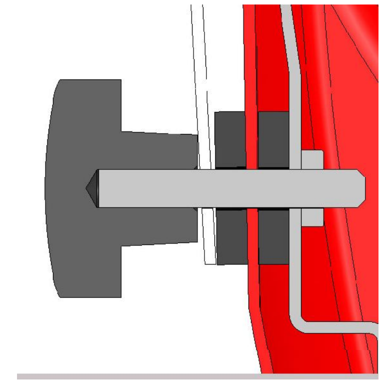


FIGURE 42: FIXATION KNOB

A nut is welded onto the internal frame to provide screw thread for the bolt attached to the knob. A rubber ring is also placed at the inner side of the casing to prevent harmful contact between the internal frame and the plastic casing (and also to make the lantern waterproof).

4.8 Internal frame

The internal frame is made of steel and is more capable of resisting shocks than plastic. Therefore the support function of the casing for the heavy battery was decreased by transferring it to the frame. To achieve this, the frame was almost completely released from the base casing and rubber rings were placed in between to absorb the energy transferred from the frame to the casing. Only the bottom part of the frame is still slightly connected due to height restrictions.

By adding a frame at the back the casing is stronger in general and the back of the product is also supported. Only little weight is added by this alteration.

The nuts to attach the frame were repositioned to the height of the point of gravity to balance the lantern. These are welded onto the frame to achieve a solid connection. By unscrewing the knobs of the handle little adjustments of the rotation can be made very easy and the lantern is not tumbling any more.

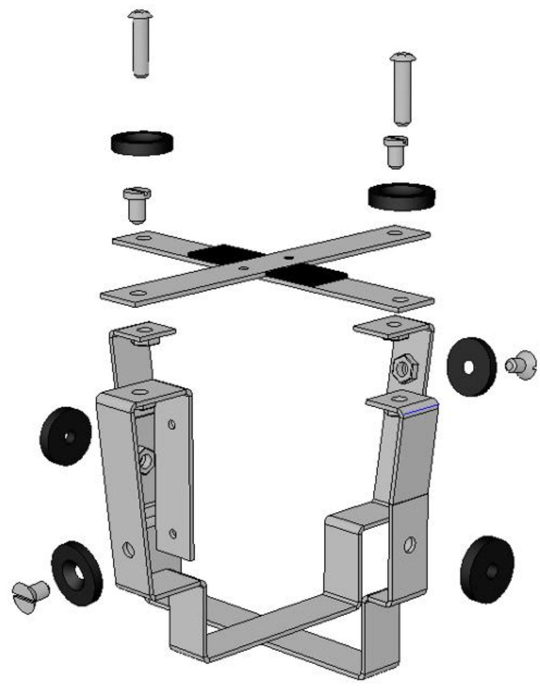


FIGURE 43: EXPLODED VIEW OF INTERNAL FRAME

The frame can be separated into two parts by unscrewing four bolts making it possible to change the battery. Each part consists of two strips welded together (after being bended). Two strips are added to the top part to support the CFL holder.

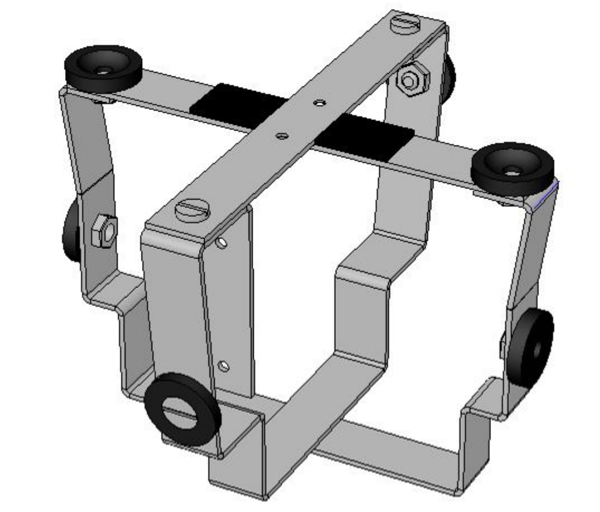


FIGURE 45: COMPLETE INTERNAL FRAME

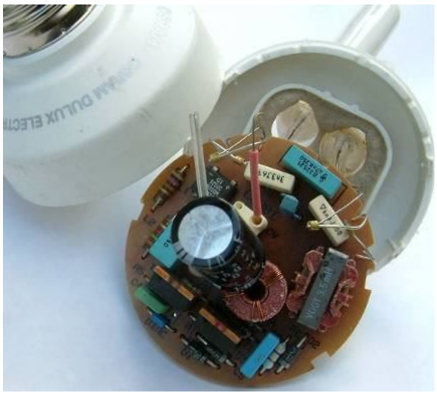


FIGURE 44: BALLAST OF A NORMAL CFL

4.9 ELECTRONICS

Simultaneously with the development of the Angkor Light new electronics were designed by two students of the "Haagse Hogeschool". The goal of this project was (among others) to design an external ballast having several advantages over a commonly used internal ballast:

- The external ballast developed is able to dim the CFL
- The ballast will be separate of the CFL giving more design opportunities
- The ballast designed will be more power efficient

Beside the development of this ballast a new controller for the CFL and a charge controller for the battery type used were designed making the lightning and loading much more efficient.

4.9.1 CFL

By quantifying the lighting categories in which the lantern need to be used the sufficiency of the light output of the final product can be checked. These values stated in Table 4 are based on the recommendation of Duco Schreuder (Schreuder, 2005) on lighting for very poor people.

Type of light	Illumination level
Orientation light	>10 lux
General light.	>20 lux
Task light	>30 lux
Spot light	>50 lux

TABLE 4: ILLUMINATION LEVELS BY (SCHREUDER, 2005) AS FOUND IN (BOOM, 2005)

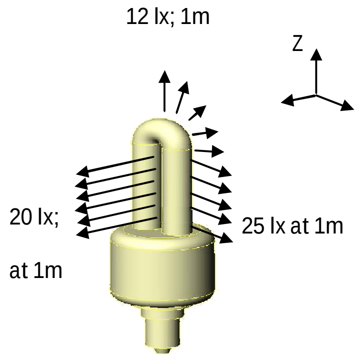


FIGURE 46: LIGHT DISTRIBUTION OF 3W CFL LAMP (KAMWORKS, 2007)

A 3W CFL has a light distribution of at least 20 lux in the horizontal direction measured at a distance of 1m (Figure 45) and is very energy efficient. The alternative, an array of led lights, is not as efficient as a CFL and its light distribution characteristics are far less suitable for general lightning purposes. A led with a capacity of about 10W is needed to match a 3W CFL (Boom, 2005).

Because the light intensity at the top side of the CFL does not fulfil the requirement of 20 lux for general light instead of the 3W variant a 5W CFL has been chosen. This CFL has an intensity of 20 lx at 1m (see Appendix J for light measurements tests).The costs for a 3W or 5W CFL are almost the same and by using the electronics dimming of the light will be possible when the extra light output is not needed.

FIGURE 48: CFL WITH AND WITHOUT BALLAST

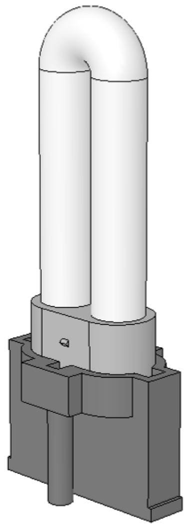


FIGURE 47: CFL AND HOLDER

4.9.2 Connection for external device

Figure 49: Phone jack

A big advantage of one competitive product was the ability to connect an external device to the battery (see §3.5.1). This can be very useful for charging mobile phones or powering a small radio. The electronic controller already supported power output control preventing the battery from being discharged too much. This new function can therefore easily be integrated in the existing system. The connection also reduces the risk of people opening the casing to connect a device to the battery directly.

The connector chosen is a 2.5 mm phone jack, normally not associated with power output. The intention with this choice was to prevent people from plugging in external devices without knowledge about the possibilities of the lantern. Only after consultation of the vendor a very cheap converter switch can be bought. This method is necessary because of the very limited knowledge of electrical devices of rural people.

4.9.3 Light intensity buttons and LED indicators

Due to the extra function to dim the CFL some extra buttons had to be added. LEDs are used to indicate the state of charge of the battery and to indicate if the solar panel is connected correctly. In the ideal situation this will be indicated by to separate LEDs, but unfortunately this is not possible because of the shortage of connections on the microcontroller as a result of the extra light intensity buttons. The microcontroller has 14 connections, which are used in the ways explained in Table 5.

A choice had to be made between the use of:

1. A set of extra buttons to adjust the light intensity and one LED indicator
2. A single power/light intensity button and two LED indicators

The first option was chosen because the use of one button as power switch and light intensity regulator is confusing to the user (this effect was seen during tests with competitive products using this method). To combine the battery state and the indication of the correct connection of the solar panel into one indicator the scheme defined in Figure 50 will be used.

A blink will be 0.5 seconds long, making the indication of the almost empty state (0-5%) a continuously blinking process. To get some extra attention from the user when the battery reaches this state the CFL will also be flickering every second for a period of 5 seconds, making it very clear that there will be no more light in about 10 minutes.

Nr.	Connection
1.	Battery current
2.	Pulse-width modulation for buck converter (CFL control)
3.	Solar panel current
4.	Dim switch +
5.	Dim switch -
6.	CFL control
7.	CFL control
8.	External connection
9.	Fault detection CFL
10.	Wake-up after connection of panel or external connection
11.	LED
12.	On/Off switch
13.	Power supply +
14.	Power supply -

Table 5: Microcontroller connections

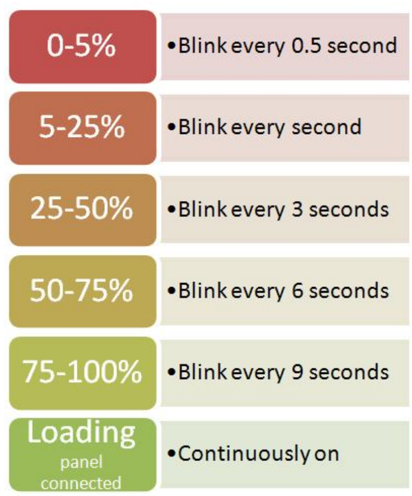


Figure 50: Battery state with LED indication type

4.10 Front plate

The front plate is the most important part for the user interaction with the lantern. It must at least contain an on-off button and a solar panel connector. Another requirement i that it has to be waterproof; especially the connector(s) and the buttons are a point of attention because they are used a lot and pressure is applied to it.

4.10.1 Layout

Due to the extra connection and the extra buttons the design of the front plate had to be redesigned and several new considerations had to be made.

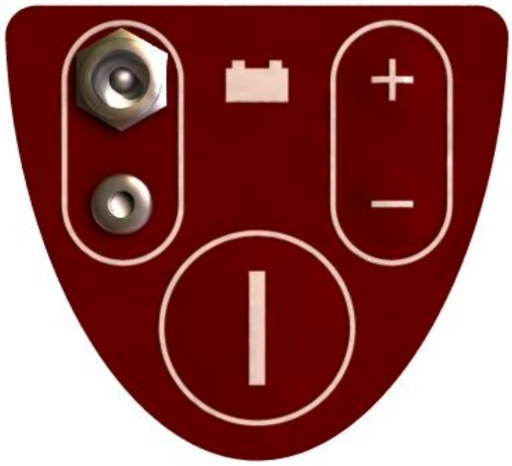


Figure 51: Front cover with connections

Not all domestic appliances are suitable to be connected via the external output, e.g. a television could impossibly run on this kind of battery. The connector of the solar panel may also not be put in the output. Clear marking of the input and the output connectors will be the best solution, but a shortage of space arose from the addition of all the new part leaving no room for clear icons.

The position of the connectors is considerably influenced by the position of the internal frame. The frame is positioned vertically in the middle of the front plate and the connectors cannot be put in front of it without drilling holes and weakening the frame. Repositioning the frame was no option, therefore the connectors had to be placed at the side of the front plate. By using two different connectors it will be completely prevented that users will choose the wrong connector by mistake.

Due to this extra output connector a new hole must me made in the front plate. To control the light intensity two more buttons were added, causing the total button count to rise to three. In the original design the connector was a separate part and not connected to the front plate directly but mounted on the circuit board. Both connectors are mounted onto the front plate using a screw to make a waterproof connection.

4.10.2 Membrane switch

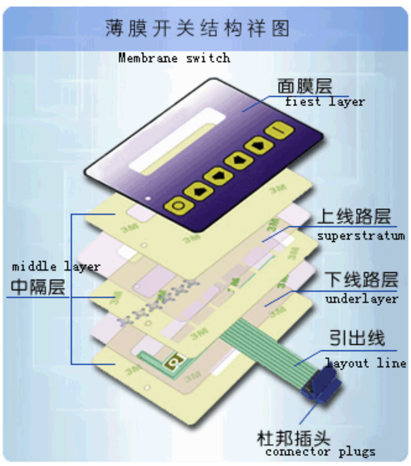


Figure 52: Membrane switch composition

A big difference with the SOLantern is the type of buttons used. Instead of a micro switch mounted unto the circuit board a membrane switch is used. The big advantages of this kind of button are its very small size, the ability to integrate it into the front cover, its durability and the clustering of all connection threads into one strip. Only one hole for this strip has to be made into the casing and because it is positioned in the centre of the cover it will be completely protected from water. Another problem solved with this kind of button is the absence of torque performed on the circuit board when the button is pressed. Also the placement of the picture of the button will be exactly on top of the button itself.

4.11 Mechanical connections

4.11.1 Preventing access to the inner parts

Touching the inner parts is potentially dangerous because of the high current used to start the CFL. In Cambodia the "creative" use of products is very common, e.g. using the battery for other purposes without the power regulating electronics. A warranty is given by Kamworks so any undesirable use causing a broken battery should be minimized. Access to the inner parts has to be restricted to end users but not to repair mechanics.

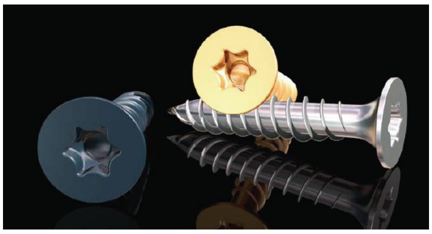


Figure 53: Torx screws

Sealing of one or more parts with for example plastic sheet will solve the problem partially. The biggest problem is the connection of the CFL and the wiring to it from the electronics through which a voltage of about 300V will run when starting up the lamp for a short period (Hil, 2007). Another point of attention is the potential access to the connection from the battery to the electronics. These electronics prevent the battery from being charged or discharged too much, but nothing should interfere with them to make this work.

Because it is not necessary for end users to access any internal part these can be sealed using the casing. A screw that can not (easily) be removed will be a good solution to this, e.g. a Torx screw (Figure 52). The drawback of this seal is that end users will not be able to replace the CFL themselves. With a life expectancy of 3 years the replacement of the CFL by a Kamworks entrepreneur will be sufficient.

4.11.2 Making the inside waterproof

To solve the problems discovered during the water test multiple alterations to the design were made.

Rubber rings were placed around the screws and between the internal frame and casing, preventing water to enter through the holes.

The front panel was replaced by a membrane switch, covering the hole necessary for the wires to the on/of switch. Jacks with screws are used to create a watertight connection. Rubber rings can be used as a seal if necessary.

Figure 54: DC power jack with screw

Finally silicone kit is used instead of a rubber hose to fill the gap between the base and upper casing. Silicone kit is more elastic and extra material can be applied in corners to follow the shape of the casing more accurate.

4.12 Electrical connections

The charge and output controller are mounted on the same circuit board making the wiring easier (Figure 56). The arrows in this figure represent physical wires between the components and are implemented in the following ways:

- The wire attached to the solar panel is connected to the circuit board with a DC power plug and a normal DC power jack (Figure 53). This jack is connected by welds on the circuit board and small crimp terminals at the side of the power jack (Figure 54)
- The connection between the battery and the circuit board is made by a wire weld to the circuit board and crimp terminals at the battery side

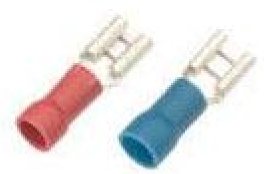


Figure 55: Crimp terminals

- The same wire is used to connect the battery with the output controller
- The wire to the CFL holder is welded onto the circuit board and screwed into the holder
- Small crimp terminals are used to connect a wire to the jack for the external device. This wire is welded onto the circuit board
- The wire from the user interface (front plate) is attached to the circuit board by a plug and socket connector (Figure 56)

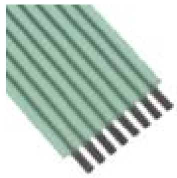


FIGURE 56: FLAT PLUG

By using a permanent connection at one side and a releasable one at the other side all components can be detached and replaced if necessary.

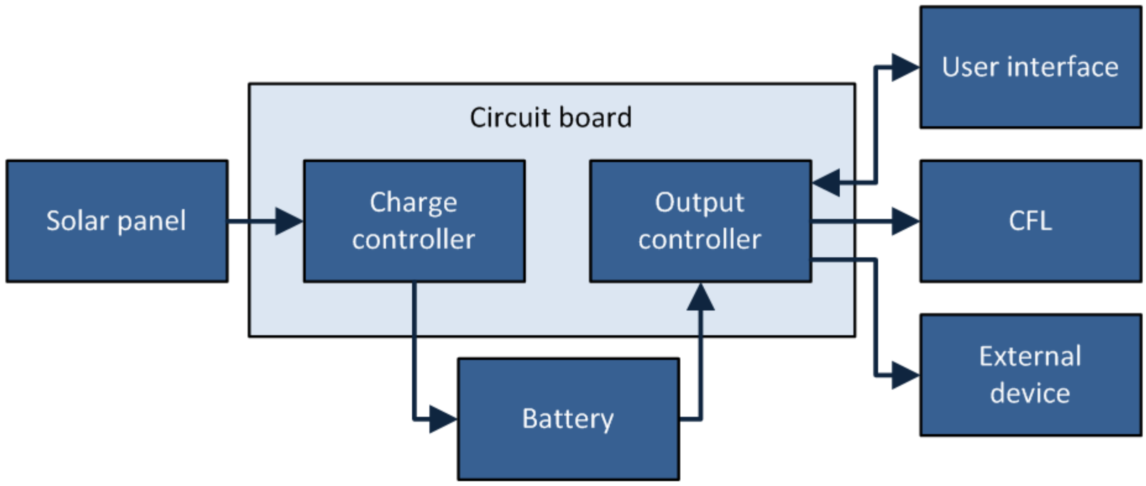


FIGURE 57: ELECTRONICS IN THE ANGKOR LIGHT

4.13 BATTERY

The battery chosen by Kamworks is the Genisis NP 4.5-12. This sealed lead-acid battery is has a current of 12V with a capacity of 4.5Ah.

The electronics developed prevent the battery to discharge more than 50%. At this rate the battery has a life expectancy of about 550 cycles. This amount increases quickly when discharged less: at a discharge depth of 30% the life expectancy rises to 1200 cycles. The expectation is that people will use the light for an average of less than 4 hours a day, making the expected life span of the battery about three years.

FIGURE 58: THE BATTERY USED

4.14 Materials

4.14.1 Plastics

The materials possible for the plastic parts were tested using a drop test described in paragraph 3.4.3. Several other considerations were made during the selection of the appropriate plastic for the Angkor Light. The characteristics are summarized in Table 6. Several inquiries have been carried out to obtain the price for all materials, which are summarized in Appendix D .

The choice for PS was made because of its low price, its easiness to vacuum form, its shiny surface look and transparency. No other material has all these properties. The only real disadvantage found is its UV sensitivity. The lantern will only be used at night, when it is kept away from the sun during day (and while charging the battery) the problem can be avoided. The packaging should inform people about this potential problem.

The parts damaged (by sunlight) should be obtained very easy from the Kamworks store at a very low price. Due to the low material costs and production costs this will be possible.

Material	Price per piece (1.5x244x250mm) see Appendix D.2	Advantages (Formech International Ltd., 2001) (Zeus Industrial Products, Inc., 2005)	Disadvantages (Formech International Ltd., 2001) (Zeus Industrial Products, Inc., 2005)
PC	$0.46	Very strong, not brittle Transparent and highly shiny Good resistance against weather influences	Expensive Hygroscopic
PS (or HIPS)	$0.18	Transparent, shiny surface look Cheap Easy to vacuum form	Does not withstand UV very well
ABS	$0.21	Very shiny Strong material Easy to paint and glue	Not transparent
PMMA (Acrylic)	$0.30	Highly transparent All colours available	Very brittle Difficult to vacuum form
PETG	$0.28	Easy to vacuum form High transparency Good recyclable Stronger than acrylic	Expensive Bad UV resistance, not used for durable consumer goods
APET (Amorphous PET)	$0.35	Easier to vacuum form than PETG High transparency Good recyclable Stronger than acrylic	Expensive Bad UV resistance, not used for durable consumer goods

Table 6: Plastic characteristics

4.14.2 Metals

The metal for the handle selected by Boom was galvanised steel. This material is hard to get in Cambodia, and only as large sheets. A possibility is to the cut the sheets into strips width the desired width, but the tooling costs would be very high. The borders are also very sensible for rust because they are not galvanised. An alternative was found by use of aluminium instead. This material is light weighted, easy available in the right size and has a quality appeal. The material costs are higher than the galvanised steel, but this is compensated by the lack of extra tooling cost.

The internal frame is still made of galvanised steel, these strips are less thick and cutting is therefore much easier.

4.15 Colours

During the basic user research of Stephen Boom several colour schemes were presented to the people. All participants favour bright colours and like shiny materials (Figure 58). A possible explanation for this fact is that most products available are not very coloured, not shiny and look cheap especially most Chinese products. People want to show off with the lantern and want a real quality appeal.

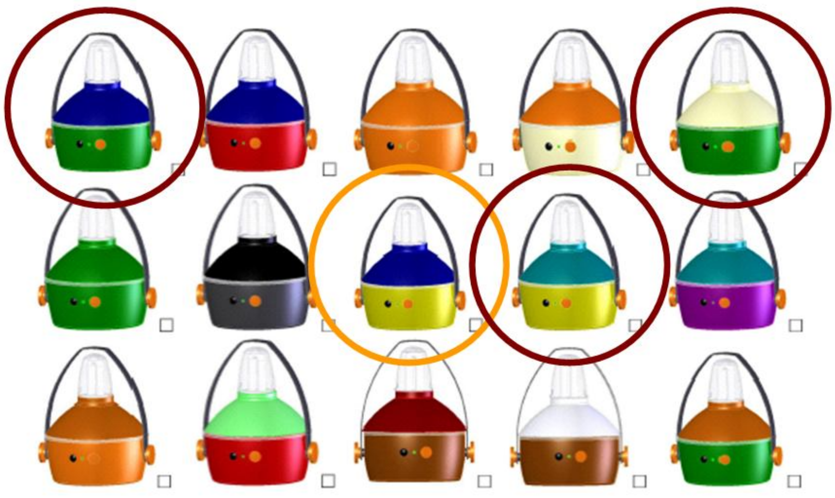


Figure 59: Colour choice out of the user test (Boom, 2005)

All plastic parts can be made in a lot of bright colours because the availability of sheets is high. The front plate however can be produced in one colour only. Very high start-up costs are required to produce them, only when a second batch is ordered it can be changed. Dark red is chosen because of the contrast with the base casing and because it matches best with all bright colours.

4.16 Cost price

Getting a reliable forecast of the cost price of the product and bringing it down was one of the most important tasks of the assignment. A lot of things were uncertain and based on rough estimations and availability of parts in Europe.

A global part list was included in the report of Stephen Boom (Boom, 2005), but it was not containing all parts used. Also a lot of suppliers were unknown. This list was used as a starting point and extended with other all parts used for the product. After the redesign of the lantern all items in the list turned out to be replaced by new parts.

The costs of all parts used in the product have been analysed. To obtain several possible distributors of components and get different price indications, many inquiries have been performed. Using these inquiries an accurate estimation of the product price could be made. The list with suppliers is also useful

Components	Subtotal	Total
Plastic components	$3,77	
Electronics	$9,94	
Metal components	$2,07	
Screws, Nuts, bolds etc	$2,05	
Electronic parts	$6,99	
Solar panel	$17,82	
Subtotal		**$42,64**
Transport	$0,31	
Packaging	$1,50	
Breakage	$1,32	
Subtotal		**$3,13**
Marketing	$1,42	
Overhead	$6,24	
Profit	$5,09	
Subtotal		**$12,74**
Margin retailer	$6,50	
Subtotal		**$6,50**
Selling price		**$65,01**

Table 7: The cost breakdown of the final product

to decide which alternative can be chosen in case of a conflict with the current one or increased cost prices. The total cost price breakdown including the complete part list can be found in Appendix E .

The total cost price (Table 7) marks the problem found during this process: the product price is $65, after intensive research for cheap suppliers. The price per component chart (Table 8) reveals the share of each main part of this total amount.

A big problem are the import taxes. The government collects about 10% VAT and 35% import tax. An exemption is made for NGOs, but Kamworks is a commercial company and has to pay them. The price of the solar panel is considered to be as low as possible after more than 25 inquiries. A comparison of the electronics of several other distributors by the electrical engineering experts can possibly lower the price of the electronics and the electronic parts (e.g. the battery). Margin for the retailer, overhead and profit are determined by the Kamworks management, when the product is put into practice it can be seen if these values are correct and reasonable.

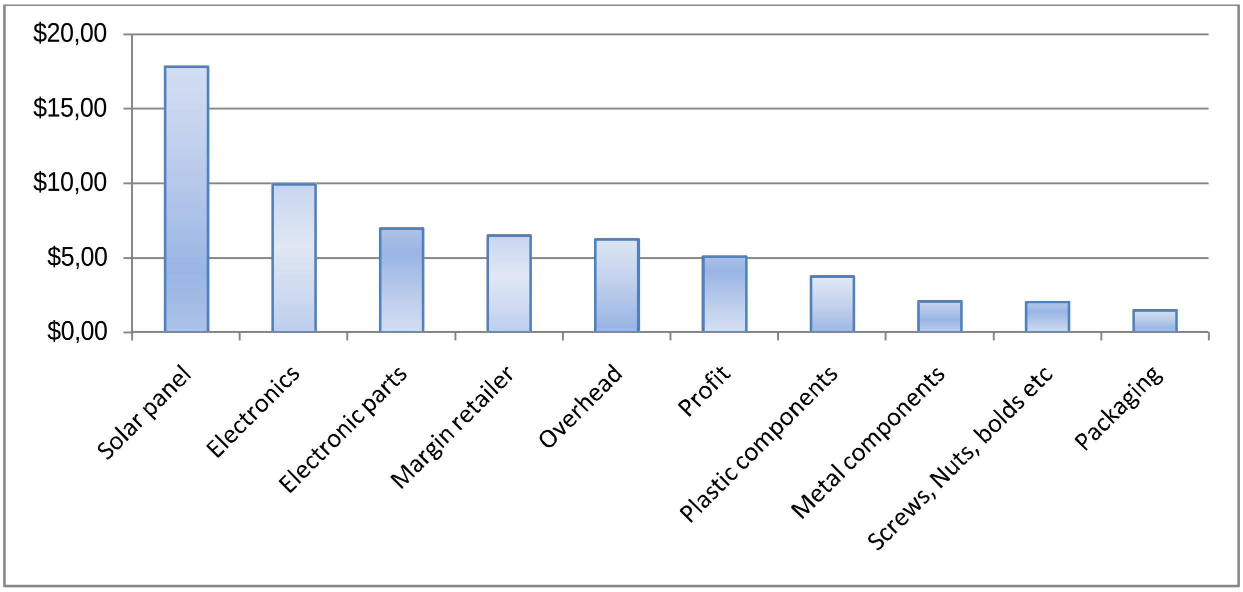
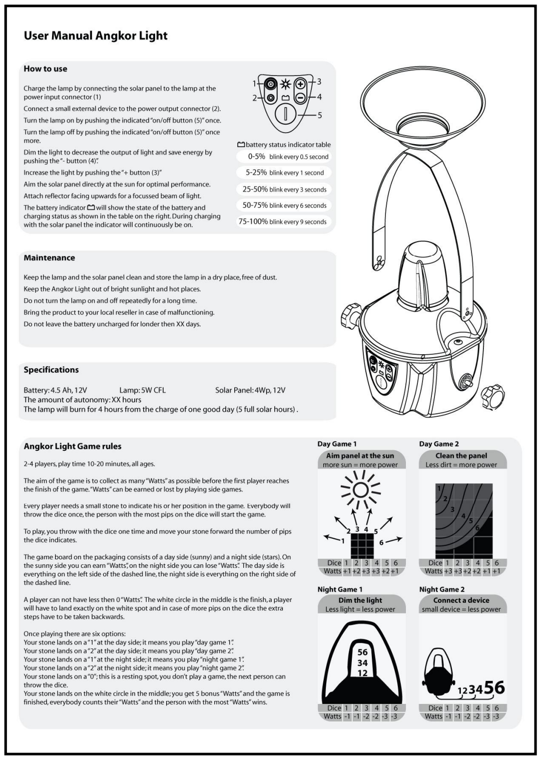


TABLE 8: PRICE PER COMPONENT

4.17 Packaging

Simultaneously with the redesign of the Angkor Light a packaging concept was developed by Stefan Ruiter as a bachelor assignment (Ruiter, 2007).

The packaging together with the manual provides information about the product as defined in PVGap, it protects the product during transportation and makes clear what the product is used for and how when placed in a market stall.



User Manual Angkor Light

How to use

Charge the lamp by connecting the solar panel to the lamp at the power input connector (1)

Connect a small external device to the power output connector (2).

Turn the lamp on by pushing the indicated "on/off button (5)" once.

Turn the lamp off by pushing the indicated "on/off button (5)" once more.

Dim the light to decrease the output of light and save energy by pushing the "- button (4)".

Increase the light by pushing the "+ button (3)"

Aim the solar panel directly at the sun for optimal performance.

Attach reflector facing upwards for a focussed beam of light.

The battery indicator will show the state of the battery and charging status as shown in the table on the right. During charging with the solar panel the indicator will continuously be on.

battery status indicator table

0-5%	blink every 0.5 second
5-25%	blink every 1 second
25-50%	blink every 3 seconds
50-75%	blink every 6 seconds
75-100%	blink every 9 seconds

Maintenance

Keep the lamp and the solar panel clean and store the lamp in a dry place, free of dust.

Keep the Angkor Light out of bright sunlight and hot places.

Do not turn the lamp on and off repeatedly for a long time.

Bring the product to your local reseller in case of malfunctioning.

Do not leave the battery uncharged for londer then XX days.

Specifications

Battery: 4.5 Ah, 12V Lamp: 5W CFL Solar Panel: 4Wp, 12V
The amount of autonomy: XX hours
The lamp will burn for 4 hours from the charge of one good day (5 full solar hours) .

Angkor Light Game rules

2-4 players, play time 10-20 minutes, all ages.

The aim of the game is to collect as many "Watts" as possible before the first player reaches the finish of the game. "Watts" can be earned or lost by playing side games.

Every player needs a small stone to indicate his or her position in the game. Everybody will throw the dice once, the person with the most pips on the dice will start the game.

To play, you throw with the dice one time and move your stone forward the number of pips the dice indicates.

The game board on the packaging consists of a day side (sunny) and a night side (stars). On the sunny side you can earn "Watts", on the night side you can lose "Watts". The day side is everything on the left side of the dashed line, the night side is everything on the right side of the dashed line.

A player can not have less then 0 "Watts". The white circle in the middle is the finish, a player will have to land exactly on the white spot and in case of more pips on the dice the extra steps have to be taken backwards.

Once playing there are six options:
Your stone lands on a "1" at the day side; it means you play "day game 1".
Your stone lands on a "2" at the day side; it means you play "day game 2".
Your stone lands on a "1" at the night side; it means you play "night game 1".
Your stone lands on a "2" at the night side; it means you play "night game 2".
Your stone lands on a "0"; this is a resting spot, you don't play a game, the next person can throw the dice.
Your stone lands on the white circle in the middle; you get 5 bonus "Watts" and the game is finished, everybody counts their "Watts" and the person with the most "Watts" wins.

Day Game 1

Aim panel at the sun
more sun = more power

Dice	1	2	3	4	5	6
Watts	+1	+2	+3	+3	+2	+1

Day Game 2

Clean the panel
Less dirt = more power

Dice	1	2	3	4	5	6
Watts	+3	+3	+2	+2	+1	+1

Night Game 1

Dim the light
Less light = less power

Dice	1	2	3	4	5	6
Watts	-1	-1	-2	-2	-3	-3

Night Game 2

Connect a device
small device = less power

Dice	1	2	3	4	5	6
Watts	-1	-1	-2	-2	-3	-3

Figure 60: User manual (Ruiter, 2007)

Figure 61: Packaging design (Ruiter, 2007)

4.18 The final product

The Angkor Light is the redesign of the SOLantern made by Stephen Boom. It is a solar lantern designed for the rural population of Cambodia and is characterized by its sustainability, its suitability for multiple lightning situations and low costs on the longer term. Possible reparations can be done by entrepreneurs educated by Kamworks against very low repair costs. The lantern will be produced in Cambodia itself with as much materials local available as possible.

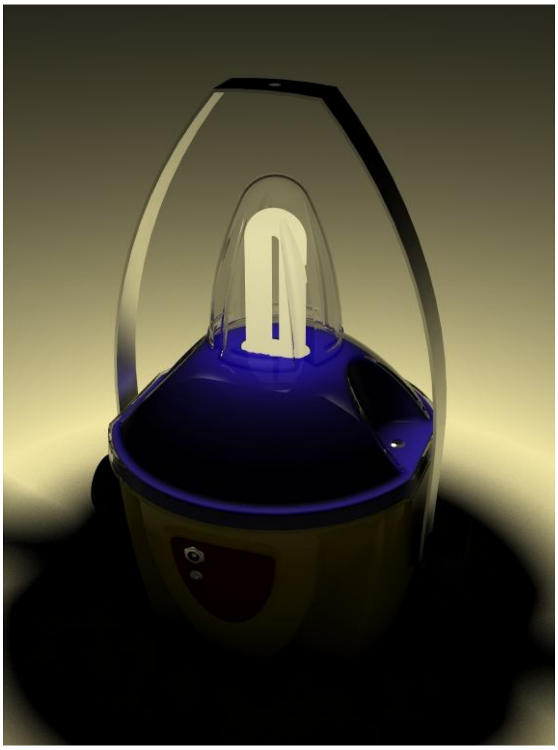


Figure 63: Angkor Light during operation

Figure 62: Exploded view of the Ankor Light

Figure 64: Angkor Light in hanging position

5 PRODUCTION

5.1 INTRODUCTION

During the product development phase the production process was analysed. Some problems encountered are used to redesign the product if possible, others are used to change the production process itself. This chapter deals with all production analysis aspects not described in the previous chapters and the implementation of the final product into a production environment suitable for Kamworks.

5.2 PRODUCTION SITUATION

Production in a third world country like Cambodia is completely different from a production situation in a Western country. Educational standards are low, quality commodities are rare, the country is very corrupt and the infrastructure is very bad. On the other hand it has a lot of advantages: labour costs are very low, employees are easily available, the local community is much easier reached and last but not least Cambodians are very patriotic and prefer “real” Cambodian products over foreign ones.

5.3 EMPLOYEES

Kamworks currently has four employees capable of operate almost all available machines. Only the vacuum forming machine is unknown to them, but it will be easy to operate because it will be programmed to perform a complete production cycle by its own.

More employees can be hired easily if necessary because of the high unemployment rate in the country. An educational level of grade 9 (comparable with 2nd class of the Dutch secondary school) will be a good starting point for an internal training. The children at the orphanage will complete at least this grade, making it possible for all of them to work at the company in theory.

Payment is a fraction of labour costs in Europe; good paid workshop workers earn about $80 a week. In addition to the salary Kamworks also provides additional health and industrial disability insurance services making them above-average employers.

A problem observed while making the prototype was the lack of accuracy of these employees now and then. In Cambodia a lower quality standard (compared to western countries) is commonly used. This is not acceptable while producing the Angkor Light in mass production. Checks for each critical part should be provided after production as well as quality checks concerning the complete product performed at random.

5.4 PRODUCTION EQUIPMENT

Several basic machines like the a drilling machine and a hand press brake are available (see Appendix C). To produce the Angkor Light some parts need to be made by a third party, e.g. the vacuum forming moulds. To ease the production process some tools were designed, making the time required to produce a part lower and the accuracy higher.

5.4.1 Tool design

The internal frame consists of a metal strip bend in angles of approximately 90°. The first consideration was to use dieing to shape the frame, but this technique has several drawbacks:

- A lot of dies are needed
- The dies are expensive to make
- Aligning the metal to the die is very difficult because the die pulls the metal into its form making the metal slide easily
- To verify if a die suites its purpose it has to be actually made. This results in a high risk of losing the invested money if the die is imperfect
- The stroke of the available machine is not big enough contain the frame (necessary for some bends)

An alternative bending tool was developed taking away all of these disadvantages. All the corners have a ±90° angle, only the distance between them varies so the tool has several positioning stops at the right distances. It consists of locally available materials and is easy to manufacture. A hydraulic cylinder can be attached to the handle to make it more productive (Figure 64).

A (rubber) stop can be used to stop the handle at the desired angle.

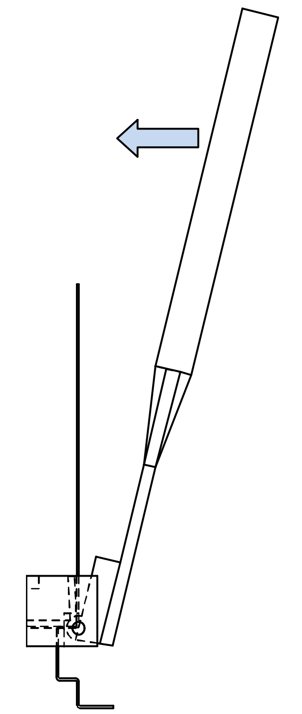


Figure 65: Top view of the bending tool

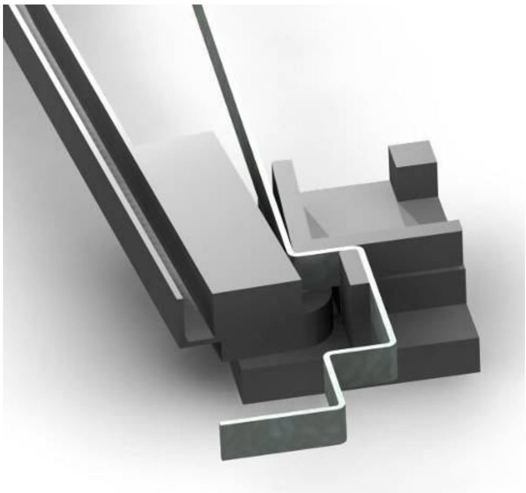


Figure 66: Section view of the bending tool

Figure 67: Prototype of the bending tool

A bending tool was also constructed to get the right shape into the handle. Aluminium is pretty easy to bend, making it possible to do this by hand. The strip is fixated onto the tool using the hole used for hanging the lantern.

To form the material a metal cylinder is used, possibly coated with rubber to prevent scratches. The aluminium strip can be turned 180° to make a symmetrical shape. This tool is also operated by hand and is therefore using no electricity.

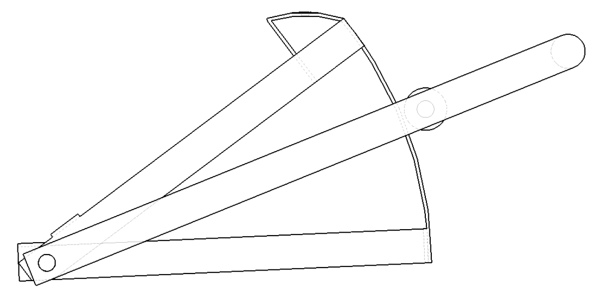


FIGURE 69: BENDING TOOL SIDE

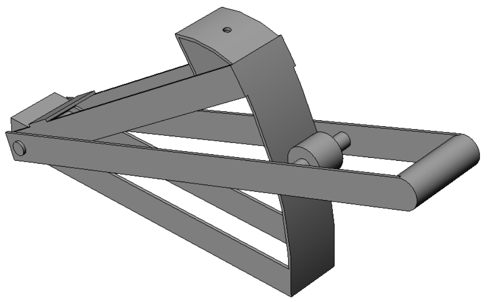


FIGURE 68: BENDING TOOL PERSPECTIVE

To fixate the plastic parts during the drilling of the holes several supports were designed and tested. A frame made of Fiberglas and epoxy built upon a metal construction turned out to be the most accurate and strong solution. The metal construction was used to attach the support to the column drill. Only a metal frame did not work because the frame could not be shaped correctly due to the double curved shape of the casings.

5.5 MOULD DESIGN

Several considerations were taken into account during the design process to ease the vacuum forming of the plastic parts. The new material thickness was implemented and tested to reveal (potential) problems.

The changes in the design of the lantern considering the vacuum forming process consisted of adding drafts to all vertical faces to ease the release of the parts (Figure 69). New ideas like the click mechanism to fixate the reflector were tested using prototypes (see Figure 70 and Figure 71).

Vent holes were added to aid the plastic shaping process. These holes are placed in cavities and places where the material touches the mould last. The ideal situation would be a mould where the plastic would hit the mould everywhere at the exact time. To approach this situation the material is pre-formed using a blower, the amount of seconds required was tested and written down to apply in the production process. By adjusting this pre-bubble face the timing and wanted material thickness can be tweaked.

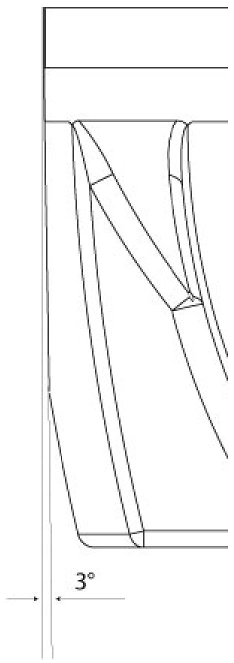


FIGURE 70: DRAFT ADDED

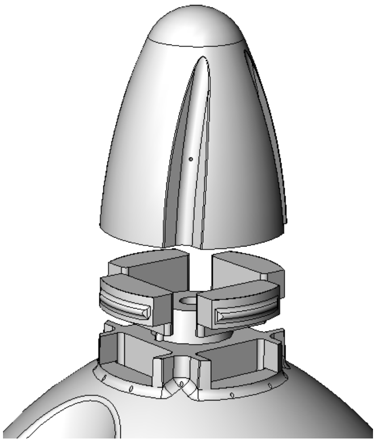


Figure 72: Inserts to make the click mechanism (exploded view)

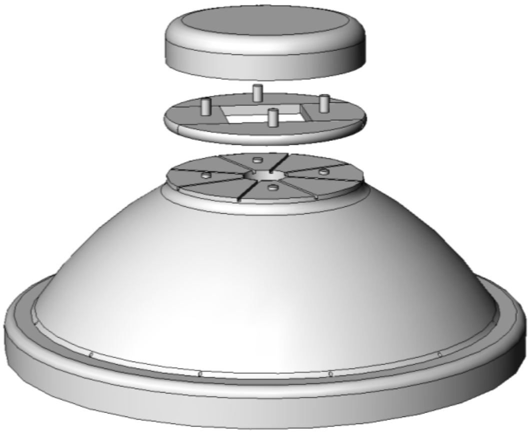


Figure 75: Mould of the reflector (exploded view)

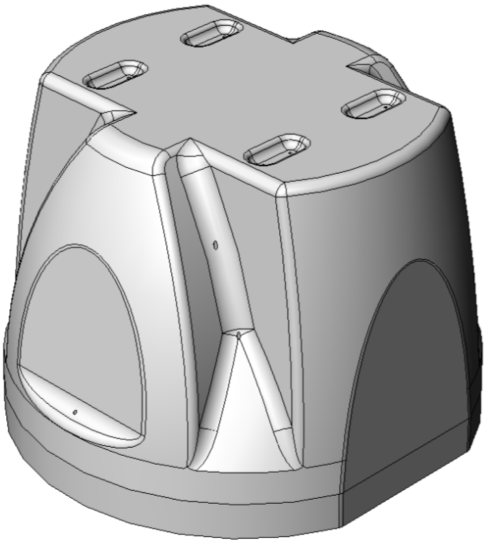


Figure 73: Mould of the base casing

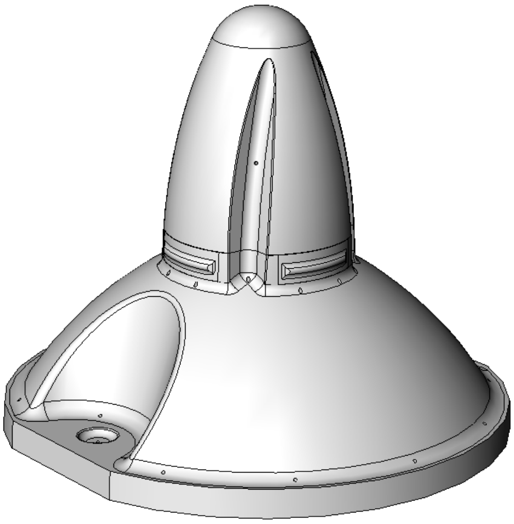


Figure 74: Complete mould of the top casing

Figure 71: Prototype of the new click mechanism

5.6 Production process

5.6.1 Energy consumption and supply

The power needed for production is produced by the existing solar panels and an additional generator. During the prototype production the values were gathered to obtain an insight in the production situation.

Figure 76: Kamworks solar system

The batteries of the solar system have a capacity of 19.2 kWh, the generator is capable of producing an extra 15 kWh. The vacuum form machine needs about 4.73 kW for heating and another 0.75 kW for all other operations. All other machines are using only a fraction of this amount.

All costs required for the operation of these machines have been used to calculate the final product price.

5.6.2 Plastic parts

Production of the plastic parts consists of vacuum forming and finishing. The vacuum forming step takes place using the moulds designed and the vacuum forming machine available.

To remove the waste material and obtain a nice upper edge several some finishing need to be done. To investigate the local possibilities the following tools were tested:

- Knives (hot or cold) are working but it takes a lot of time. Hot knives are a little bit faster.
- A hot wire separates the plastic but also melts it together again
- An angle grinder is much faster then a knife because it melts and removes the plastic in the grinding process but is less accurate then previous methods
- A hand saw is working but it costs a lot of human power
- A figure saw is very suitable but an often occurring problem is that the product is too big to fit into the machine

The conclusion was that saws with fine tooth are in general the best solution to separate the product and the waste material. To make a smooth upper edge a simple knife can be used to scratch the burs off. To apply this method to mass production a band saw is most useful, these machines are not very expensive and are available in Phnom Penh.

The holes needed are made with a column drill. Several options to fixate the parts were investigated; the problem encountered was the many double curved surfaces. By making epoxy moulds described earlier the exact internal shape of the parts could be reproduced. The plastic parts can be places on the moulds very easy and the placement is accurate.

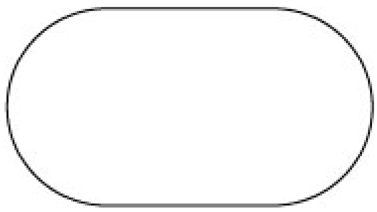


Figure 77: Inner top frame cut shape

Cutting the hole of the inner top casing will be done using a die. Because of the round shape of the die it can be made pretty easy, while corners are difficult to produce (see Figure 76). An epoxy mould will be used to position the part.

5.7 Metal parts

5.7.1 Cutting

The internal frame consists of metal strips with a width of 20 mm and varying length. Only metal sheet is local available making cutting it to the correct size necessary. The guillotine shears in the Kamworks workshop are only suitable to cut sheet in 90° angles or into vary small pieces. Sawing by hand is not possible because of the necessary tolerances; machined sawing or cutting is not possible because no such machines are available at the workshop and buying them would be to expensive. An external company capable of machined cutting was found in Phnom Penh, the only drawback of outsourcing the cutting is the slightly higher cost but the quality is much higher. The last option mentioned is used.

Aluminium for the handle was found with the right width as described earlier, cutting it into the right lengths is done with a hand saw. Rounding the edges can be done with a sanding machine or a grindstone (both available). Quality checks will be done using a template of the curves.

5.7.2 Bending

Bending is done by the tool design. Because the hole on the top side is used to fixate the part it should therefore be drilled first.

5.7.3 Drilling

In contradiction to the hole used for hanging the holes for the knobs to attach the handle onto the internal frame will be drilled after the bending process. This is done to make sure that they are made at the right positions.

5.8 Production guide

All actions needed to produce a part are summarized in the following pages. The assembly of parts that cannot be parted are also described in this section, e.g. connections by welding.

5.8.1 Internal frame – lower part

Front-to-back and side-to-side frame

1. Cut a metal strip of 1.5mm thick galvanised steel to the desired length
2. Drill the holes using a drilling template
3. Bend the frame using the bending tool into the right shape
4. Check the precision of the frame using a reference template

Both

5. Place both parts in the welding template and weld them together
6. Remove wired edges if necessary

Figure 78: Internal frame –lower part

5.8.2 Internal frame – upper part

Front-to-back and side-to-side frame

1. Cut a metal strip of 1.5mm thick galvanised steel to the desired length
2. Drill the holes using a drilling template
3. Check the precision of the frame using a reference template

Both

1. Place both parts in the welding template and weld them together
2. Remove wired edges if necessary

Figure 79: Internal frame – upper part

5.8.3 Top casing, inner top casing and base casing

1. Vacuum form the casing with a 250x250mm PS sheet with the following thickness:
   - Top casing and base casing: 1.5mm
   - Inner top casing: 0.5mm
2. Remove the rest material
3. Drill the holes using the supports

Figure 80: top casing

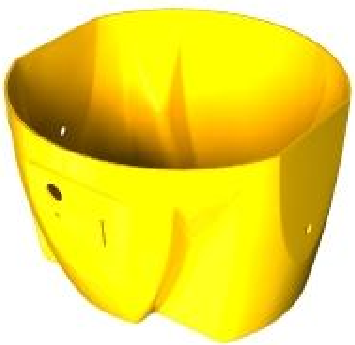


Figure 81: Base casing

Figure 82: Inner top casing

5.8.4 Handle

1. Cut a metal strip of 2mm thick aluminium to the desired length
2. Round the edges
3. Check the precision of the edges using a reference template
4. Drill the holes
5. Bend the frame using the bending tool into the right shape
6. Check the precision of the frame using a reference template

Figure 83: Handle

5.8.5 Reflector

1. Vacuum form the reflector with a 1.5x250x250mm PS sheet
2. Remove the rest material
3. Place the reflector in the paint support and paint a chrome layer
4. Place the reflector in the drying cabinet
5. After drying: place the reflector in the paint support and paint a transparent layer
6. Place the reflector in the drying cabinet

Figure 84: Reflector

5.9 Assembly

After production of the different parts required assembling them is the next step. The assembly has been broken down into several sub-assemblies, making it possible to complete one part at a time. The process can be managed and optimized according to work capacity and possibilities. The complete assembly process can be seen in Figure 84.

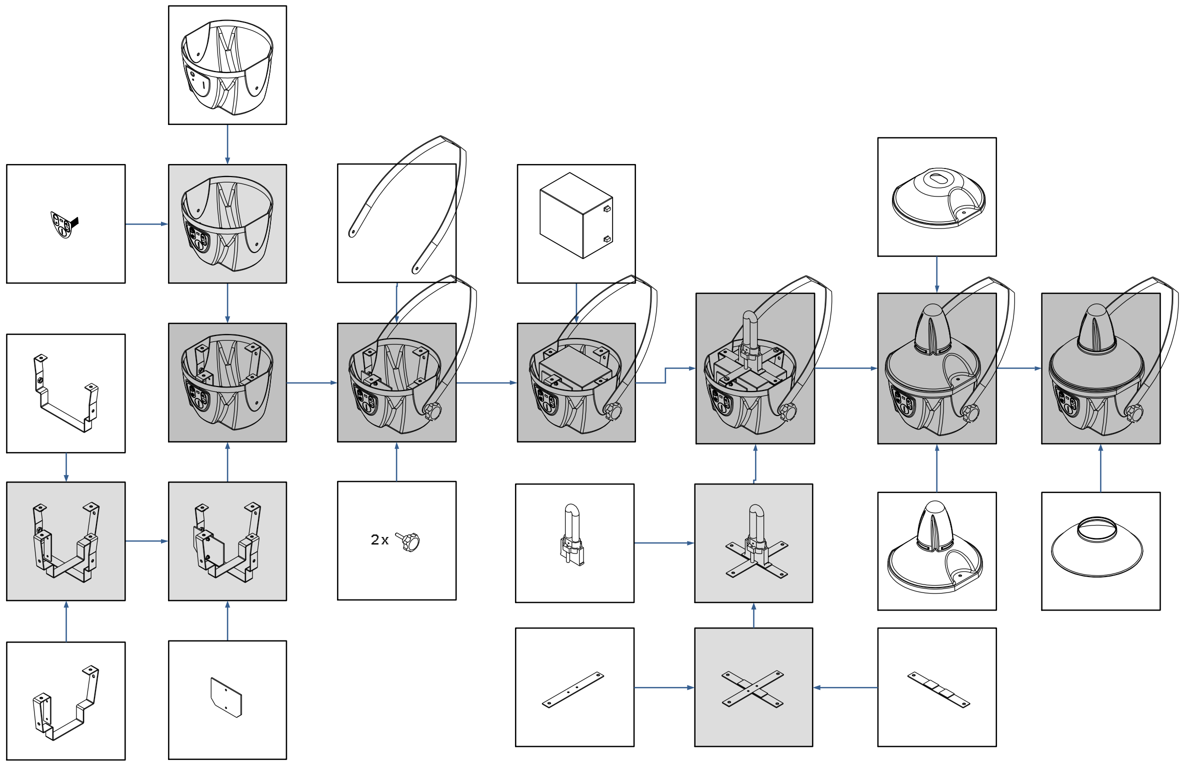


Figure 85: Angkor light assembly chart

6 Conclusions and recommendations

6.1 Meeting the requirements

After te redesign it has to be checked if the requirements defined at the beginning are met. Colour codes are used to mark in which level the requirement is met in the following way:

- Green mains = requirement met
- Orange = partially met / not checked yet
- Red = not met

When a requirement is partially or not met an explanation is given, with recommendations to meet it in the future. Also ways to determine how requirements that are not checked yet can be verified will be given in the recommendations section.

6.1.1 Production

- Vacuum forming should be used as production technology for the plastic parts
- Final assembly should be in Cambodia

6.1.2 Aesthetics

- The product should have a modern western look and feel
- The product style should fit with the mood board made by Stephen Boom the colours should be bright and powerful the Cambodian way
- The product should express stability
- Make people feel proud to own a product like this; Refer to the Cambodian look and feel
- The product should have a quality appeal and consist of plastic parts
- The product should look and feel robust

6.1.3 The product should meet the demands of the PV-GAP

- The on/off switch should withstand cycle of 100000 times
- Charge controller protect from damage from voltage under open circuit conditions
- Protected against damage from reversal polarity conditions of battery and solar panel
- The battery should be protected by a fuse. This may be on the circuit board
- Solar panel connection should withstand minimum of 1000 connection cycles
- The battery capacity (C2) shall not decrease over the testing period more than 10% of the initial battery capacity. C0-C2/ C0 <10%
- The measured days of autonomy shall match or exceed the defined minimum days of autonomy as indicated by the manufacturer
- The lamp shall operate undamaged according to the manufacturer specs. At maximum battery volt and max radiation
- The manufacturer shall specify the daily number of hours the system can service the load under test conditions
- The product should be able to operate during rainy conditions a according to IP23
- The product should be able to withstand the shipping vibration test

6.1.4 Electrical components

Light

- The light bulb should be visible

- The light bulb should be able to be replaced
- The CFL should meet the PV-GAP standard

Battery

- The battery should not make contact with the electric system when stored
- The battery should have a minimum capacity of 2,5 Ah (at 12V)
- After purchase, a fully charged battery should be able to operate the product 3 hours without being recharged in between
- The battery should be protected from direct sunlight
- The user should be able to obtain information when the battery is almost empty
- The user should be able to obtain information about the charging status of the product
- The battery should be able to be replaced
- The battery should meet the PV-GAP standard

Solar panel

- The panel should be able to take inside the house
- The panel should be able to be fixated and aimed at the sun
- The product should operate on 12 Volts
- The panel should meet the PV-GAP standard

6.1.5 Other

- The selling price should not exceed the maximum of $50
- The product should be sold as one integrated package containing the solar panel determined in (Boom 2005, 3.4.4), mobile lighting unit and instruction guides

6.1.6 Use

- The product should be able to be carried by the user
- The lighting product should be able to stand on a rough underground like stones and sand and mud
- The lighting product should be able to be hanged
- The light should shine evenly distributed in an angle of 110 degrees measured from the vertical axis, around the product
- The minimum illumination level should be at least 20 lux at a distance of 1m
- Components that are irreplaceable, like casing and frame, should be able to operate after a fall of 50 cm (walking height and table height) on earth ground

6.1.7 List of preferences

- The product should made be out of local materials which are easy provided
- The production of the product should fit with the main objective to contribute to the development of Cambodia by offering local labour
- Users can easily take the lantern and solar panel to their work (rice field or marketplace)
- The product should be easy to repair
- The product should fit all lighting categories
- The product should have a connection to supply power to other products (e.g. a mobile phone)

6.2 Recommendations

Some requirements for the redesigned Angkor Light have not been tested yet. These tests should be incorporated into the field test planned for the nil series. The following list needs to be checked:

- The product should have a modern western look and feel
- The product style should fit with the mood board made by Stephen Boom, the colours should be bright and powerful the Cambodian way
- The product should express stability
- The product should be able to withstand the shipping vibration test
- The minimum illumination level should be at least 20 lux at a distance of 1m
- Users can easily take the lantern and solar panel to their work (rice field or marketplace)

The following requirements are not met:

The selling price should not exceed the maximum of $50

De high selling price is discussed in previous chapters and changes in margins for the retailer and the company should be reconsidered by Kamworks to lower this amount.

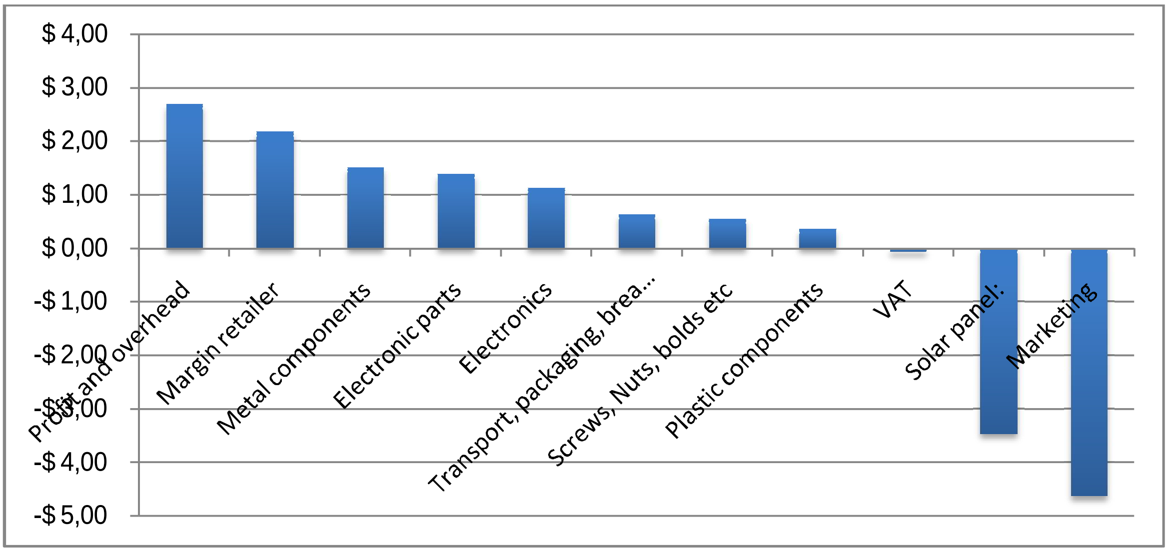


Figure 86: Absolute price increase per component of the Angkor Light compared to the SOLantern

The increase in price can be analysed by looking at the increase in price per component compared to the SOLantern (Figure 85). The increase of the profit and overhead in combination with the decrease in price of the distribution and marketing can partially be explained by a redistribution of these budget items (the items *profit* and *overhead* are combined to be able to make a comparison with the SOLantern). When all these costs are added to each other a total decrease of almost $2 can be seen. Marketing will be done via the market stalls, which use a different way of funding. The profit and overhead together are still $2,7 higher than the SOLantern despite the advise of the MIT research to lower this costs (MIT Sloan - GLab team, 2007). It should be considered to find ways to lower the overhead, e.g. by sponsorships or more local and cheaper employees. This implications however are out of reach of this assignment and should be investigated by the company itself.

The extra money for the retailer was a decision made by Kamworks in order to give more financial support the local entrepreneurs. It also has to be considered if this addition will be the best way to earn more money, considering the lower returns. Previous market research done by the MIT (MIT Sloan - GLab team, 2007) and Mando Rotman (Rotman, 2006) suggests giving a profit to the entrepreneur depending on the amount of items sold.

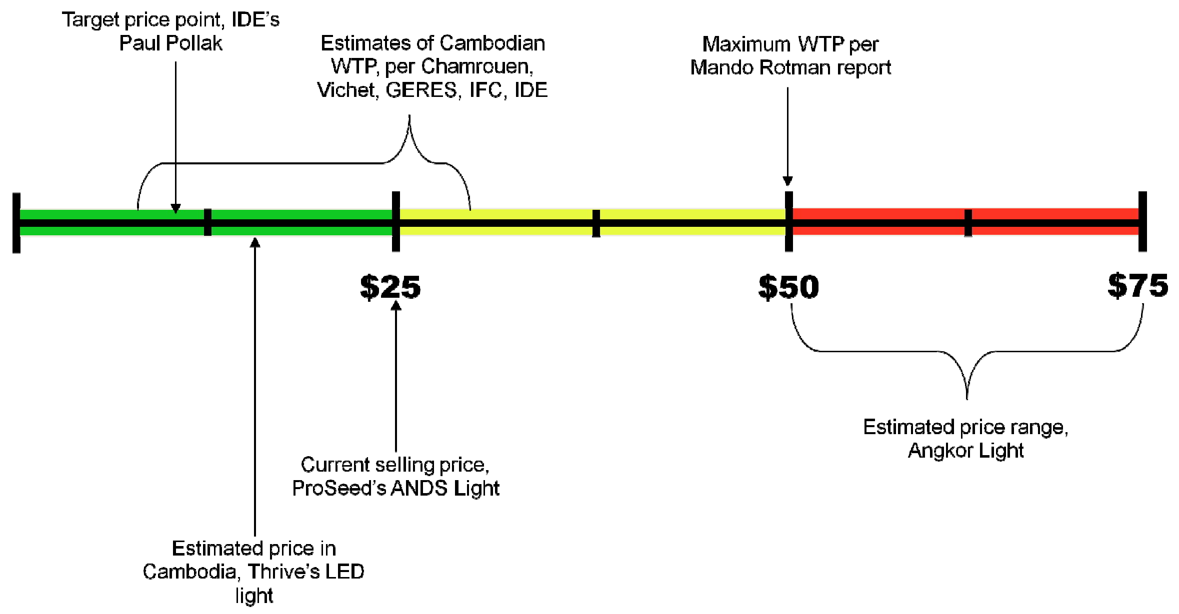


FIGURE 87: PRICING RANGE OF THE ANGKOR LIGHT INDICATED BY SEVERAL STUDIES (MIT SLOAN - GLAB TEAM, 2007)

A comparison of the electronics of several other distributors by the electrical engineering experts has to be considered to lower the price of the electronics and the electronic parts (e.g. the battery).

The product should be sold as one integrated package containing the solar panel determined in mobile lighting unit and instruction guides

The considerations made by Stefan Ruiter are:

1. The solar panel size is approximately 400x500mm, this will not fit in one casing together with the lantern in an easy way
2. A package for the solar panel is already provided by the manufacturer. A Kamworks sticker will be added

(Ruiter, 2007)

7 LIST OF DEFINITIONS

Rural population

Country people with a low income of about $50 per month

Solar Home Systems

Autonomous solar energy installation powering a building. This kind of installation is used when no power grid is available.

PV

Abbreviation of Photovoltaics, meaning technology based on solar energy

Nil series

Series of products made in mass production which is fully functional and user test could be performed with.

Compact fluorescent lamp **(CFL)**

Also known as a compact fluorescent light bulb or an energy saving light bulb, is a type of lamp designed to fit into roughly the same space as an incandescent lamp, but with the advantages of a fluorescent lamp.[1]

FOB

Free On Board (named loading port): the classic maritime trade term, Free On Board: seller must load the goods on board the ship nominated by the buyer, cost and risk being divided at ship's rail. The seller must clear the goods for export (Maritime transport only).[2]

CIF

Cost, Insurance and Freight (named destination port): seller must pay the costs and freight to bring the goods to the port of destination. The seller must procure and pay for insurance for the buyer (Maritime transport only).[2]

Glass Transition Temperature (Tg)

The glass transition temperature is the temperature below which the physical properties of amorphous materials vary in a manner similar to those of a crystalline phase (glassy state), and above which amorphous materials behave like liquids (rubbery state).[3]

Tuk-Tuk

A tricycle used for the transportation of people and goods (see Figure 87).

Insolation

The incoming solar radiation that reaches the earth and the atmosphere.

Ballast

An electrical ballast is a device intended to limit the amount of current flowing in an electric circuit.

FIGURE 88: A TUK-TUK IN PHNOM PENH

[1] http://en.wikipedia.org/wiki/Compact_fluorescent_light_bulb
[2] http://en.wikipedia.org/wiki/Incoterm
[3] http://en.wikipedia.org/wiki/Glass_transition_temperature

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