The design of a Solar Home System series.

Realizing an expandable, compact, multiple sized system for rural Cambodia

TU Delft Delft University of Technology

KAMWORKS

The design of a Solar Home System series.

Graduation report

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I Preface

One and a half years ago, I got the opportunity to do my first project abroad: the redesign of a gasifier stove in Uganda. Designing for emerging markets and being involved in new cultures intrigued me. That is why this graduation project, that is about the redesign of a solar energy system in Cambodia, feels like a privilege to me.

This project, lasting from August 2016 till May 2017, was initiated as the continuation of Rixt Siebinga's thesis: "The redesign of a Solar Home System - An expandable and understandable solar home system for rural Cambodian families". During this project, her results were evaluated and additional focus topics (that defined this project's design goal) were identified. The first six months were conducted in Cambodia, after which the design was finalized in the Netherlands.

In this project, the Solar Home Systems of Kamworks were redesigned in order to make renewable energy more accessible to rural Cambodia. Throughout the project local shops, factories and markets were visited to explore the possibilities of the context. Prototypes were made and validated with users to ensure that the outcome would be feasible and contribute to the vision of the company: improving the rural areas of Cambodia. This report is an overview of the actions and considerations that led to the design of a next generation Solar Home System series.

Enjoy reading,

Justin Kane
May 2017

II Acknowledgements

I first would like to thank Dr.ir. J.C. Diehl and Dr.ir. Bas Flipsen, my supervisory team, for their enthusiastic involvement and helpful support throughout the project. Followed by Javier Garnelo, Laurent Leleu and Arjen Luxwolda, who made this project possible and were involved in the whole process.

I am grateful to the employees from the Sre Ampil workshop: Kalyan, Sarin, Sarun, Sueng Hai and Sopha. They spend many hours helping me with building prototypes or finding the right materials in shops.

Next I would like to thank Rixt Siebinga, who created a valuable foundation for this project. Moreover, she was really helpful in the few days that our projects overlapped. Also I would like to thank Thomas Den Heeten and Bunheng Suoy for an unforgettable field trip.

Last but not least I would like to express my gratitude to the many colleagues I was pleased to work at Kamworks for their willingness of sharing their knowledge and expertise, my family for their support and the inspiring people I was pleased to meet in Cambodia.

III Terminology & Abbreviations

A	Ampere
Ah	Ampere hour
B2B	Business to business
BoP	Base of Pyramid
Design proposal	The result(s) of the graduation project of Rixt Siebinga
DIP	Dual in-line Package
DTV	Digital Television
GSM	Global System for Mobile Communications
IEC	International Electrotechnical Commission
KC	Kampong Chhnang
Kg	Kilogram
Khmer	Official language of Cambodia & major ethnic group
KHR	(Cambodian) Riel
KW	Kamworks (Solar Ltd.)
L	Litre
LED	Light-Emitting Diode
MDF	Medium-density fibreboard
MFI	Micro Financial Institution
MOSFET	Metal-oxide-semiconductor field-effect transistor
Net metering	A construction where overproduction of solar energy is sold back to the grid.
NGO	Non-Governmental Organization
PAYGO	Pay as you go
PBM	Province Brand Manager
PCB	Printed Circuit Board
PP	Phnom Penh
PV	Photovoltaic
Riel	Local currency (1 USD ≈ 4000 Riel)
SA	Sre Ampil
SHIFT	Shaping Inclusive Finance Transformations
SFO	Sales Field Officer
SHS	Solar Home System
SIM	Subscriber Identity Module
SNV	Netherlands Development Organisation
TukTuk	A simple vehicle with an engine and three wheels
USB	Univeral Serial Bus
USD	United States Dollar
V	Volt
VRTM	Vacuum Resin Transfer Moulding
W	Watt
Wh	Watt hour
Wp	Watt peak

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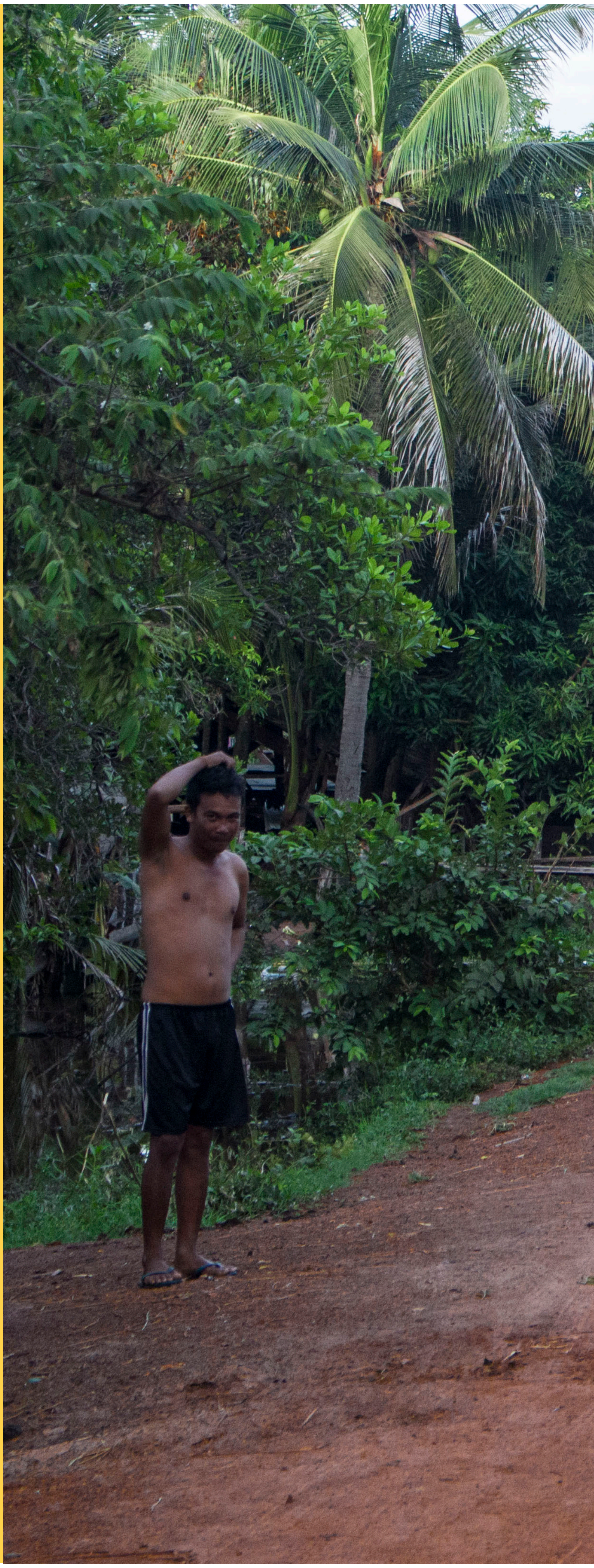

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KAMWORKS

1.

1 Project introduction

1.1 Introduction

Kamworks is one of Cambodia's most innovative solar companies. They develop, engineer and sell solar energy systems. This design project focusses on Kamworks' Solar Home Systems (SHS, figure 2): small, standalone solar energy systems designed for single households. The vision of the company:

"Improve the rural areas of Cambodia by introducing lighting and electricity products to the local population."

The Solar Home Systems provide energy (and lighting) to a single rural household. In order to fit varying energy needs, two system sizes are offered to customers. Compared to other solar energy systems available to these communities, the advantages of Kamworks' solutions can be found in the safety and reliability of the technology through their integrated design. Through an innovative GSM technology, integrated in the electronics of the SHS, systems can be monitored throughout the use. This enables Kamworks to provide customers a better service and the possibility to repay loans through mobile money. The next chapter will further elaborate on this. At the start of the project the following goal was provided:

"To develop the next generation solar home systems for the Cambodian market, which uses Kamworks GSM enabled technology but is simpler, has less components and can be installed by the customer him/herself."

This described goal is a cluster of potential design challenges. Firstly there is the desire for a simplified assembly with a reduction in components. This is inseparable from the request for a simplification and/or reduction in production processes. Besides, there is the wish for a SHS that can be installed not only by the Kamworks' technicians, but also by the customers themselves. The motivation behind the challenges and their feasibility is elaborated later on. They were given to overcome the local barriers and challenges of Cambodia. The following mission can be retrieved from the potential design challenges:

"Making clean energy more accessible to rural Cambodia"

Since Kamworks' foundation in 2006, they have cooperated with several student teams and individual students from the faculty of Industrial Design Engineering (TU Delft), to renew and improve their products and systems. This design project was initiated as a continuation from the graduation project "The redesign of a Solar Home System: An expandable and understandable solar home system for rural Cambodian families" (R. Siebinga, 2016).

figure 1. Workshop Kamworks (Sre Ampil village)

Siebinga developed a design proposal for Kamworks' next generation Solar Home Systems. Throughout this project, the design proposal is evaluated and further developed. Additional topics broaden this project's focus.

1.2 Project definition

Two starting points were given before the start of the project: Siebinga's graduation project and the design brief provided by Kamworks. These are analysed first, after which the goal for this project is defined.

1.2.1 Design proposal

Siebinga identified six topics regarding the SHS that were most in need for improvement. They are described below:

1. High price - Cambodia is a low income county and most Cambodian families cannot afford a SHS. Reducing the costs of a SHS can make renewable energy more accessible.
2. Installation - When a SHS is purchased, two technicians from Kamworks visit the customer to assemble and install three assemblies (the battery box, solar panel with support and lamp kit). Due to the complexity of the system, this cannot be done by the customer. These installations result in higher costs and limits the sales due to the available technicians in specific areas. Moreover, the required administrative actions take a lot of time. Simplifying the installation so that they are easier to perform–or customers can self-install their SHS–is therefore desired.
3. Misunderstanding and misuse - Some customers experience problems when using their SHS. The majority of these complaints are related to the capacity of the SHS. It turns out that most customers do not (fully) understand their SHS. Misunderstanding can lead to misuse, resulting in more damaged Solar Home Systems and therefore an increase in repair visits. This results in higher costs for Kamworks, but also reduced customer satisfaction. The customer's satisfaction is important for the stimulation of sales and can help the acceptance of the technology. Therefore a SHS should be easy to understand.
4. Fixed system - The current SHS is available in two system sizes. They differ in the capacity of the battery and power of the panel. When a user wants to increase its energy capacity, a separate second system or a new, larger system could be purchased. Separate systems do not collaborate, however: when appliances are attached to one SHS and the battery is empty, the appliances should be unplugged and plugged into the second system. Enabling collaborating Solar Home Systems to increase the capacity of a household is desirable. This will give customers who cannot afford a large SHS in the first place the possibility to start small and expand later.
5. Production process - The two system sizes result in a large amount of parts. Service and stock management is therefore complicated. Since Kamworks is producing in low volumes, reducing the amount of unique parts can lower the price. With less spare parts, repairs can be performed more easily. Production processes can also be simplified. The current fibreglass battery box is produced at Kamworks' workshop. This production process takes a lot of time and is not sustainable. An alternative production process, that takes less time and uses recyclable materials, might be needed.
6. Aesthetics - The 'heart' of the system is the battery box. It is an object that users see every day. The current design is bulky and big, with a highly noticeable yellow colour. A redesign of the appearance is needed to make the system more appealing to customers. Improving the aesthetics, together with making the SHS understandable, will contribute most to the value and the credibility of the system.

figure 2. Kamworks' current (large) Solar Home System

Not all topics were included equally in the development of the design proposal. The design proposal (figure 3) was evaluated to the 'degree of completion'. This evaluation formed the first framework for this project.

As can be seen in figure 5, "Misunderstanding and misuse" and "Aesthetics" are perceived as completed. A structured and elaborate research was performed in order to come to suitable solutions regarding these topics. A redesign of the interface (providing information about battery status, payments and system health) and new manuals were designed, making the working principle of a SHS better understandable. The new aesthetics were developed and validated through an extensive form study. The results of these topics can be implemented in the design; the other topics still need further development.

1.2.2 Design brief

The design brief that was provided at the start of the project described five design challenges:

1. **Self-Installation** - With the current system, two technicians are needed to install a system. The places of instalment are mostly hard to reach (figure 4). If the customer would be able to install a system him/herself, it would save Kamworks a lot of time and money.
2. **Modularity** - Currently the two SHS sizes use different components. Using standardized parts and products for the whole system range, reduces the inventory and makes stock management and production easier, cheaper and more efficient.
3. **Expandability** - The current Solar Home System is offered in two system sizes: a regular and a large system. When a household desires more electricity, it should be able to expand their SHS. This can be done by purchasing a second regular or large SHS.
4. **Packaging** - The current system is being transported by TukTuk. Reducing the size of an unassembled SHS in order to make transport by motorbike possible would increase transport efficiency as well as the area in which the SHS can be sold. To avoid damaging, protection during transport is also important.
5. **Interaction** - The electronics of the SHS monitor the health of the system. They provide the user with information about the battery status, the system health and possible needed payments. On the other side, the SHS sends this information to Kamworks' database from unique user profiles. The integration of several electrical components is one issue. Moreover, more innovative goals regarding machine learning and a new app for customer service are described.

figure 3. Siebinga's design proposal: enabling expansion and improving comprehensibility and aesthetics (© R. Siebinga)

1.2.3 Project goal

Kamworks has provided approximately 150.000 rural lives with solar electricity and/or light, but they still have a hard time selling their Solar Home Systems. The given design challenges are suggested topics that need to be tackled to satisfy the market's demands. Together with Siebinga's thesis, they give enough input for defining this project's focus. The project goal is equal to the aforementioned mission:

"Making clean energy more accessible to rural Cambodia."

This mission does not ask for radical changes and/or innovations, but for a viable set of goals. The goals should contribute to easing the ability of the local population to obtain a SHS. With households growing in numbers and increasing in energy demand, the Solar Home Systems should also enable flexibility in capacity. First analyses and gained insights (chapter 2) helped combining the topics from the design proposal with the given design challenges into four main topics (figure 5), pointing out this project's focus:

1. **Modularity: lower costs and simplified stock**

Besides some standard parts like sockets and wiring, the two Solar Home Systems use different parts and a large variety in materials and material sizes. By using standardized parts and reducing their numbers, costs can be reduced, making the product more affordable for the (potential) target group. Reducing the part count and material variety will make the stock management easier. Moreover, simplifications (through modularity) make repair visits easier and reduce the chance of production errors.

The biggest cost reduction of the design proposal was achieved through the integration of several electronics. Where the design proposal consists out of one SHS size, this project will include the development of a second SHS size. The use of a universal support for the solar panels will be evaluated on cost reduction and complexity.

2. **Expandability: two SHS sizes and potential self installation**

Siebinga proposed to only offer the regular SHS, which is expandable. An expansion SHS would cost less than a first system since some parts (like lamps, the GSM technology and the display) only need to be provided once. However, the large SHS is currently more popular than the regular SHS. Even with a cheaper expansion, one large SHS would cost less than two regular Solar Home Systems (two regular systems have approximately the same capacity as a single large system). It should be possible for the customer to choose what SHS they initially need (or want) and how to expand their systems when their

figure 4. A road to a customer's house for installation

demand in electricity is growing.

With two SHS sizes offered to the customer, there is the freedom to invest directly into a source of energy or first test the technology, as well as the freedom to increase a system's capacity in bigger or smaller steps. This requires the systems to be combinable. With this goal, the growing energy demand of households through (1) family expansion and (2) the desire for (more) electrical appliances is tackled. The aesthetics of the design proposal will be implemented into the design of the second SHS size.

With the idea of a core and an expansion SHS, the desire of self-installation comes into the discussion. A visit of a technician is desirable, since he/she makes sure the SHS works properly and gives instructions about how to–and how not to–use a SHS. When this part of service is removed, it is probable that many Solar Home Systems will be installed incorrectly, resulting in customer dissatisfaction and a big increase of needed repair visits. To set a realistic balance between Kamworks' services and responsibilities of a customer, the goal of this project is to enable a core system being installed by one technician (currently done by two) and enabling self-instalment

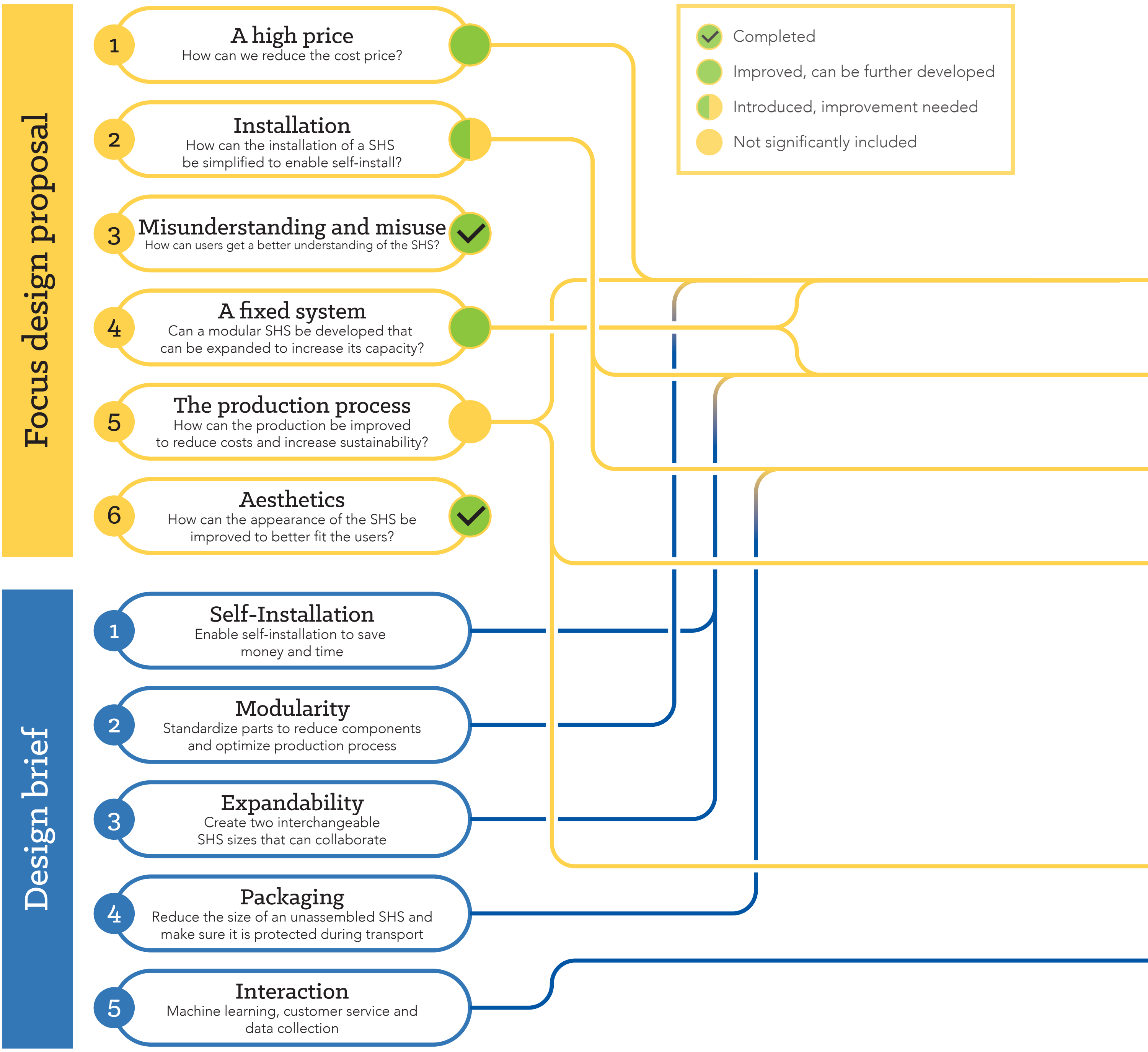
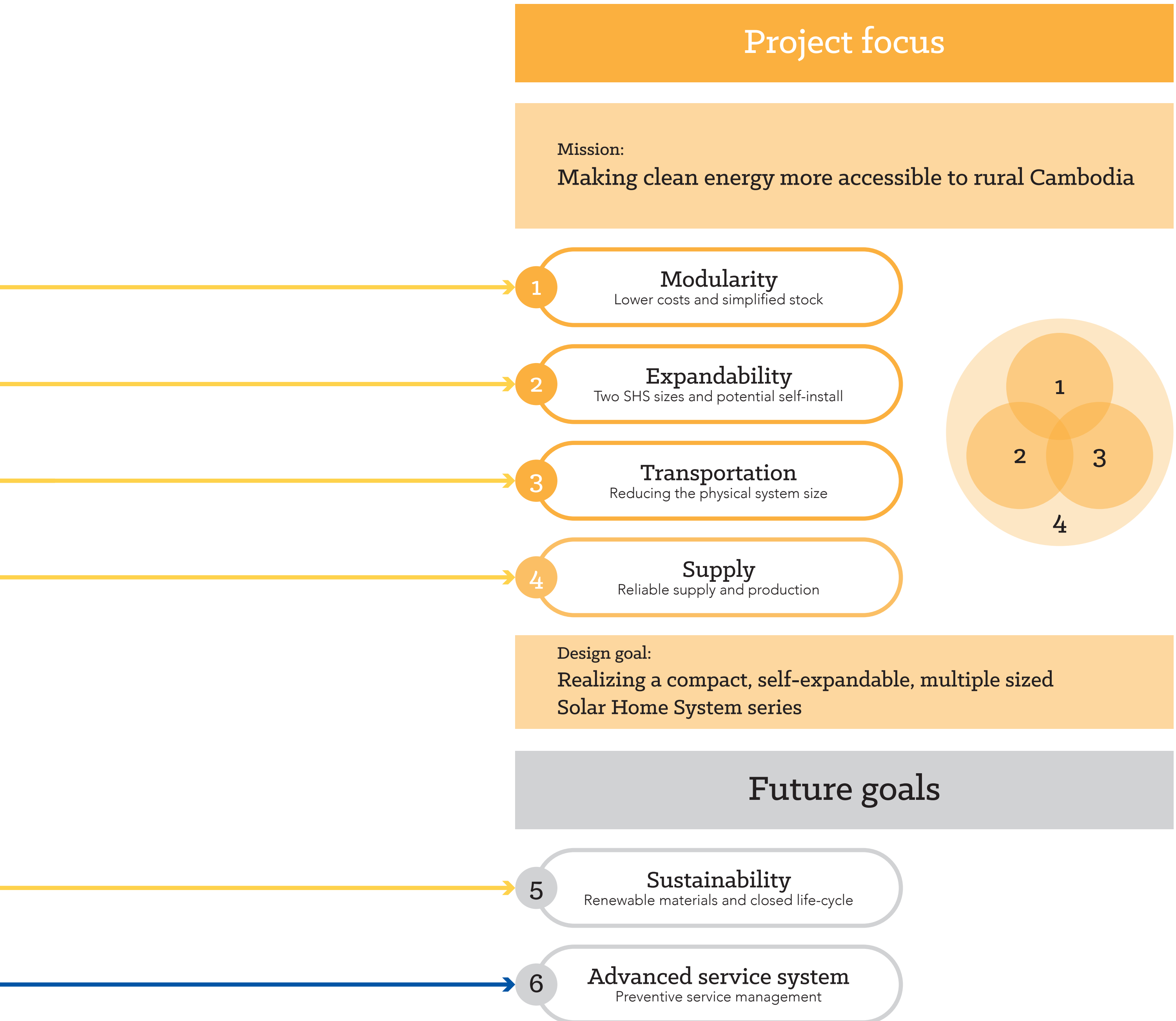


figure 5. The process of shaping the design goal

for expansions. Regarding the electronics, the design proposal already implemented a plug-and-play solution. For other parts of the SHS, additional development is needed.

3. **Transportation: reducing the physical size**
With the desire to reduce the amount of technicians and enable self-install, the biggest challenge is the physical size of an unassembled SHS. As mentioned before, a SHS is currently transported by TukTuk (figure 7). Especially for self-install, but also to increase the reach of Kamworks' sales, the (unassembled) system size should be reduced to make transport by motorbike possible. It would make transport easier, more efficient, enable customers to pickup expansions at stores and thus increase the accessibility to clean energy.

4. **Supply: reliable supply and production**
Where the first three topics focus on varying properties of the SHS's contents, this fourth topic can be perceived as the comprehensive safety net of feasibility. This topic emerged from the first analyses in the specific context. In order to make the SHS more accessible to rural Cambodia, a reliable supply and production is needed. Poor logistics, unreliable



domestic suppliers and a limitation in production facilities are some of the challenges affecting the decision making process.

With the current low sales (0-10 a week), a high stock of Solar Home Systems and spare parts is a waste of money and hinder the development of its contents. Assuming that stock supply of items ordered from abroad is reliable and will not cause problems, reducing the lead time of the domestic processes is desired. This will enable Kamworks to reduce the stock and actually deliver a SHS soon after a sale has been closed.

Design goal
The previous topics are most relevant to the mission of making clean energy more accessible. Each topic overlaps with the others and any decisions within one topic will influence the others. The design goal can be summarized as follows:

"Realizing an expandable, compact, multiple sized Solar Home System series for rural Cambodia."

At the end of this project, a physical prototype and implementation plan will be provided. The results of the final design will show the improvements that were made compared to the current SHS. There it will be evaluated how the final design meets the project goals.

1.2.4 Future goals

Two additional topics were identified as future goals. Because of the limited time frame of this project, and the limitations of Kamworks' current (economical) situation, they cannot be included in the project.

The first topic that needs to be postponed is the implementation of sustainable materials and production processes. Especially the production process of the box, which needs to be evaluated in the future. The current production of the battery box with glass fibre is harmful to the environment and non-recyclable. Alternatives, for example injection moulding, should be explored in the future. The reason that this is not included now, is because the current situation of the company does not allow large investments. A short-term increase in sales is needed to not only allow investments but also ensure the existence of Kamworks. When the stability of the company improves, the life cycle of the battery and the maintenance of the system should be included into this topic as well.

Another future goal is the improvement of services and insights through the GSM technology. This topic becomes mainly interesting when the stability of the–to be designed–next generation Solar Home Systems has been validated. This development needs to be performed in close collaboration with Kamworks' electrical engineers.

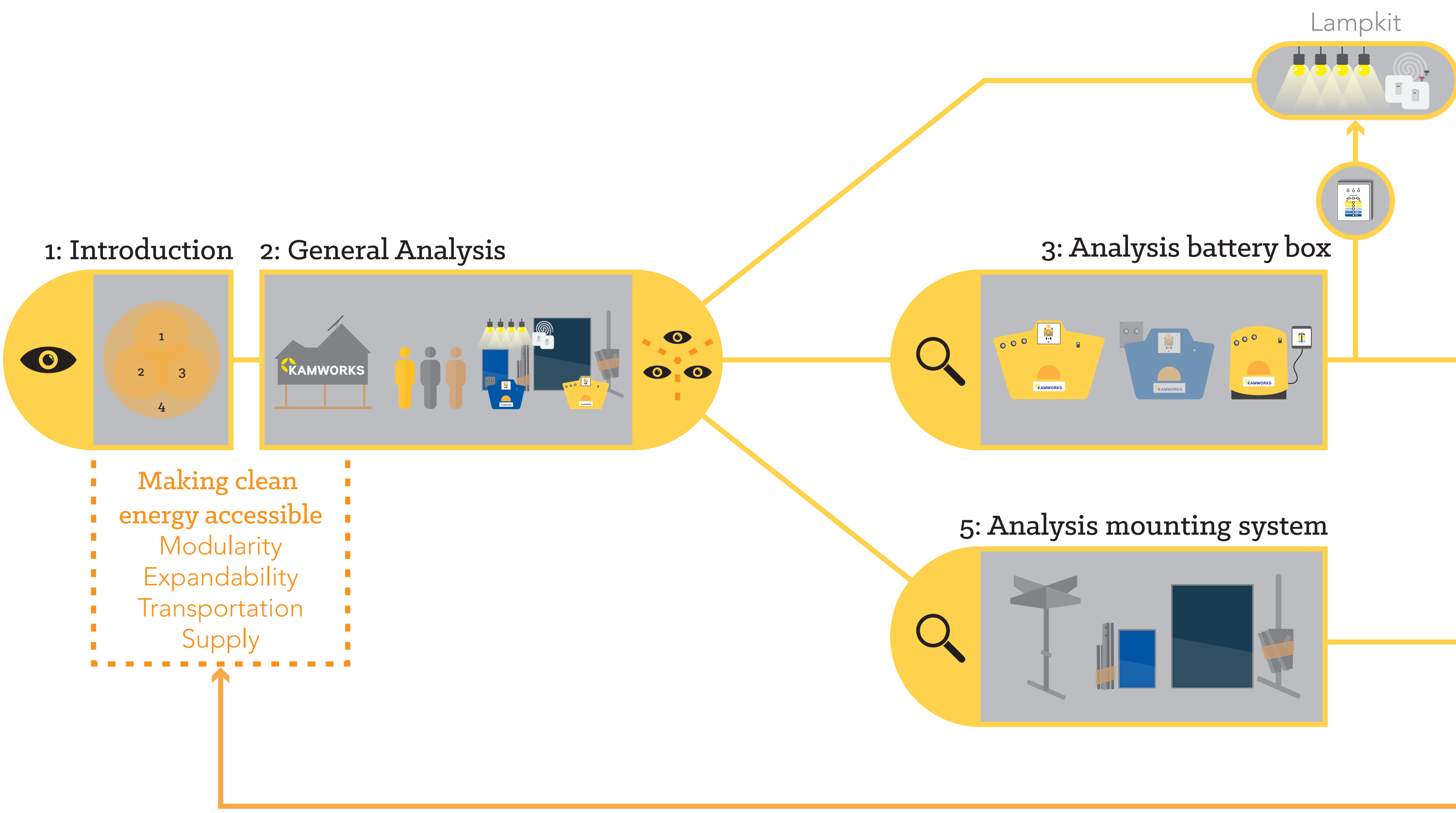


figure 6. The structure of the report

1.3 Project Planning

This project is mainly executed from Cambodia. Based on extensive research in the actual context, Kamworks' next generation Solar Home Systems will be developed. The project has a broad range of topics which cannot be all developed by the student directly. Therefore, a project team was formed.

1.3.1 Project team

Four employees of Kamworks were involved into this project. A short introduction:

Laurent Leleu - Project manager
One of the two company mentors. He will mainly focus on the planning of activities (i.e. organizing field research and involving the right co-workers) and the communication with the other departments.

Javier Garnelo - Production manager
The second company mentor and manager of the production and stock. He knows all about the possibilities within the company and previous decisions. He will have an important role in certain decision making processes.

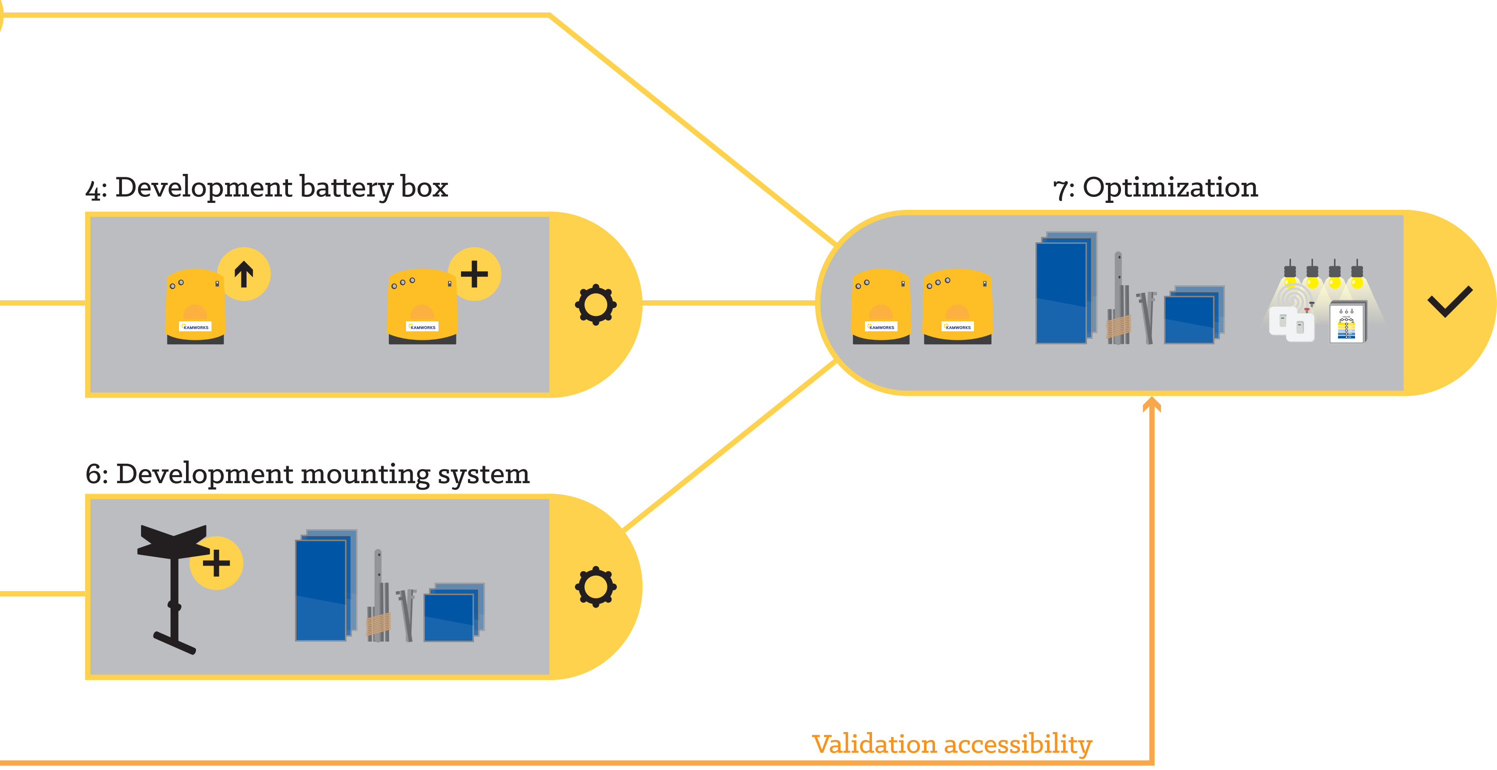
Timothé Delhaise & Leon Hiemstra - Electrical Engineers
Forming the electronics team; focussing on the electronic part of the expandability and combinability. All issues or required adjustments regarding the electronics are discussed and implemented in close collaboration with this team.

1.3.2 Planning

Before the start of the project, an initial planning was made (appendix A). The focus topics of the project cannot be treated separately, but the different components of the Solar Home System can. In general, the project will follow an analysis phase, (concept) development phase and an optimization phase. After a general analysis of the current situation, the components are developed independently. There are three parts of the SHS: a solar panel with a support, the battery box with sockets and display, and a lamp kit. The visualisation in figure 6 shows how they are separated after the general analysis. The final chapter combines the components to conclude with a comprehensive redesign. This redesign will be linked back to the topics described in this chapter in order to validate the success of the redesign.

General analysis
In this chapter the current situation of the company, the context and the user is introduced. The SHS as a system is analysed also, after which the focus per component is determined. This will give direction to the analyses of the different components of the SHS.

Analysis battery box:
Both the battery box of the current SHS and the regular box of the design proposal are analysed. Issues regarding both designs and possibilities for improvement are identified. As a result of this phase, a set of recommendations and requirements form the basis for the development of the battery



box. Necessary adjustments for the electronics are communicated with the electronic engineers.

Development battery box
A large SHS is developed with the aesthetics of the design proposal. With modularity in mind, the battery boxes are evaluated and optimized. The final design is prototyped and its performance is validated through a user test. To conclude this chapter, achieved improvements and recommendations for optimization are summarized.

Analysis mounting system
The mounting system requires a more elaborate analysis and, eventually, development. The current mounting systems are analysed and evaluated elaborately. Installations are visited to identify occurring issues during transport and installation. The production processes, which take place at multiple workshops, will be analysed during this phase through visits and observations. The design proposal for the mounting system is involved in the final discussion and a foundation is created for the redesign.

Development mounting system
Where the battery boxes were developed based on the design proposal, the mounting system needs a total redesign. Concepts are developed that focus on the interchangeability and expandability of the SHS. Enabling easier transportation and simplified installations are important as well. Through prototyping and close collaboration with the employees of the workshop, the design is evaluated on its improvements. Recommendations for the implementation of the redesign and an overview of the improvements conclude this phase.

Optimization
The two designs and the lamp kit are merged into a total overview. The implementation of the last details and some final iterations are made here in order to come up with a comprehensive SHS design. The design is subjected to the project focus topics and its 'success' is evaluated. A set of future recommendations for both the short and the long term will complete the project.

figure 7. One of Kamworks' TukTuks (left bottom) for transporting the Solar Home Systems

1.4 Summary

In this chapter the reason for the initiation of this project was introduced. Four focus topics, that need to be improved in order to move towards a more accessible source of clean energy, were created based on the first analyses, the most recent design project of Kamworks' SHS and the provided design brief. The focus topics and their definitions were explained. They provide a framework for the project and make the process understandable.

In the following chapter, the context and the product are more elaborately analysed, giving more detailed information and in-depth knowledge about the subject. The end of chapter 2 shows how the focus is divided amongst the components of the system and what improvements are needed. Thereafter, the SHS's components are developed separately. In the analysis chapters, more detailed issues will be introduced and the project will obtain more boundaries and requirements. In the last chapter (chapter 7) the final SHS design is assessed to the topics of this design project.

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2.

2 General analysis

The introduction gave a general overview about the project's context and focus. These aspects are evaluated in depth throughout this chapter. In this chapter the current situation of the company is presented first, after which the context and the current SHS are analysed. The chapter will be concluded with a set of actions for each component of the SHS. These actions are needed for a successful redesign.

2.1 The company

Kamworks Solar Ltd. is a social enterprise founded in 2006 by two Dutch engineers. They develop, engineer and sell solar energy systems. Kamworks' core business is the Solar Home Systems: a complete solar energy package including a solar panel, battery with electronics and a lamp kit providing light and electricity to their customers. Besides the SHS they also develop professional systems: bigger (on-grid) systems, which are mostly sold business to business. Since this project is about the redesign of Kamworks' Solar Home System (SHS), the professional systems are disregarded in this report. Kamworks' Solar Home Systems are designed for single households in the BoP market of rural Cambodia. These households usually have no access to regular grid electricity.

Kamworks operates from three locations (figure 8), with the headquarters based in Phnom Penh. All activities of Kamworks are organized and managed from this office. The workshop is located just outside Phnom Penh: in the Sre Ampil village (figure 1, p.12). This is where the Solar Home Systems are produced and stored. These two locations include all development and engineering activities. The office in Kampong Chhnang is the headquarters to the local salespeople and technicians. They go to the villages to promote and sell or install the Solar home systems. The Kampong Chhnang office allows only a little stock for Solar Home Systems and spare parts.

2.1.1 Partners

Kamworks is collaborating with a large variety of companies. The way Kamworks' most important partners are involved is visualized in figure 9 and further explained below.

The good solar initiative

This initiative from the SNV Netherlands Development Organisation is the first certification system for quality solar companies and products in Cambodia. The goal of the label is to gain trust and confidence in solar products amongst the (Cambodian) customers. The good solar initiative also provides a set of regulations and guidelines to the joined companies to ensure good quality products and customer service (Good Solar Initiative, 2016).

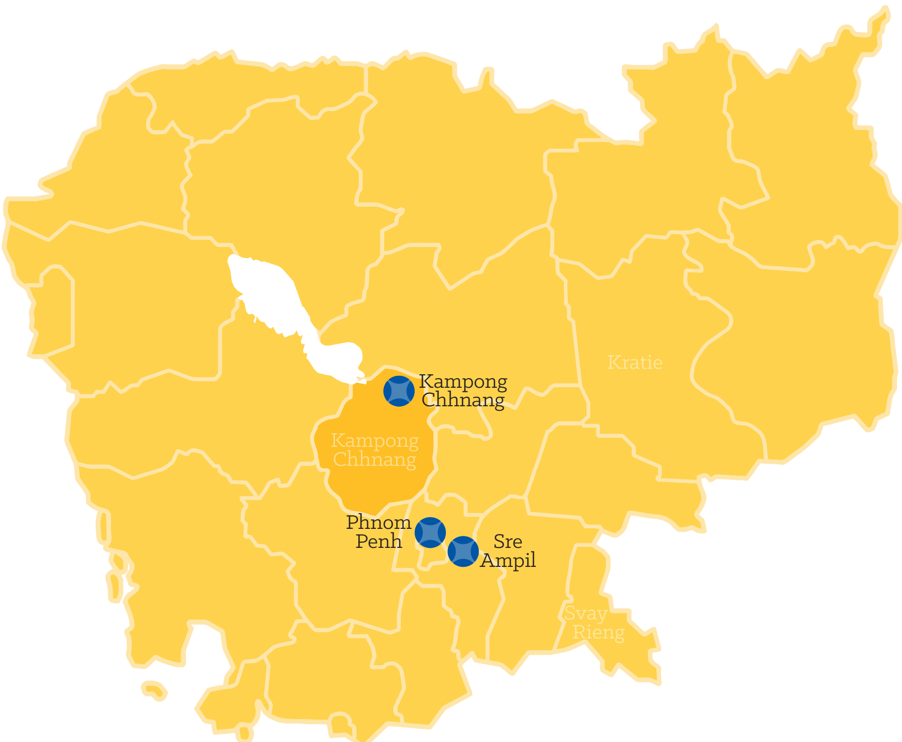


figure 8. Map of Cambodia with (approximate) locations of Kamworks' offices

Cellcard & Wing
Each SHS has a Cellcard SIM card to transmit data allowing remote monitoring, management and servicing (Cellcard, 2016). When a SHS is purchased through a Kiva loan, the mobile banking service Wing is used to transfer money through this SIM card.

People in Need & Picosol
People in Need, a Czech non-governmental, non-profit organization, helps Kamworks to recruit and train their salespeople (People in Need, 2016). Picosol is a training centre next to the workshop where training is given for Kamworks' technicians. They can also practise installations there, since Picosol has a typical Khmer house for this purpose.

AFD & UNCDF
The French development agency (Agence Française de Développement; AFD) and the United Nations Capital Development Fund (UNCDF) are the two most important partners to Kamworks regarding funding. AFD awards a fee to Kamworks for each SHS financed through a loan at one of the Micro Financial Institutions (MFI). They also helped establishing the

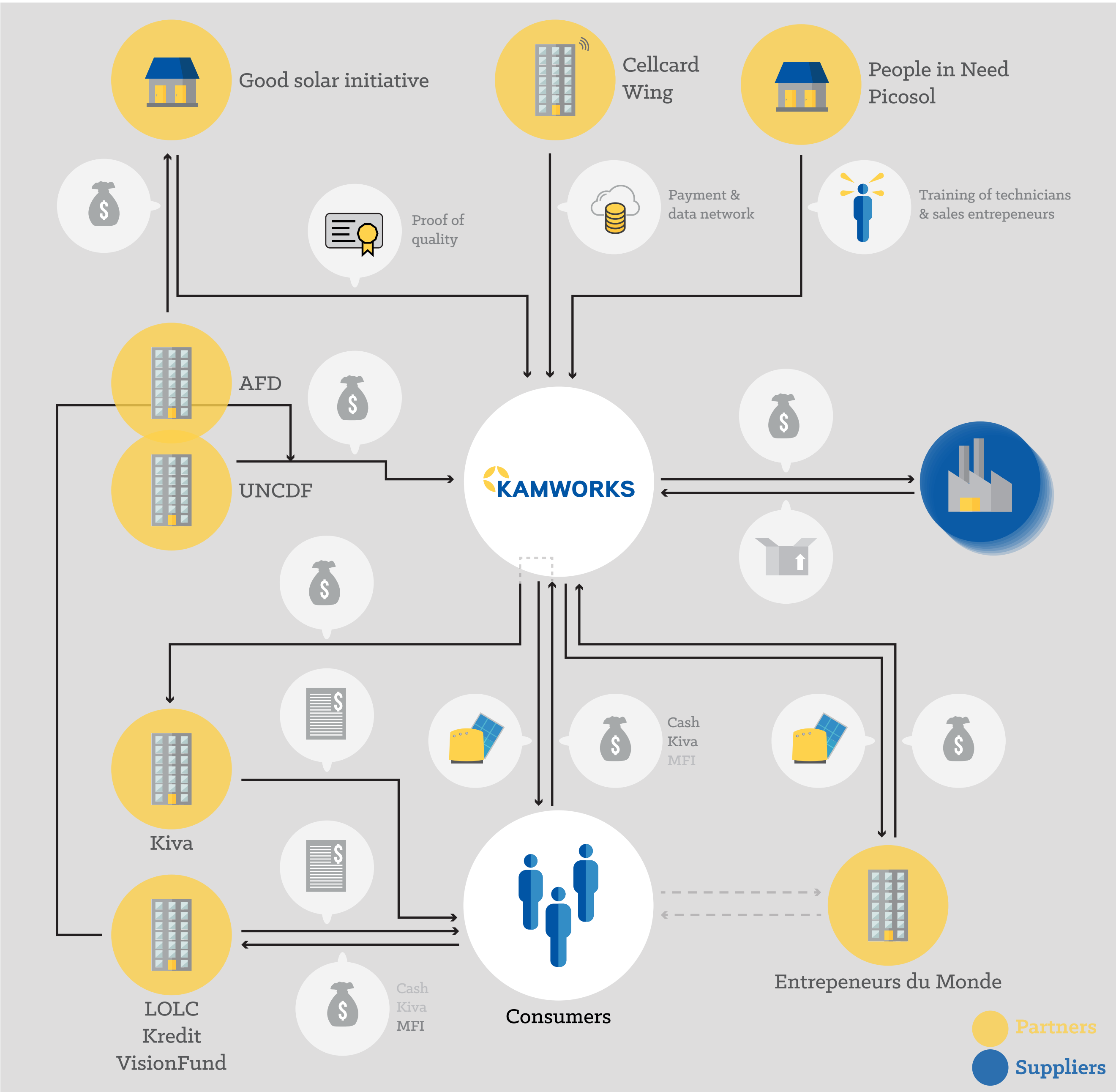


figure 9. Stakeholders

good solar initiative (Good Solar Initiative, 2016). UNCDF is funding Kamworks through the SHIFT challenge fund (UNCDF, 2016).

LOLC, Kredit & VisionFund
When a customer cannot afford the upfront investment of a SHS, they can apply for a loan at one of the three largest MFIs in Cambodia. These loans are repaid in a term of one or two years.

Kiva
If a customer is rejected at one of the MFIs, he or she is applied for a Kiva loan. These loans are repaid through mobile money. The term of repayment is two years.

Entrepeneurs du Monde
This NGO from France buys small batches of Kamworks' Solar Home Systems and sell them amongst their own distribution network in Cambodia. They do this through their own brand: Pteah Baitong (Good Solar Initiative, 2016).

2.2 The context

The Solar Home Systems developed by Kamworks are for the BoP of rural Cambodia. The purpose of the SHS is providing people with electricity who do not have access to grid-electricity.

2.2.1 Target group

From the nearly 16 million people living in Cambodia, 90% is Khmer. About 96% of the total population is Buddhist (CIA, 2008). Nearly 60% of the population has to live from less than $2,5 a day (Knoema, 2015). Although the poverty rates dropped over the last years, incomes are low.

Five years ago, only 31,1% of the total, or 18,8% of the rural, population in Cambodia had access to electricity (Worldbank, 2012). Despite recent progress of increasing electricity access, there are still an estimated 6,9 million people that have no access to a reliable source of electricity (WWF, 2016).

The solar home systems are mainly sold in rural areas where no grid-electricity is available. Kampong Chhnang, Svay Rieng and Kratie (figure 8) are the three provinces in Cambodia where most Solar Home Systems are sold. These provinces have a low electrification rate and a relatively promising financial situation of potential customers (Kamworks, personal communication, August 15, 2016). Currently Kamworks only focusses on the Kampong Chhnang province before expanding their services to other areas.

Through a survey in the Kampong Speu and Svay Rieng provinces, four different social classes can be identified: The upper-, middle-, lower- and lowest social class (UNDP Cambodia, 2008). The distinction in social classes is mainly made by the quality of housing (figure 13). Although this division does not

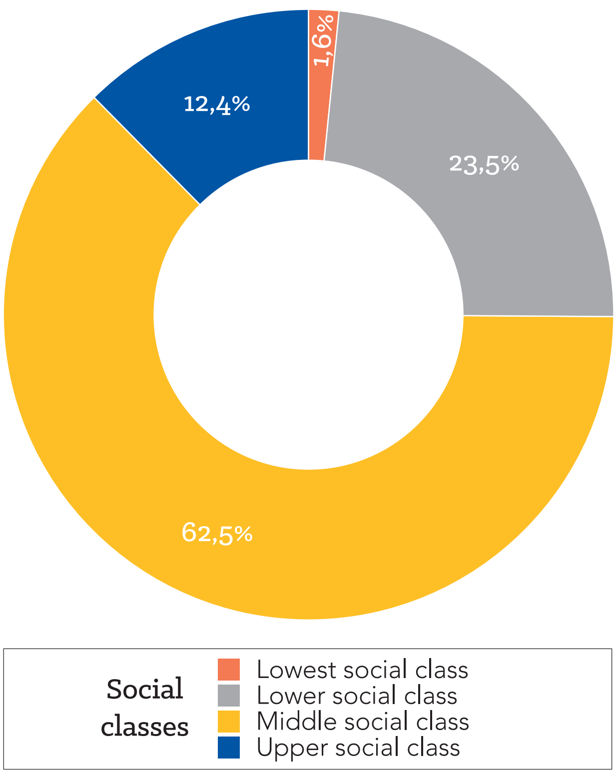


figure 10. Social classes in Kampong Speu and Svay Rieng

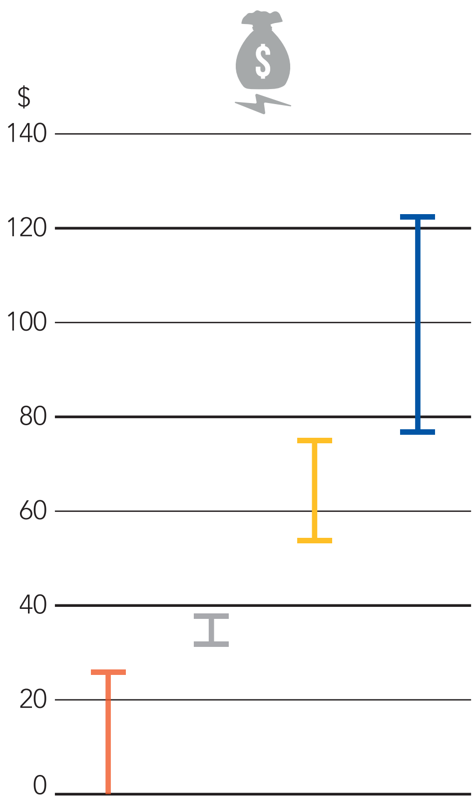


figure 11. Monthly energy expenditure per social class

provide accurate information regarding household income, it does show differences in a household's monthly energy expenditures (figure 11).

During visits to the rural areas it became clear that the largest group of customers belong to the middle social class (figure 14). Their current monthly energy expenditures, that also includes the expenses for other energy sources like fuel for cooking, of this social class are approximately double the monthly costs of a SHS (explained later on). Although the middle social class is the biggest group (figure 10), a cost reduction making a SHS affordable for the lower social class could significantly increase the group of potential customers.

2.2.2 Challenges

With almost 5 hours of full sun every day (NASA, 2017), Cambodia is an excellent country for solar energy. In practice however, there are quite some challenges to overcome in order to stimulate the acceptance of solar energy. Some of them are already explained, others are mentioned below.

From the rural households having access to any form of electricity, 60% is provided by car batteries (USAID, 2015). These car batteries are heavy, expensive and inefficient. Moreover they bring safety issues, since


figure 12. Bringing a battery to the charging station

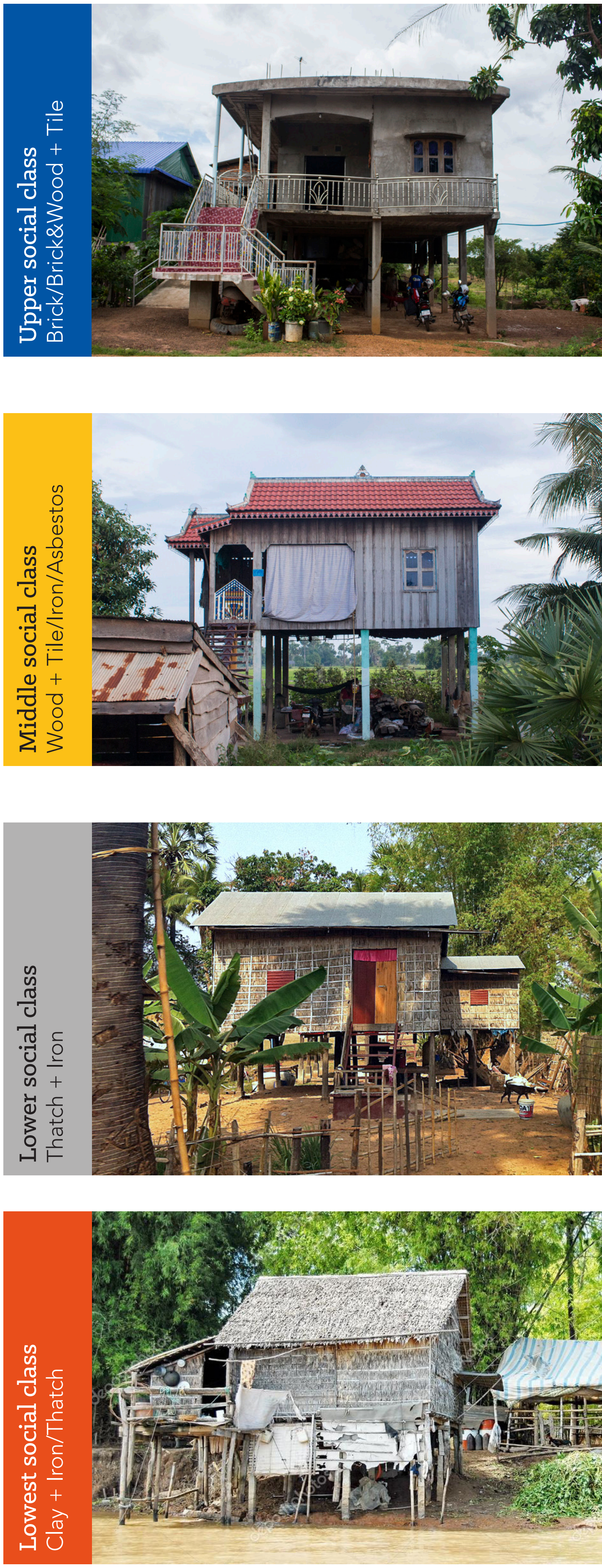


figure 13. Social classes in Cambodia

figure 14. A selection of visited homes of SHS owners

the electronics are unprotected. A car battery requires charging every one or two days, forcing users making long journeys to a charging station carrying a battery of 20 kg or more (figure 12). Besides the safety issues and all the effort needed to acquire electricity, car batteries are 3 to 4 times as expensive in use compared to a good quality Solar Home System. Compared to car batteries, a SHS has a payback time of 1 to 2 years (USAID, 2015).

With that said, it seems an easy job to convince people to switch to solar energy. But there is a reputational issue. A large variety of solar energy products–with very poor quality–are offered to customers on local markets. Batteries, electronics and panels of low quality are sold without or with very little instructions. These systems are self-installed, resulting in panels placed in an inefficient angle (figure 16) and (messy) electronics that are still unprotected (figure 15). Without service, parts break down easily, causing a feeling of distrust amongst Kamworks' potential customers. When Kamworks (or one of their competitors) tries to sell their systems, these customers are not inclined to pay another high upfront investment. This attitude is easily spread amongst villagers, causing this general negative reputation of solar energy.

Another 'competitor' of solar energy is the regular grid. Although the grid is expanding, it is still rarely accessible in the rural areas. Moreover, the costs for grid electricity are high because of private electrification enterprises (Project Everest, personal communication, February 3, 2017). Despite the high price and poor distribution of the grid, its expansion makes people hesitate if they want to invest in solar energy instead of waiting for access to the grid.

An overview of challenges (and possible actions to overcome them) is given in figure 18, providing more insights in the Cambodian solar energy market.

2.3 The product

Kamworks' Solar Home Systems comprise an integrated design providing energy and lighting to the customer. The Solar Home Systems from Kamworks that are currently available for the market (figure 17) are explained and analysed in this section.

2.3.1 SHS components

Each Solar Home System consists out of three main components: a solar panel (and its mounting system), a battery box (and its battery) and a lamp kit (figure 20). They are briefly described below.

figure 15. Self-installed solar energy inside

figure 16. Self-installed solar panel

Strengths

- **Value proposition:** Lower cost and increased convenience and reliability. Short payback time
- **Environmental impact:** Lower diesel consumption and toxic waste compared to alternatives.

Weaknesses

- **Logistics:** Customers are hard to reach. This increases the costs of sales, installations and service visits.
- **Reputation:** Low quality cheap solar energy systems have created distrust and a negative image.
- **Financial:** The upfront costs are most of the times unaffordable to most customers.

Opportunities

- **Market size:** Reducing the assembly's complexity and simplify distribution increase the potential market significantly
- **Customer Loans:** Through MFIs and Kiva, customers can apply for a loan and thereby avoid upfront costs.
- **Collaborations:** With the support of NGOs like AFD and SNV, costs can be reduced.
- **Branding:** The good solar label, but also the reputation of Kamworks, can help create trust in the Solar Home Systems

Threats

- **Grid expansion:** The expansion of the grid make customers hesitate about the upfront investments or (temporary) high monthly costs
- **Competitors:** Competitors offer lower capacity, cheaper solar energy systems of reasonable quality.

figure 18. Analysis of Strengths, Weaknessess, Opportunities, Threats

figure 17. The two sizes of Solar Home Systems that are currently sold by Kamworks

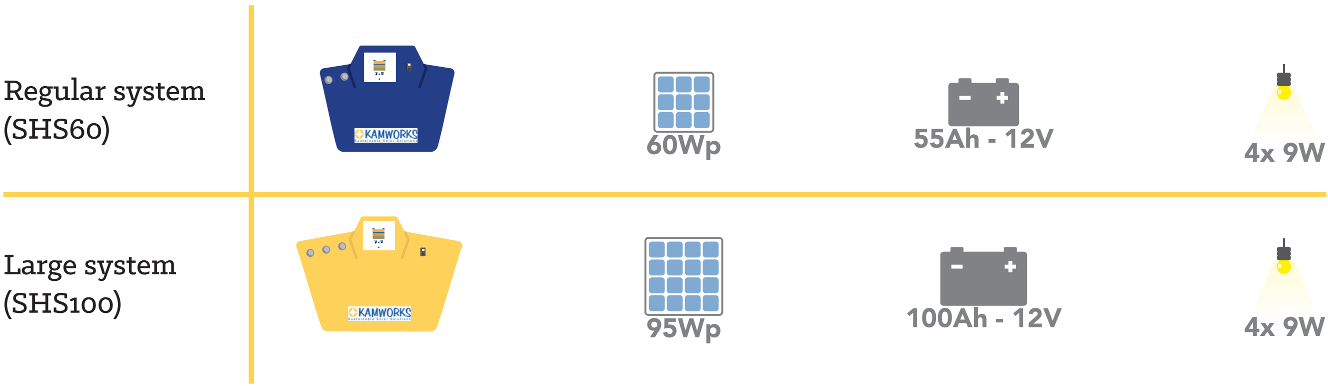


figure 19. Available SHS and their main components

Solar panel (1)
In order to power the system, a solar panel is positioned on top of the roof. The panel is supported by a mounting system, placing the panel at an efficient angle. The size of the panel and the type of mounting system depend on the size of the SHS. The mounting system is assembled on site, after which it is installed together with the solar panel.

Battery box (2)
The battery box can be called the heart of the SHS. It contains the battery and electronics of the system. The electric current received from the panel is used to charge the battery. The stored energy is used to power the lamp kit and appliances connected to the SHS. A display provides information about the energy, the health of the system and payment status.

Lamp kit (3)
Kamworks believes the access to lighting is fundamental for improving the lives of rural Cambodia. This is why the lamp kit is included in the SHS. Additional appliances that are used on a regular basis like a TV (+DTV) and a fan can be provided with a SHS, but they will increase the total price. The lamp kit exists out of four 9W LED lights, light switches and the necessary wiring.

2.3.2 System sizes

The names given to the SHSs were previously based on the power (Wp) of the solar panel. Where Kamworks used to sell five system sizes (SHS20, 40, 60, 80 and 100), they decided to reduce this to only two. This decision was made, in the first place, because some systems did not sell well. Besides, customers have too little knowledge about their (potential) power consumption to make decision this accurate (i.e. in some cases two systems had the same battery and the decision had to be based on how fast a system would need to charge).

The Solar Home Systems that are still sold are a SHS60 and the SHS100. They differ in the size of the panel and the capacity of the battery (figure 19). The names of the systems caused customers comparing Kamworks' SHS with systems of competitors based on the power of the solar panel only, while the capacity of

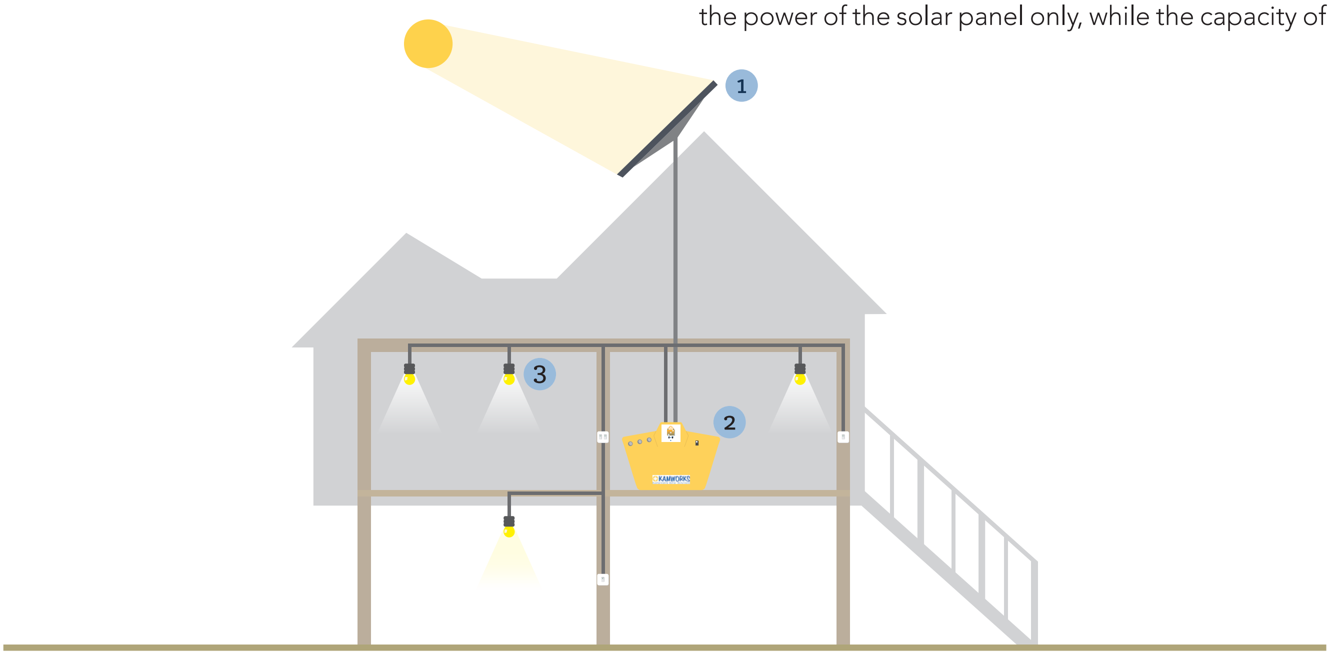


figure 20. The components of a SHS

the battery and the reliability of the system is of great importance too. This is why the names are changed to Kamworks' "Regular (Solar Home) System" and "Large (Solar Home) System". From this point on this naming will be used throughout the report.

2.3.3 Contents of the SHS

A simplified overview of the contents can be found in figure 21. Also the way the contents are connected is indicated by the blue line. There are minor differences between the regular and the large system, but they will not be treated separately yet. The contents of the SHS are explained below.

Battery box
Protects the battery and electronics from damaging. It keeps water and dirt away from the electronics. The closed box also prevents users to misuse and/or damage the battery or electronics.

Sockets
The front of the battery box has three cigarette plugs that can be used for appliances. At the back there is one 4-wire connector for the lamp kit and a power connector for the solar panel.

Charge controller
Controls the received electric current from the solar panel. It prevents the battery being overcharged or deeply discharged, which both would decrease the lifespan of the battery.

Power board
Functioning as the central board of the system, this PCB measures and controls all (electric) power flows within the battery box. The power board monitors the functioning and health of the SHS.

Display & SIM board
Two Printed Circuit Boards receiving and providing data and information. The display provides information to the user regarding the energy level, payment status and information received by the power board. The SIM board sends mobile payments and data about usage and system health information to Kamworks. When payments are not received, the SHS can be switched off remotely.

Circuit breaker
When the system is overloaded (e.g. by attaching an unsuitable appliance) the circuit breaker will shut down the system to avoid the electronics to damage. When the cause of the overload is resolved, the system can be switched back on again.

Mounting system
The mounting system is a steel structure that supports one solar panel. It makes sure that the solar panel is pointed south, while being positioned at an angle of 20˚.

Battery & Solar panel
The size of the battery and the solar panel influence the type of battery box, charge controller and mounting system necessary.

2.3.4 Cost price

Based on the Unit Costs provided by Kamworks (September, 2016) a cost price calculation was made for both the regular SHS and the large SHS (appendix B). Since making the SHS more affordable is one of the project requirements, it is important to know

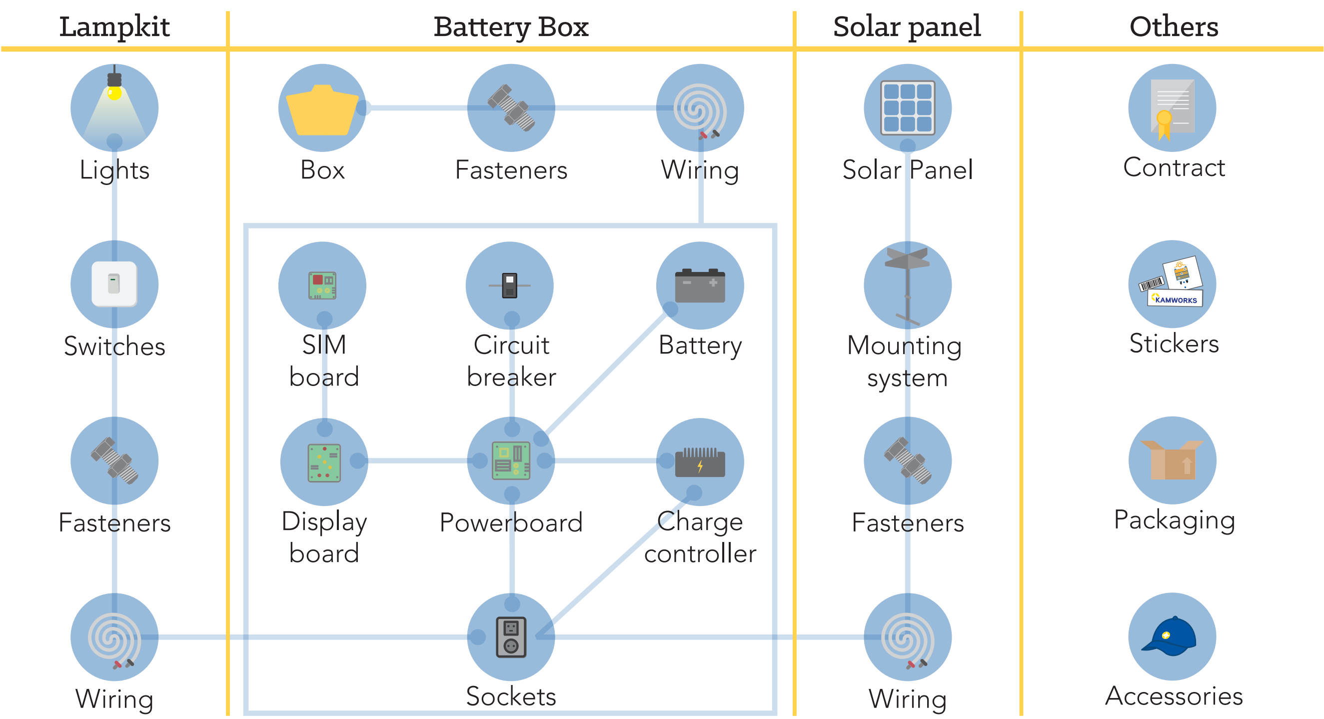


figure 21. SHS' general contents

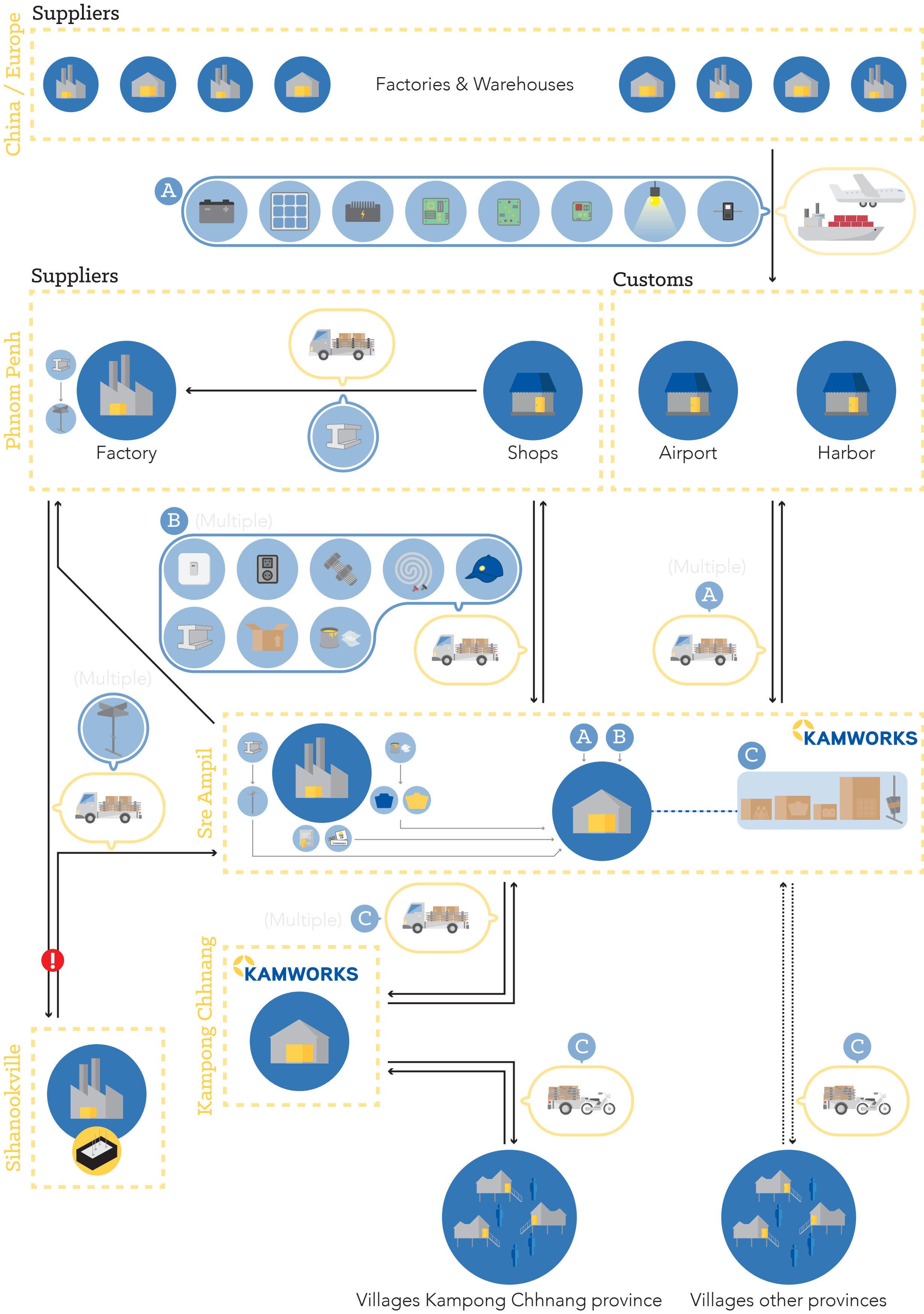


figure 22. The journey of resourcing parts and materials to delivering a SHS to a customer's home

how costs can be reduced. In figure 23, a division in contents is made to show how the components of the SHS impact the total cost price.

The battery box with its components (especially the battery, charge controller and the PCBs) form the biggest expenses. Where the price of the battery is fixed, the biggest cost reduction can be made in the contents of the battery box.

The labour costs include commissions received by the installers for each installed system. Transportation and labour costs can be reduced by decreasing the size and complexity of the SHS, but hey will not influence the total cost price too much.

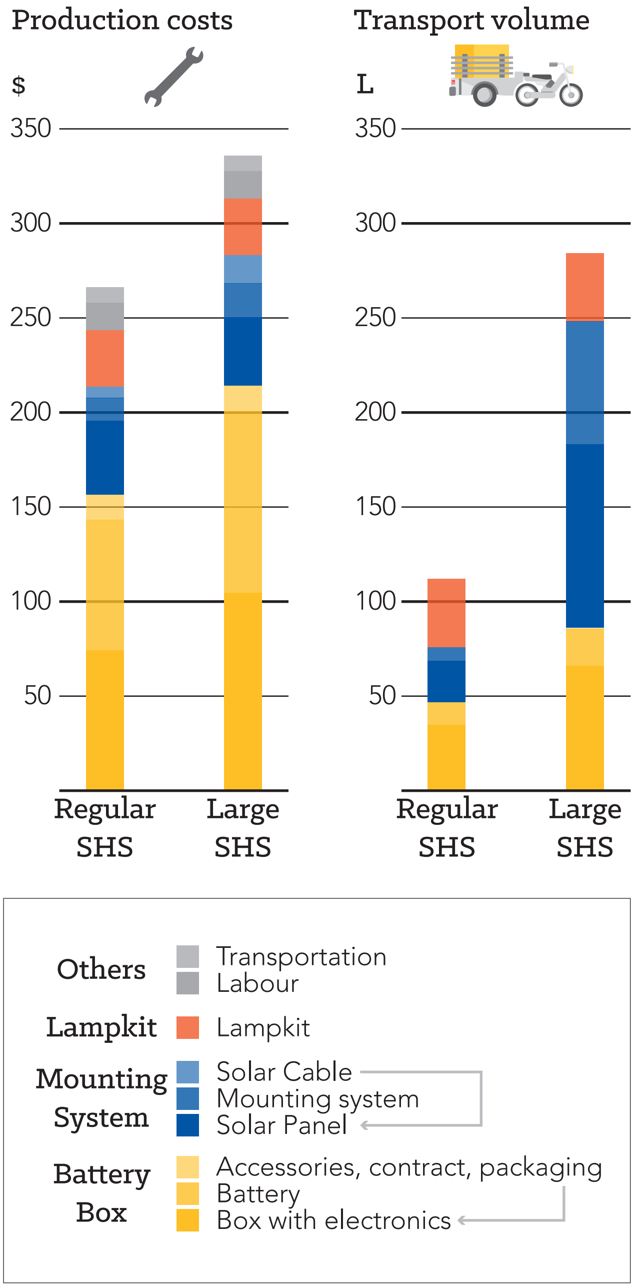


figure 23. Cost price and transportation size of both SHSs

On top of the production costs, there is a risk margin of 2%, based on Kamworks' previous experiences. The risk margin includes theft, loss, and production errors. Adding it all together the production costs are $270,8 for the regular system and $342,4 for the large system. They are sold for respectively $450 and $595 (with cash payment).

2.3.5 SHS Journey

The SHS consists out of a wide variety of parts and sub-assemblies. An overview of their origin and journey was created (figure 22). Repair visits and deinstallations use parts of this logistical network.

It is possible to divide the journey in three stages: Stock collection, SHS distribution and installation. They differ in complexity and the length of transition.

Stock collection
All parts and raw materials are collected and stored in Sre Ampil, since the production facilities are based here.

The battery, solar panel, charge controller, circuit breaker and the PCBs and most important electronics are imported from outside Cambodia. The electronics and Solar Panels come from China, while the batteries are ordered from Europe. They are ordered occasionally from fixed suppliers, in large quantities.

More available parts, like fasteners, raw materials and general electrical components are bought in shops throughout Phnom Penh. Depending on their availability, they are purchased in various places.

In a country without trustworthy delivery services, Kamworks relies on its own trucks and TukTuks. Acquiring stock from Phnom Penh takes at least half a day, since a one way drive from Sre Ampil to Phnom Penh takes approximately two hours. In order to reduce the amount of these trips, the workshop has a stock of parts and materials.

The mounting system for the large SHS is the only Cambodian custom made part of the SHS that is not produced in-house. The main reason for this is because the design requires galvanization after welding. Galvanization is an expensive process in Cambodia and not widely available. With the goal of a reliable supply chain in mind, this hitch needs to be tackled in the development of the mounting system.

SHS distribution
Most of the production and assembly is done in Sre Ampil. The regular mounting system and battery box are produced from raw materials, where the other parts and sub-assemblies are assembled and packed for distribution. A 'SHS package' will consist out of an unassembled mounting system and four boxes containing the lamp kit, the battery, the solar panel

and the battery box. Since the battery can not be transported inside the battery box, the box stores the contracts, manuals, accessories and fasteners used for the mounting system. When everything is packed, it is distributed to the office in Kampong Chhnang or kept in stock in Sre Ampil.

The physical sizes are relevant for the efficiency of transportation, thus the accessibility of the system. Looking at the transport volumes (figure 23), it can be noted that especially the large solar panel and mounting system require a lot of transportation space. The battery box also seems to take more space as needed: with the main function of protecting the battery, it is remarkable that the battery box is transported separately and has (roughly) twice the size of the battery. These issues need to be taken into account during the development.

Installation

The office in Kampong Chhnang is used for storage of the unassembled Solar Home Systems. When a system is sold and an installation is planned, a SHS will be brought from the Kampong Chhnang office to the customer with Kamworks' TukTuk (figure 7, p.20). It sometimes happens that a SHS is sold in other provinces. In that case the SHS is distributed directly from Sre Ampil.

Depending on the amount of installations in a day, the TukTuk can take up to 4 systems at a time. In practice, however, there are only one or two installations a day. There are always two installers traveling by TukTuk due to the required installation steps. The installation will be analysed more in depth during the analysis of the mounting systems (chapter 5).

2.4 SHS in use

When a product is installed at a customer's home, they get instructions on how to use the SHS and they sign a contract in which the terms and conditions for a two year warranty are documented. Within these two years, the maintenance and replacement of parts is free of charge as long as the terms and conditions are not violated. To manage all of this, Kamworks developed a platform based on GSM connectivity.

2.4.1 Remote monitoring, management and servicing

Technicians are responsible for both the installations and repairs. It is important to know what's wrong with a system before planning a service visit, due to the commission a technician receives for each visit. This is where Kamworks' GSM platform comes into action.

Every 15 minutes, the SHS sends a set of data to Kamworks about the battery health, power consumption and energy production. This gives insights into the daily usage of a specific household and the health of the system over time. If a customer experiences issues with their SHS, they should contact Kamworks. The issue then is explained and evaluated by the secretary. Based on the online data, Kamworks can evaluate if a service visit is needed or if the customer can solve the problem by themselves (e.g. cleaning the solar panel, disconnect an unsuitable appliance). In this way the service visits can be planned efficiently and unnecessary commissions are reduced.

2.4.2 Payments

One of the most important functions of Kamworks' platform is to enable payment by mobile money. This allows Kamworks to sell a SHS on credit and therefore overcome the barrier of upfront costs, stimulating the adoption of solar energy (Lighting Global, 2015). Two other payment methods are offered first however. The three options to pay for a SHS are listed below.

1. Pay at once - The system is bought by cash or mobile money. For a regular system this is $450, for a large system this is $595. If a customer is not able to pay this fee at once, a MFI loan is offered. This can be a loan for the total fee, or a part of it.

2. MFI loan (VisionFund, Kredit, LOLC) - When a loan is provided to a customer, Kamworks receives their money from the MFI, after which the SHS is installed. The customer will repay the loan to the MFI in one or two years, through monthly payments. With a two year repayment schedule, a customer will pay $31 a month for a large SHS ($744 in total) and $23,44 a month for a regular system ($562,5 in total). These repayments are explained more in detail in appendix C. Before a customer can get an MFI loan, the MFI assesses

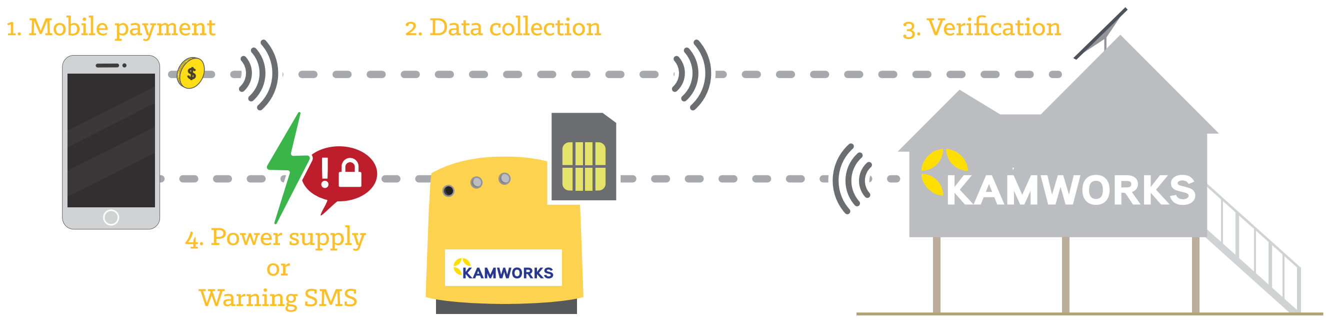


figure 24. PAYGO through Kamworks' GSM based platform

their financial situations. If a customer is rejected, they can still register for a Kiva loan.

3. **Kiva (PAYGO)** - In this case, Kamworks applies a customer for a loan on the website of Kiva. Since these loans, that are funded with private investments, are rarely left unfunded, Kamworks can immediately install a SHS after the application. The loan is repaid through Kamworks' PAYGO system (figure 24). Each month, for two years, a fixed amount of money is transferred through mobile money. When payments are not received, Kamworks sends a notification to the customer. In addition, a red light on the display indicates that a payment is needed. When a customer still does not pay, the SHS can be switched off remotely by Kamworks. A large SHS is purchased through Kiva with $45 down payment and thereafter, a monthly payment of $30 ($765 in total).

Besides reducing the upfront investment, the loans also enhance the system's credibility. Together with the warranty, the monthly payments give customers the power to refuse payment when their SHS does not function properly. In this case Kamworks contacts the customer to plan a service visit. It also happens that a monthly fee is not paid because of a customer's lack of financial resources. In this case, if Kamworks fails to agree with the customer about a payment solution, the SHS is repossessed.

2.4.3 Usage

When customers call with Kamworks' hotline, 59% is about power problems of their SHS (Siebinga, 2016). The three most occurring reasons for these problems are mentioned below.

Use of unsuitable appliances

The knowledge about suitable (12V) appliances is low amongst the customers. Through inverters they try to connect all kinds of appliances to the SHS (e.g. an old TV or Karaoke set). This results in the battery draining energy in a fast rate. In this case the data shows a peak in energy use. Disconnecting the unsuitable appliances solves the problem.

Dirty solar panels

The instructions of the SHS mention that a customer should clean their solar panels every two months. In practice, however, customers rarely comply. The orange dust from the rural roads of Cambodia will gradually reduce the daily energy production of the solar panel, resulting in the battery running down. When this is the case, the solar panel should be cleaned and the energy consumption should be temporarily reduced so that the battery can charge.

High daily use of SHS

There are customers who only use the lights provided by Kamworks with a phone being charged now and then, but there are also customers who use the SHS a lot more intensively. Sometimes this just means a customer needs a bigger SHS, but it can also happen that the battery runs empty over time (one or two weeks). The solution would be to let the battery charge for a couple of days without using it too much, but this is quite a lousy compromise.

When we look at the battery (figure 26), only 30% is used for the actual energy consumption. Another 30% is the buffer that is included when the battery is wearing down. The last 40% of the battery is never used to let the battery make more cycles and thus last longer. The problem customers experience when they have a high usage, is that the solar panels do not generate enough power to fully charge the 30% of the battery during one day.

With a growing energy demand this problem will occur more often when the SHS is remained unchanged. To avoid this issue, the ratio between the power of the solar panel and the capacity of the battery should be redetermined.

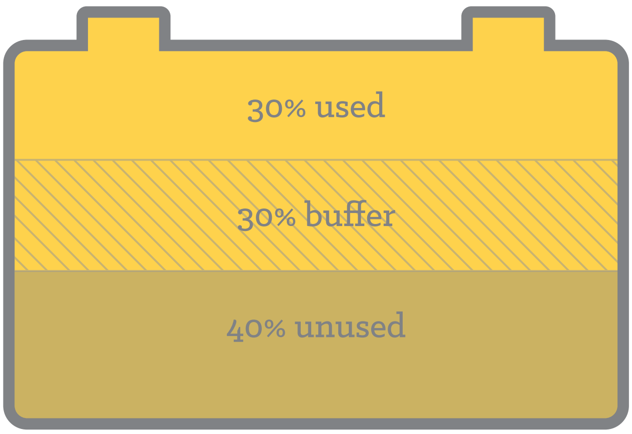


figure 26. Division of a lead-acid battery's capacity

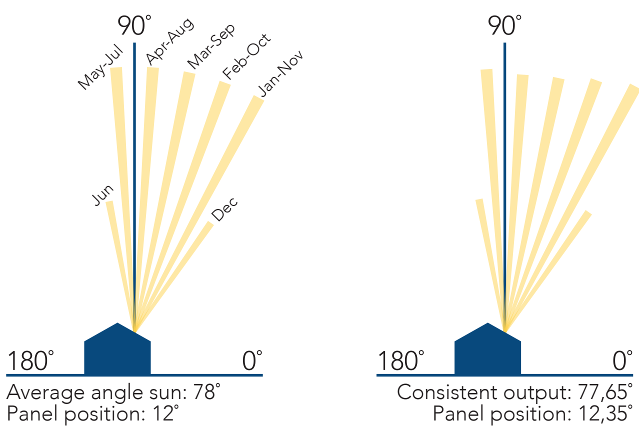


figure 25. Positions of the sun throughout the year

2.4.4 Position of the solar panel

Besides the Wp of a solar panel, the efficiency also affects the daily production. To optimize the efficiency of a solar panel, it needs to be positioned perpendicular to the position of the sun. Advanced systems allow solar panels to 'follow' the sun, but most systems have a panel faced in a fixed position, determined by the position of the sun throughout the year.

Kamworks' solar panel is faced south, inclined 20˚ from the horizontal position: an advice from the good solar initiative (SNV, 2015). Remarkably there is no argumentation found for the 20˚ inclination. Therefore, solar data for Cambodia was analysed (Solar Electricity Handbook, 2016). The data and calculations made can be found in appendix D.

A simple way to determine the positioning of the panel is to place the panel perpendicular to the average angle of the sun during a year. This would mean the panel needs to be placed in a 12˚ angle (figure 25). The average hours of sun per day can be included to will give an optimal energy production of the solar panel. Positioning the solar panel at an angle of 11,65˚ would give an optimal annual production. Placing the panel in an optimal position would make sense when the solar panel would support the grid through net metering. However, this kind of collaboration does not exist in Cambodia. Moreover, Kamworks aims to provide their SHSs to the rural areas that have no access to grid electricity.

A more suitable approach to determine the solar panel's position is by aiming for a continuous generation of electricity throughout the year. The months with less sun hours require more efficiency than months with more sun hours. This gives an optimal angle of 12,35˚.

2.5 Developing the SHS

In the previous chapter, the focus topics for this projects were determined: modularity, expandability, transportation and supply (§1.2.3). In this section they are linked to the separate components (battery box and mounting system) of the Solar Home System in order to create a set of concrete goals.

2.5.1 Modularity and expandability

Modularity and expandability are closely related, which is why they are addressed together. Modularity can reduce the costs of both SHS by reducing the complexity of the design and the amount of unique parts. This also simplifies stock management. The cost reduction of the battery box can impact the total production costs most, while the reduction of unique parts is more relevant to the mounting system(s).

figure 27. 'SHS game': validating expandability

The modularity of the battery box is mainly focussed on the electronics. Eventually it should be possible to connect a regular or large box to one or two other boxes in any configuration. The design proposal of the battery box is expanded through a plug-and-play system: only three cables need to be connected in order to expand this part of the SHS. This will be implemented in the second system size as well, making the battery box interchangeable.

For the mounting system, modularity is linked to the development of a universal mounting system. This will reduce the variety in parts and materials. One mounting system should support one–or multiple–panels, regardless of the type of panel. Where the battery boxes are interconnected, the panels are only connected to their corresponding battery box. How the panels are added (on the roof) is explored during the development of the mounting system.

The understanding of, and the demand for, expandability (by the users) is a critical part of this project. Moreover, the desire for a multiple-sized SHS series needed verification. A field trip of three days, to different villages in the Kampong Chhnang province, was performed to research this. The setup and the results of the research can be found in appendix E.

A game was designed to test the understanding of an expandable system (figure 27). Participants played the game, simulating the use of a SHS. The game included the following aspects:

- The capacity of a system
- The price of a system
- The energy consumption of appliances
- The price of appliances

Throughout the game, appliances and additional systems could be 'purchased'. Afterwards, their opinion and understanding were evaluated.

After the research, it could be concluded that:

- Participants understood the concept of an expandable system and different system sizes.
- Expandability is needed.
- Combinable, multiple system sizes are desired.

2.5.2 A compact SHS and reliable supply

The physical size and amount of packages should be reduced to make the SHS accessible. In order to achieve an increased market scope, a SHS should be transportable by motorbike instead of TukTuk. This also means the installation must be simplified to enable installation by one technician. Having a SHS that is easy to transport is only useful when its supply is reliable too.

With self-installation of expansions in mind, a compact, simple expansion package should be offered to the customer. Looking at the components' transportation sizes, it is clear that a compact system can be mainly achieved by reducing the size of the (large) mounting system and solar panel. Also transporting the battery within the battery box can reduce the transportation size.

In order to make the supply more reliable, mainly the logistics within Cambodia should be improved. This means that the need for proceedings that require a lot of time (i.e. galvanization) need to be reduced as much as possible.

2.5.3 For who is this design

There are several groups involved in this design project. Their interests in the accessibility of the SHS slightly differ.

SHS users

The customers have interest in the development of a expandable system that is more affordable than the current Solar Home Systems. With expandability they are provided with security regarding their (future) energy supply. When their family grows or are able to purchase more appliances, they don't have to invest in a new, larger and more expensive system anymore.

Workshop employees

Collecting parts and materials can be challenging due to the poor logistics of Cambodia. A modular system with reduced complexity means an easier to manage stock and production. This will make their work flow more efficient.

Technicians

The current amount of needed spare parts result in loss and confusion. With two SHS sizes containing the same electronics, repair visits will become more efficient. With self-installed expansions, technicians can focus more on service visits; a part of the SHS package that is currently neglected.

2.6 Conclusions

The general analysis of this chapter gave additional insights forming a framework for this project. They are summarized below.

The main focus for the battery box is the modularity of the contents of both sizes and the cost reduction of the parts. Aside from the simplification of the contents, the assembly should be simplified too: knowing that repair visits are inevitable, a battery box that can be repaired easily is a must. Enabling the battery to be transported within the box will reduce the transportation size.

The development of the mounting system will focus on the expandability, including the ease of installation and the reduction of transportation size. These are the two topics that impact accessibility the most. Moreover, the supply chain of the required materials is evaluated and optimized. This will result in a universal mounting system that is easy to produce and distribute.

In the next chapters, the components of the SHS are analysed (chapter 3 and 5) and developed (4 and 6). The battery box and the mounting system are developed separately and combined in the final chapter. This will result in a SHS family of two system sizes: a regular and a large system. Because of the expandability there will be a core SHS and an expansion SHS. The core SHS has a lamp kit and a mounting system, where an expansion does not need these components.

To summarize this chapter's most relevant findings:

› Reducing the costs can significantly increase Kamworks' target group. §2.2.1

› Sales can be stimulated by good branding and conveying reliability. §2.2.2

› The biggest cost reduction can be made by simplifying the (contents of) the battery box. §2.3.4

› The supply chain can be more reliable by avoiding the need for galvanization. §2.3.5

› It should be evaluated if it is better to produce the mounting systems in-house, or at the factory. §2.3.5

› The amount of separate boxes can be decreased. Reducing the amount of separate objects simplify the logistics and chance of loss. §2.3.5

› With the reduction of transportation size as a goal, the biggest improvements can be made by reducing the size of the large mounting system and panel. §2.3.5

› A good (monthly) payment system can enhance trust towards the product. §2.4.2

› Solar panels with a higher Wp are needed to give more balance to the system and eventually reduce customers' complaints. §2.4.3

› An inclination of 12,35° would be optimal for Kamworks' SHS. §2.4.4

TU Delft Delft University of Technology

KAMWORKS

3.

3 Product analysis: Battery box

Up to now we have generally discussed the context and the contents of the SHS. By evaluating the early insights, a first framework for the battery box was created. Cost reduction (through modularity) is the most important focus of the battery box. In this chapter the most relevant aspects regarding the physical properties of the battery box are further evaluated. A list of requirements and recommendations will conclude this chapter, forming the basis for the development of the battery box.

The total assembly of the current battery box (called 'V2' for its generation of electronics) will be analysed first, after which the design proposal for the SHS (V3, figure 28) is introduced. They are compared on their strengths and weaknesses.

3.1 Battery box V2

As mentioned before, the battery box is the heart of the SHS (§2.3.1); storing and providing energy. It is the access point to electricity, always in sight for the user. In figure 30 the main functions of the battery box are given. All components that are involved with the processes are included within the (contents of the) box. By fixing and protecting the electronics, the Solar Home System is an integrated product.

When relating the described functions to the designs of the two battery boxes, it can be concluded that only the large battery box fulfils all functions. The regular battery box does not provide space to the cigarette sockets, requiring the addition of an electrical box as housing for these sockets. Since only the large battery box fulfils all functions, this will be the only one analysed in this section. Moreover, the analysis of the large battery box includes all steps and actions needed producing and installing the battery box for the regular SHS.

3.1.1 Production

Although the large battery box is the only box that will be analysed, there are some differences between the regular and large box that are worth mentioning.

- The regular battery box has no space for sockets and therefore needs an external electrical box. This box is a standard plastic box, available in electrical shops Phnom Penh.
- The regular battery box is an injection moulded plastic box, produced in China. The large SHS uses a fibreglass battery box that is produced in-house. In 2011 there was an order for 1200 regular SHS, which made Kamworks decide to invest in injection moulding (Kamworks, personal communication, September 14, 2016). These extraordinary orders are

figure 28. The large SHS V2 (left) and a physical prototype of the regular SHS V3 (right). Prototype by R. Siebinga (© R. Siebinga)

rare and that is why the large box is still produced in-house. The specifications of both boxes can be found in appendix F.

The production and assembly of a (large) battery box was observed. The production steps were noted and photographed (figure 32), after which an overview was made (figure 31). The total production time for one battery box is estimated to be just under four hours (observation, August 15, 2016).

Nearly three out of the four hours of production time is spent on the production of the front and the back of the battery box (figure 29). One hour is related to labour, two hours are waiting time for the parts to harden. They are produced by vacuum resin transfer moulding (VRTM): a process for producing composite parts. The VRTM process is explained more in detail in the next chapter.

Most parts and sub-assemblies can be 'prepared', apart from the main assembly line. For example, the wires are soldered to the PCBs, while holes are drilled in the boxes before moving them into stock. This makes the final assembly, when a new batch of Solar Home Systems is needed, faster. In figure 31 the blue circles with a yellow outline indicate the prepared parts and sub assemblies.

3.1.2 Installation

The battery box and the battery are transported separately because the box cannot be lifted with the battery inside. Otherwise, the box will break.

When a SHS arrives at a customer's home, the battery box is positioned and the battery is installed. For this, the box needs to be opened and closed (red section figure 31). This takes about 15 minutes.

As soon as the lamp kit and the solar panel with mounting system are installed too, the lamp kit and the solar panel are connected to the battery box. This can be done within a minute.

After installation, one of the technicians provides the user with a manual, instructions on how to use the SHS, and a contract (with terms and conditions for the two year warranty). Although the box is sealed for warranty after installation, it happens regularly that customers open their box when the SHS stops working for whatever reason. This is an undesirable side effect, since the electronics are damaged in most cases (Kamworks, personal communication, August 29, 2016).

figure 29. The front of the large battery box before finishing.

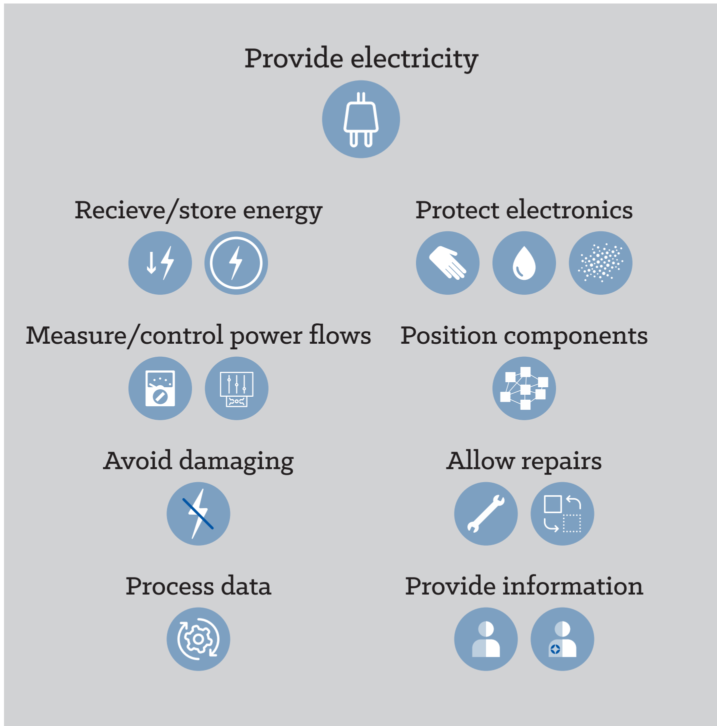


figure 30. Functions of the battery box (V2)

3.1.3 Pros and cons

After the analysis of the current battery box, a list of strengths and weaknesses can be made.

Strengths of the design:

› The prepared parts and sub-assemblies lower the production time when a batch of systems is needed.

› When the box is opened, all components can be replaced without having to dismount other components (figure 33). This simplifies the assembly (i.e. no specific sequence needed) and make repairs easier.

Weaknesses of the design:

› The back has to be slammed into the front to fit. They need to be firmly pressed together while drilling holes (figure 34). Closing the box is a rough and imprecise action. This unprofessional looking action needs to be repeated in front of the user.

› The bottom of the battery box is not attached to the back panel. This makes it impossible to lift the box with the battery inside without breaking the box.

› Opening and closing the battery box while customers are present, 'demonstrates' how the box is opened and how warranty seals are applied. This is not beneficial if opening the box should be prevented.

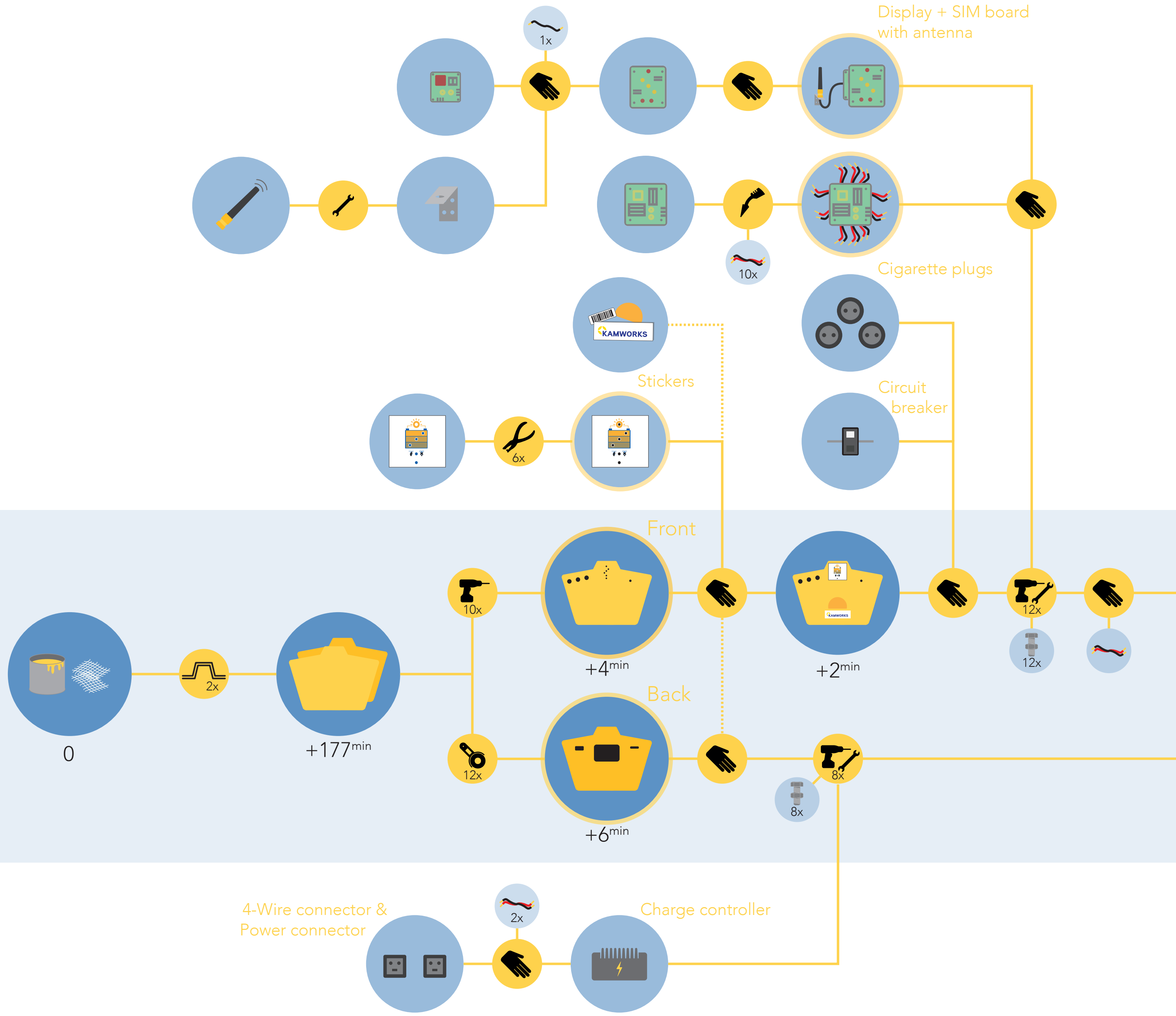
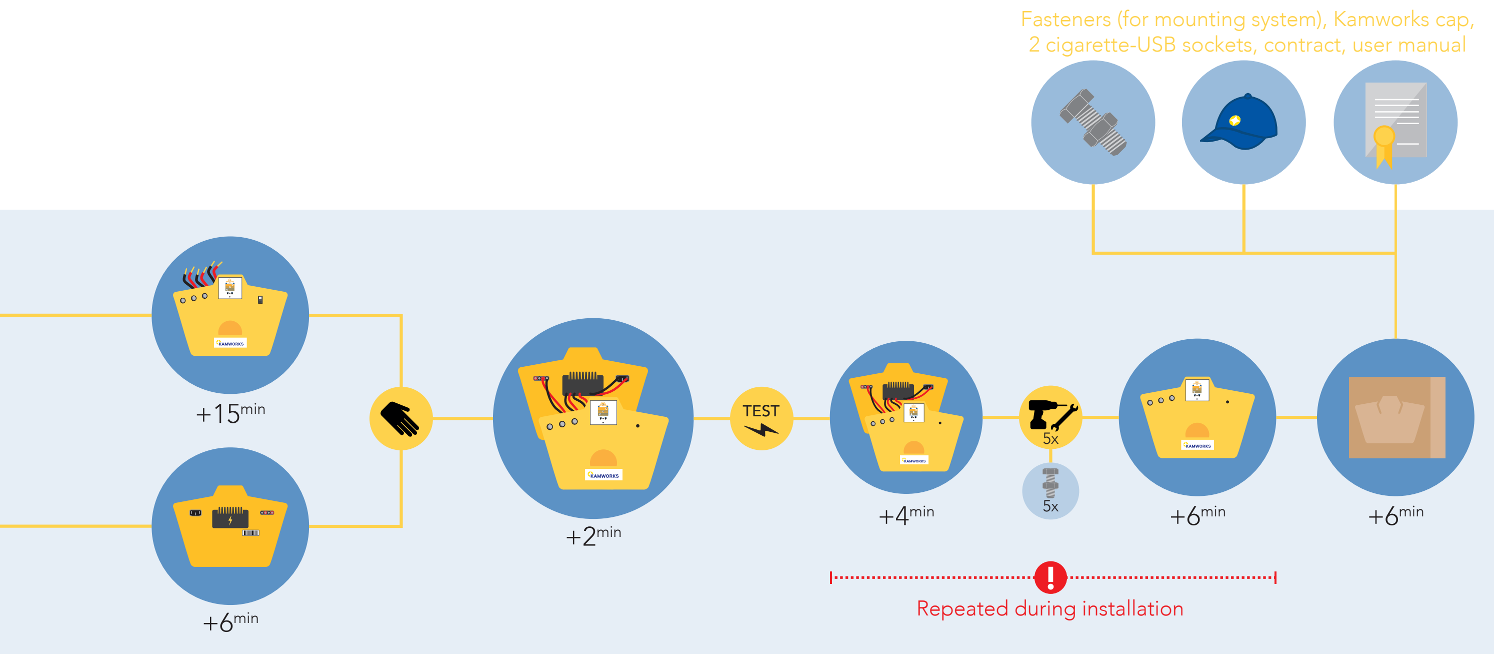


figure 31. Assembly of the large battery box

figure 32. Kamworks employee (Seang Hai) assembling the battery box for the large SHS



Total production time:
228 minutes
Total labour time:
108 minutes

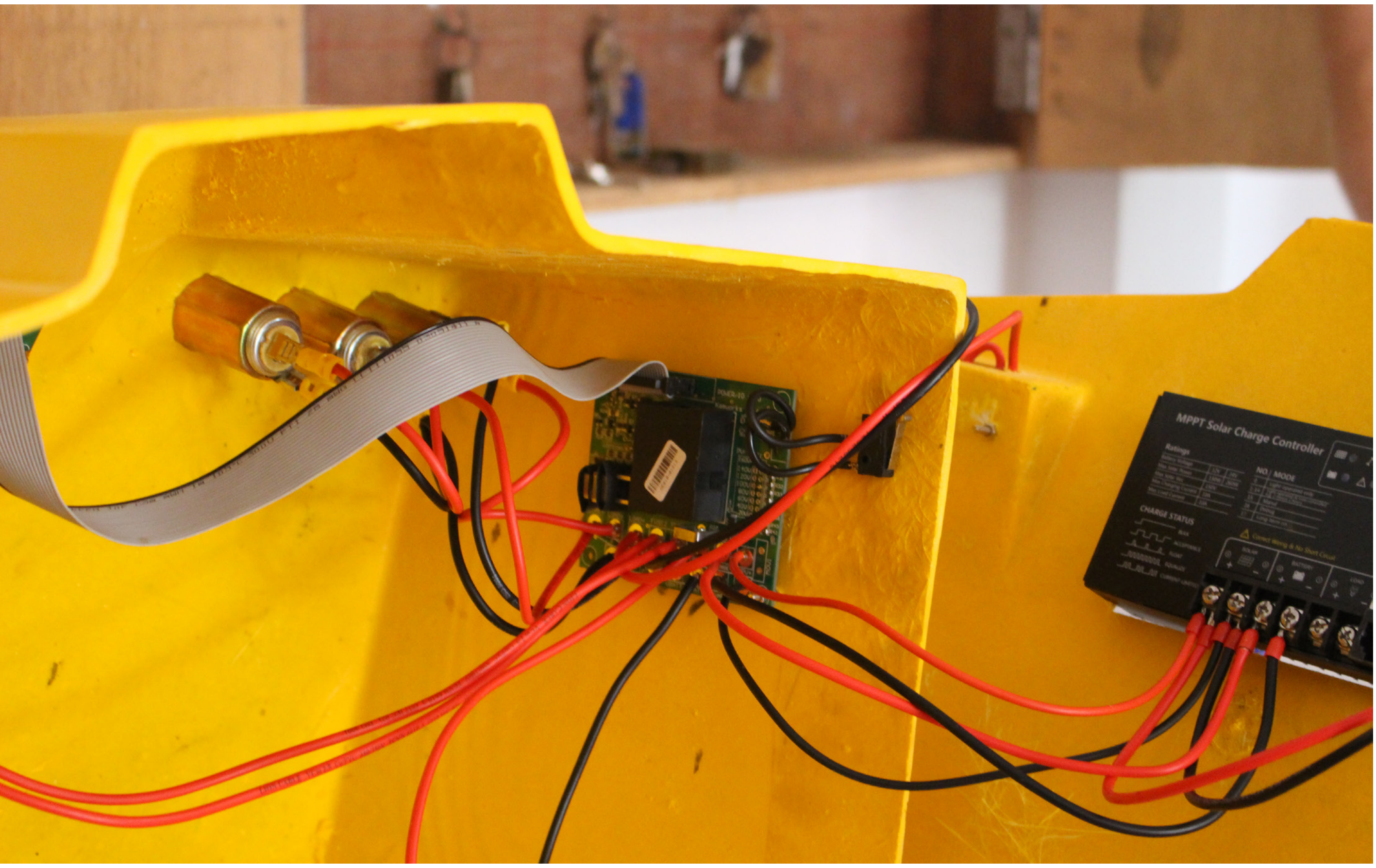


figure 33. An opened battery box (without battery)

figure 34. Closing the battery box

3.2 Battery box V3

The design proposal includes one system size: the regular SHS. In this section this design proposal is analysed. Although this design is not finished, it is possible to estimate the production steps and time.

The production and assembly of the design proposal shows many similarities to the current battery box. One major difference is the separation of the display and SIM board from the box (figure 35). This decision was made since only one display is needed for an expandable system (figure 40). Removing the display also removes two functions from the battery box: providing information and processing data.

Two functions were added to the battery box. The first one is allowing movement (figure 38), which means that the box should be able to be moved around together with the battery. This enables a more compact transport (§2.3.5) and prevents the need for opening the box during installation. The second function is providing storage for a mobile phone. Because a USB is added to allow charging a phone with a cable only, a flat surface is integrated in the design to allow the phone to be placed on top of the box.

Since R. Siebinga did a thorough study on the new shape of the battery box, the main aspects regarding aesthetics will remain unchanged. The box does not fully encase the battery, but covers the top and the majority of the sides of the battery. The shape provides sufficient protection to the electronics and minimizes the use of fibreglass. A design for the large battery box is still to be developed.

figure 35. The physical prototype of the design proposal. (© R. Siebinga)

figure 36. Contents of the design proposal. (© R. Siebinga)

figure 37. Closing the box. (© R. Siebinga)

3.2.1 Production & Installation

The production of the battery box V3 (figure 39) is an estimation of production times and assembly steps, based on the production of the current battery box and the assembly test performed by Siebinga (figure 37). Throughout the development of the battery boxes (chapter 4), these steps will be described in more detail.

The total production time is estimated on 2 hours for the battery box (and 7 minutes for the display box): half the time required producing a current battery box. The time reduction is mainly achieved by removing one fibreglass part.

The biggest difference in the assembly can be found in the configuration of components, and thus wiring. Since the display- and SIM board are separated from the battery, an external cable is needed to connect (and power) this part of the system. Moreover, the power board and charge controller are combined into a new power board. This integration saves costs, since the charge controller was the most expensive electronic component. The required space within the box decreases due to this integration, allowing a more compact design. Within the new battery box, all wiring goes directly to the power board.

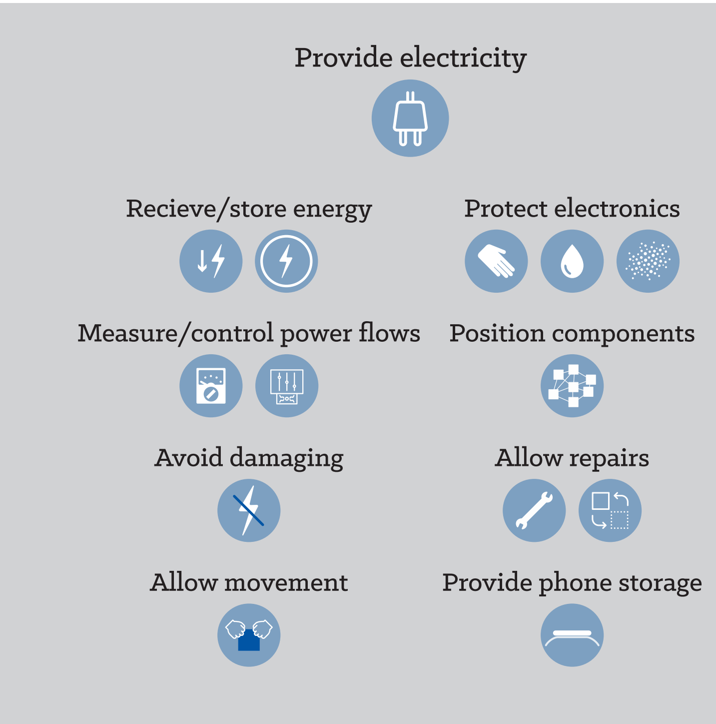
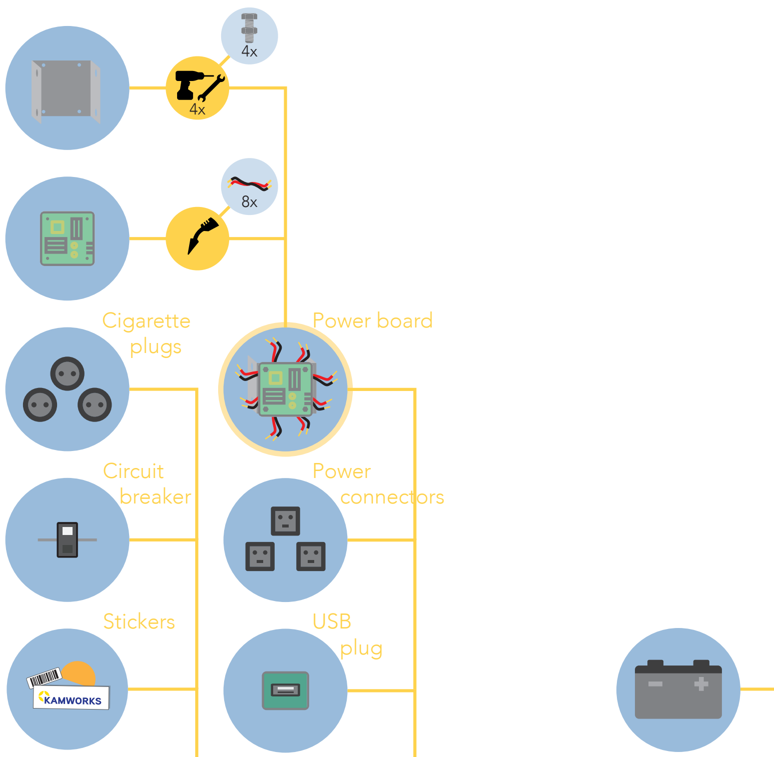


figure 38. Functions of the battery box (V3)



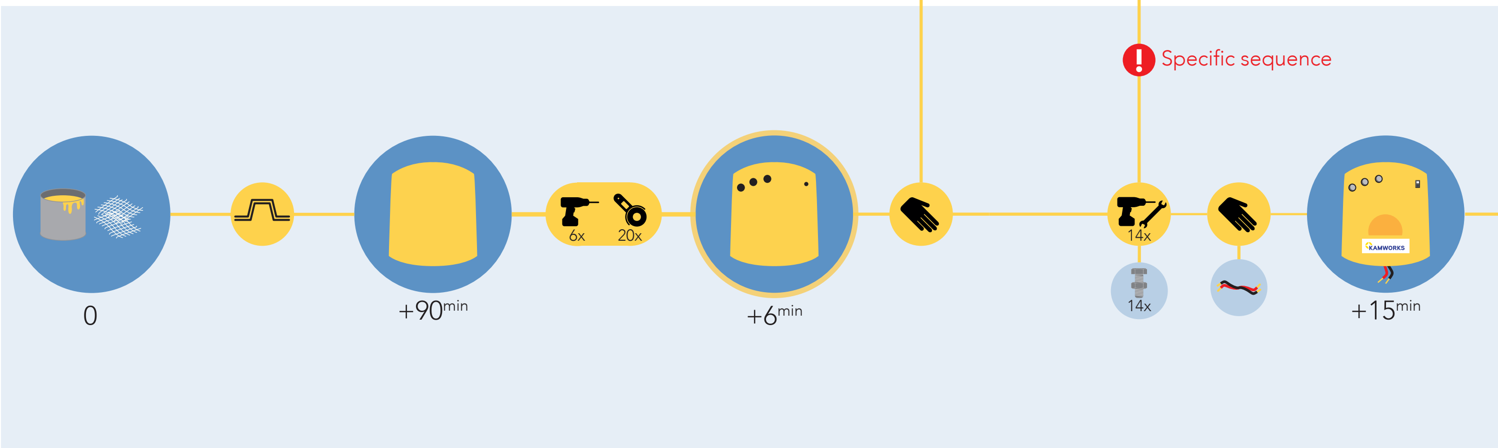


figure 39. Assembly of the battery box V3

The compact space brings a disadvantage to the design proposal regarding repairs of the battery box. The power board is placed below the other components (figure 36), while the USB component is positioned behind the cigarette sockets. When small repairs or software updates are needed, the power board needs to be disassembled because it is facing up. The current configuration requires a specific sequence of assembling and disassembling, causing the assembly and repairs to become more complex.

When the battery is connected to the box, they can be transported together. Although a part of the 'empty space' in the current battery box was filled with manuals, contracts and accessories during transport, a large amount of space was wasted by the separate transport of box and battery.

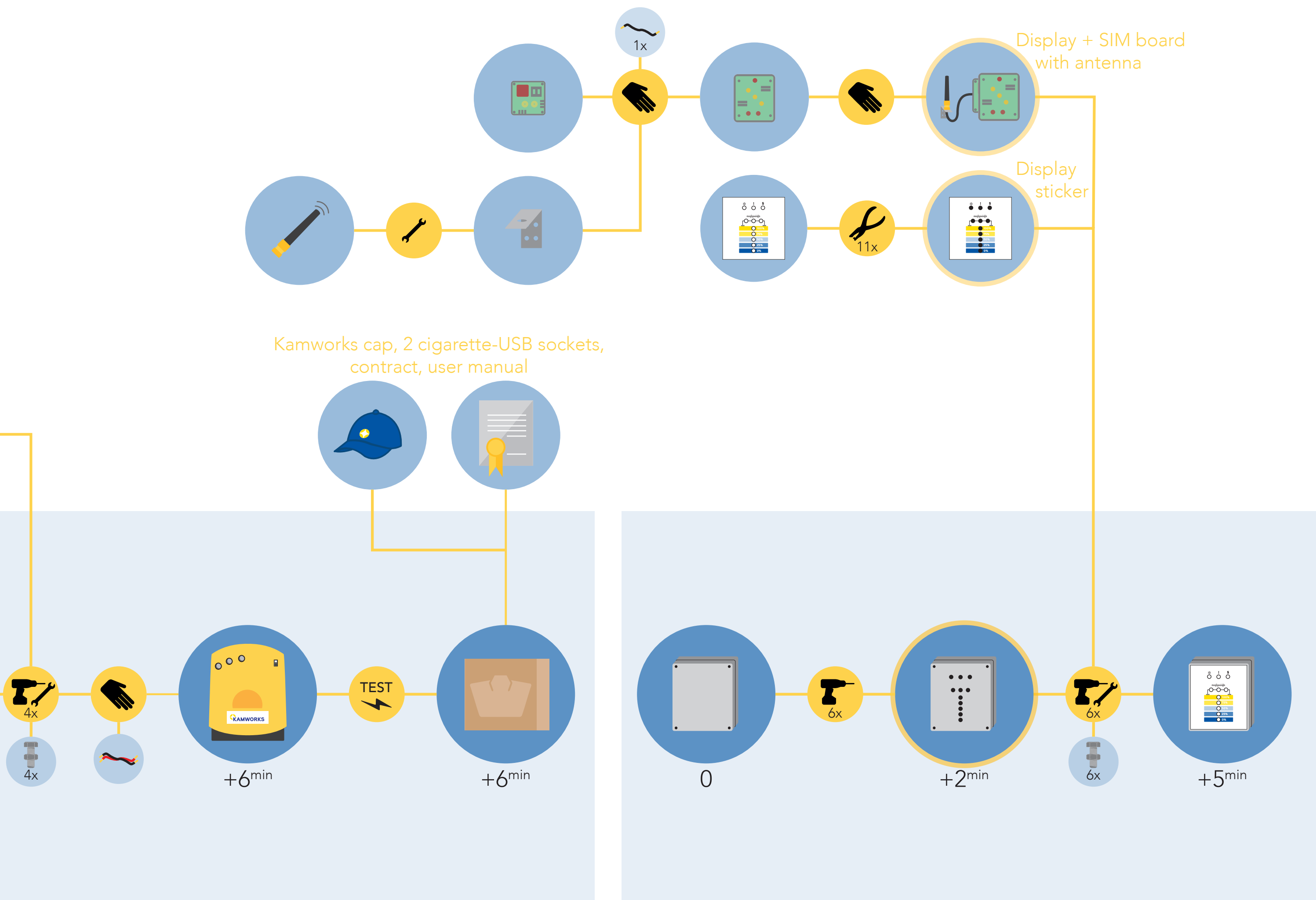
3.2.2 Pros and cons

Also for the design proposal, a list of strengths and weaknesses was made, based on the design proposal itself and the comparison to the current battery box.

Strengths of the design:

› The production time is reduced significantly by eliminating one fibreglass component.

› There is only one display in the whole system



Total production time: 123 minutes
Total labour time: 63 minutes

Total production & labour time: 7 minutes (figure 40), reducing the production costs of an expansion SHS.

› The charge controller is integrated into the power board. This saves costs and space.

› The assembled battery box requires less space than storing the prepared parts and components separately (which is the case with the current one). This makes it logical to put ready to go SHS in stock, ensuring a faster and more reliable supply.

› The battery box can be moved and transported with the battery attached to it. This reduces the transportation size, and simplifies the final installation.

Weaknesses of the design:

› The battery box requires an assembly in a specific sequence. When certain parts need to be repaired or replaced, other parts have to be removed first. For example the power board is oriented in between an aluminium sheet and the top of the box (figure 42), which requires removing them both when (small) repairs are needed.

› The power board is attached to the aluminium sheet, which is fixed with bolts from the outside of the box. These bolts are accessible for the users and that might cause users to loosen them. If that happens, components inside might damage due to moving parts.

› Both the battery box and the aluminium sheet requires precise production to fit the box. This sheet is not suitable for the large box.

› It is relatively easy to open the battery box (removing four bolts). Initially the bolts will be covered with warranty seals, but this might not be sufficient.

3.3 Discussion

In the previous sections both battery box designs were analysed. There are strengths and weaknesses for each box, which can be divided in several topics for discussion.

Electronics

The two biggest changes that are made in the electronics are the separation of the display and SIM board and the integration of the charge controller with the power board to one PCB. These changes were made to reduce costs and make the system expandable.

The relations between the components of the SHS (figure 21, p.32) generally remain the same. The sockets that are make the SHS work, however, need to be adjusted. The adjustments, visible at the back of the box, are numbered in figure 41 and figure 42 and discussed below:

1. The (IEC male) power socket to connect the solar panel [Power in]. Since the solar cable has an IEC female power plug attached to it–and these standard power sockets are widely available–this socket remains unchanged.
2. The current connection for the lamp kit is a 4-wire connector [Power out]. Since the lamp kit only uses half of the connector, it can be replaced by a smaller connector. However, this connector is used as an access point for all kinds of (unsuitable) appliances by users since it is easy to connect wires to it. Compared to the other electrical components the 4-wire connector is an expensive part. In the

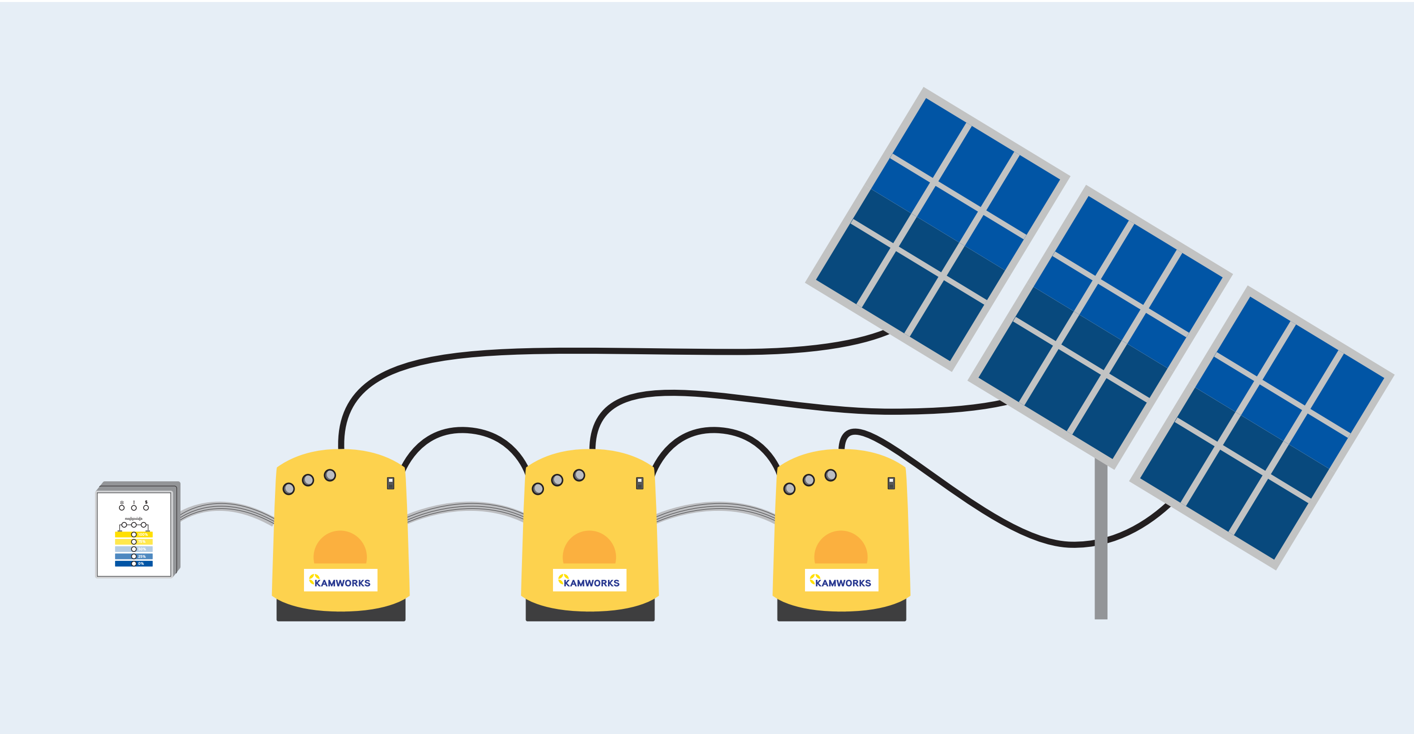


figure 40. Connecting multiple Solar Home Systems

redesign it is replaced by an IEC female power socket. Just like the male socket, this (universal) component is widely available. It does require the lamp kit to be provided with correct right plug.

3. Since the new SHS should be expandable, an additional female power socket is added to interconnect the batteries. This enables a system using the energy of all batteries.
4. Two Ethernet sockets are added to the box. Where the IEC female sockets are added for the batteries, these sockets are added for the display. The Ethernet sockets power the display and provide information about the SHS. When a SHS is added, two cables connect the boxes: the IEC connection and the Ethernet connection. The software in the powerboard can combine the information of multiple Solar Home Systems in order to provide the display with the correct information.
5. Two LEDs are added to the box to show if a box is functioning properly. If a problem occurs at a household that owns multiple systems, the LEDs show the technician(s) which system is broken when they come for a repair visit.
6. A USB socket is added on the top of the box with the purpose to power products with a low energy consumption (e.g. charging a phone). This is an

figure 41. The back of the current large SHS

figure 42. A section view (left) and the back (right) of the SHS V3 (© R. Siebinga)

addition to the cigarette sockets.

The changes that were made are logical, but are not yet validated. In the next chapter they will be further developed. Two recommendations regarding the electronics, given in Siebinga's thesis, are taken into account as well:

› *Implementing a 1,2,3 switch.* A switch is needed to determine whether a SHS is the core system, a first expansion or a second expansion (the limit of the expandable SHS is three systems). This switch needs to be accessible when the box is closed.
› *A second USB socket*. This low cost component uses little power and provides the user with more 'luxury'. The possibility to implement a second USB should be explored.

This means that the electronics still need adjustments. There was no physical prototype of the detailed V3 electronics yet. The assembly and the configuration of the electronics will therefore be evaluated in more detail in the next chapter.

Batteries
Because of the reliability of the current batteries and the available stock, the same batteries will be used in the new SHS. This means that the boxes will be designed for the Ritar 55Ah and 100Ah 12V batteries. The detailed properties can be found in appendix G. For the design, the dimensions and possibilities for attaching the box are the most relevant (figure 43).

Where the 55Ah battery has the possibility to attach the box with four bolts through the holes that are normally used for the carrying ropes, the 100Ah has no option to do that. To secure the large battery box to the battery, a connection piece needs to be designed that fits the two cavities on the short sides of the battery.

Production and assembly
The size of the power board and the addition of components, influence the assembly steps and repair process. Therefore, the assembly of the battery box needs to be evaluated during the development of the battery box.

As mentioned before, the VRTM process is not sustainable, but will not be reconsidered on the short term (§1.2.4). Large investments are financially not feasible and the risk of running into start-up problems can have a great impact on the position of Kamworks in the solar energy market. This also means that other parts of the SHS are developed with the available tools and resources in mind.

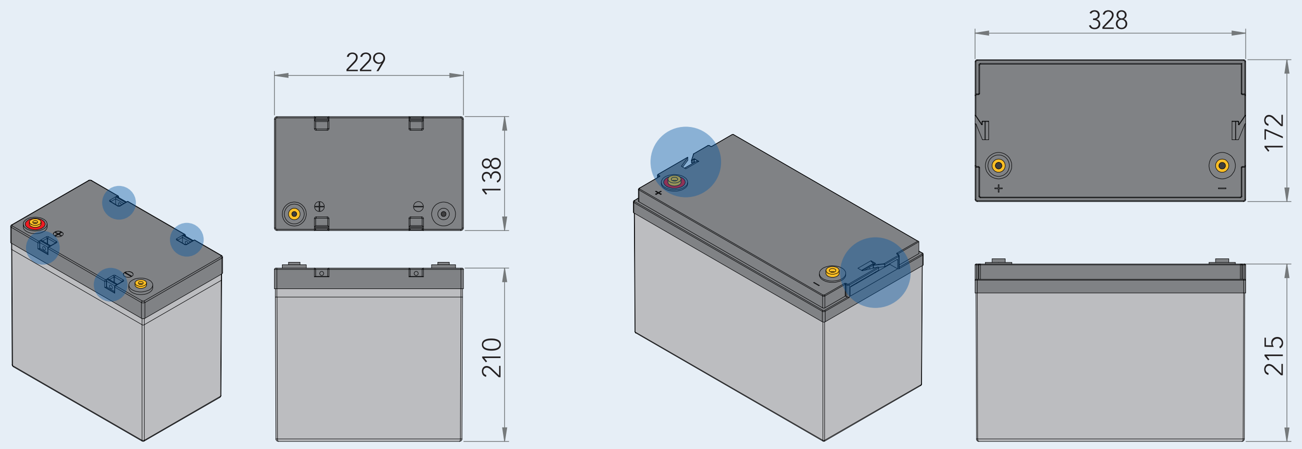


figure 43. The batteries used for the SHS: the regular 55Ah battery (left) and the large 100Ah battery (right)

3.4 Conclusions

The most relevant improvements for the battery box are the reduction of costs (§2.3.4) and the merged transportation of the battery and battery box (§3.1.2, §3.2.1). Based on the performed analyses, the following requirements and wishes for the redesign of this part of the SHS can be formulated:

3.4.1 Requirements

Modularity and expandability:

› It must be possible to connect three systems to each other. §3.3
› The 'position' of a SHS should be adjustable while the box is closed. §3.3
› Different system sizes should be combinable. §2.5.1
› The power sockets must be able to use energy from all batteries.

Assembly and production

› It must be possible to store and transport a fully assembled system. §3.2.2
› The battery box is able to lift its battery. §3.2.2
› The user does not see the box being opened or closed during installation. §3.1.2
› Both battery boxes should provide space for all sockets and components (display not taken into account). §3.1
› When the box is opened, each component can be replaced without removing other components first. §3.1.3
› The box should (at least) cover the top and the upper three centimetres of the battery. §3.2

Avoiding misuse

› The power board can only be dismounted after opening the box. §3.2.2
› The box can be produced with the available production facilities. §3.3
› It should be noticeable if a user has opened the battery box.

3.4.2 Wishes

› The power board can be mounted in the same way in both the regular and large battery box. §3.3
› A second USB is implemented in the design. §3.3
› The amount of separate 'packages' for one SHS can be reduced. §2.3.5
› The difference in parts and components between both systems is minimized. §1.2.3
› The two battery boxes have coherent aesthetics. §3.2

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4.

4 The development of the battery box

Where the main goals are reducing the cost price and transporting the battery box together with the battery, the requirements and wishes (on the previous page) provide a broader foundation. The focus of this chapter will lay on the design of a large battery box and the detailed elaboration on the assembly and production.

The large battery box is developed based on the design of the regular battery box first. Since the SHS is expandable and combinable, a coherent appearance is desired. If the shape is determined, the connection with the battery boxes is developed.

When both boxes are in an equivalent state of development, the assembly is optimized. A detailed overview of the electronics is given and the configuration of components is determined. A detailed overview of the design and its improvements conclude this chapter.

Several criteria influence the design process (described below). They are used to justify changes and decisions in this process.

Modularity
Where possible, parts used for the battery box should be the same for both the regular and the large system. This will reduce the amount of unique parts needed for the systems, leading to an easier to manage stock and therefore, more reliable production. It will also result in technicians requiring less spare parts to take with them for repair visits.

Price
If the price can be reduced by applying certain solutions, which eventually make the system more affordable for the users, this should be considered. Quality should not be lost however. One major improvement was already made: the integration of the charge controller with the powerboard. Some other changes are considered throughout this chapter.

Assembly
The assembly should be simplified to avoid the need for a specific assembly sequence. Also complex, precise production or assembly steps should be avoided, since they will make the assembly vulnerable for mistakes. During the two-year warranty, components may need to be repaired or replaced. It is desirable that technicians can perform small repairs to the electronics without having to remove any components.

4.1 Large battery box

Before looking inside the box, a design is made. Since a coherent appearance is desired, the aesthetic of the design proposal (of the regular battery box) will be used as a starting point.

4.1.1 Shape

The (new) shape of the box comprises two general functions: a cover that protects the electronics, and a 'shelf' to place a mobile phone on while charging. They are discussed separately to determine how the boxes can be visually related to each other.

Box
Three shapes were developed based on the shape of the regular system (figure 44). The shapes are explained based on the front view, since it is the most prominent view (i.e. the box is placed with the back against the wall).

Shape "A" follows and continues the curves of the regular battery box. With this shape the middle part

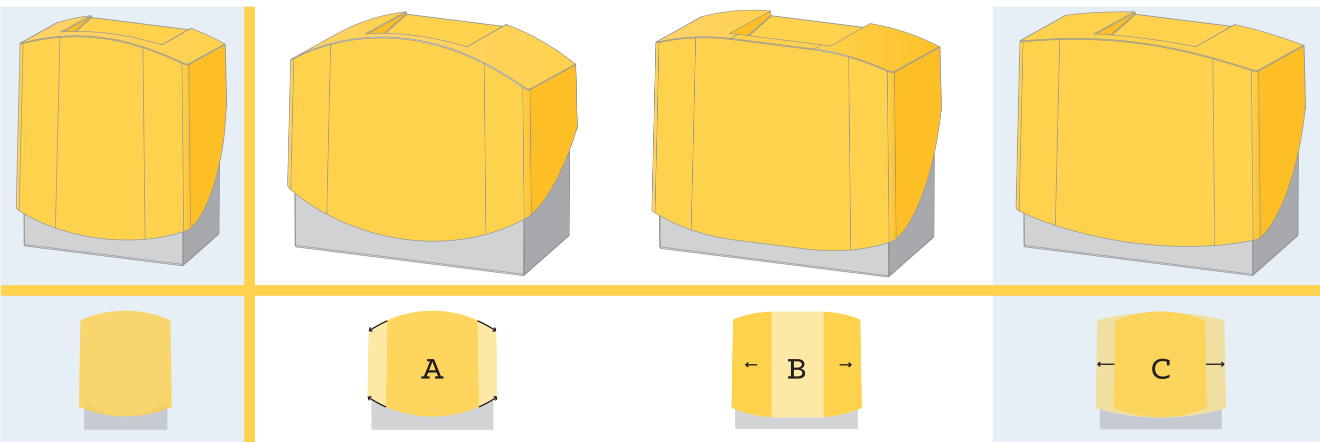


figure 44. The shape of the regular battery box (left) and three shape options for the large box

would offer most space for electronics, where the slope at the sides of the box becomes steep, leaving little space for components. With the box following both the top and bottom curve, less surface of the battery is hidden.

Shape "B" has the same curves as the regular box with the same width. To increase the size, an extrusion of the middle section is placed in the middle. This shape provides a lot of space for components, but the interruption of the curve might turn out bulky

Shape "C" is a stretched version of the regular battery box, resulting in a similar height difference from the middle to the side, but a different curve. Although the difference with B is little, the continuous curve may convey a more dynamic form.

Charging station
By determining the dimensions of the horizontal surface, the functional aspects were taken into account. Making the platform wider would result into a decrease of available space inside. With the desire of adding an extra USB, a larger surface could be beneficial, but the surface of the regular battery box cannot be increased. By having a charging station of a similar width for both systems, the difference in the size of the curved surface, and therefore the system size, is visually emphasized, so the width of the platform is kept similar.

The three shapes were presented to and discussed with five Khmer employees from Kamworks. The regular box was shown and they were asked which shape relates to it most. By giving their preference a rating (3 is most desired, 1 is least), a shape was chosen.

	A	*B*	*C*
Participant 1	1	2	3
Participant 2	1	2	3
Participant 3	1	3	2
Participant 4	3	1	2
Participant 5	1	2	3
Total:	7	10	13

As shown in the table, shape C was the most preferred shape and will be used for the development of the large battery box.

4.1.2 Battery box - battery connection
Where the regular battery box can be attached to the battery with four bolts (§3.3), the large box should have an additional shape or component to connect it to the battery. In addition to the listed requirements and wishes, some criteria are specifically relevant for this part of the design:

› Since the custom parts of the battery box are all produced in-house, it should be able to produce this component in Sre Ampil. Outsourcing a small, custom-made part like this to a local factory, would increase the price and make Kamworks unnecessarily dependent on external parties.

› Possible movement should be minimized. Vibrations during transport can damage the electronics, while movement may also invite users to try and open the box.

› It should be noticeable if a box has been opened by a user (§3.4). In that case, the warranty expires. However, it is preferred that users do not open the box at all. For this, it is desired to make the opening of the box something that the users cannot do themselves. Concealing the connection is one possibility. This can also contribute to the aesthetics.

A morphological chart was made to support the idea generation (figure 45). Eventually three concepts were developed (figure 46).

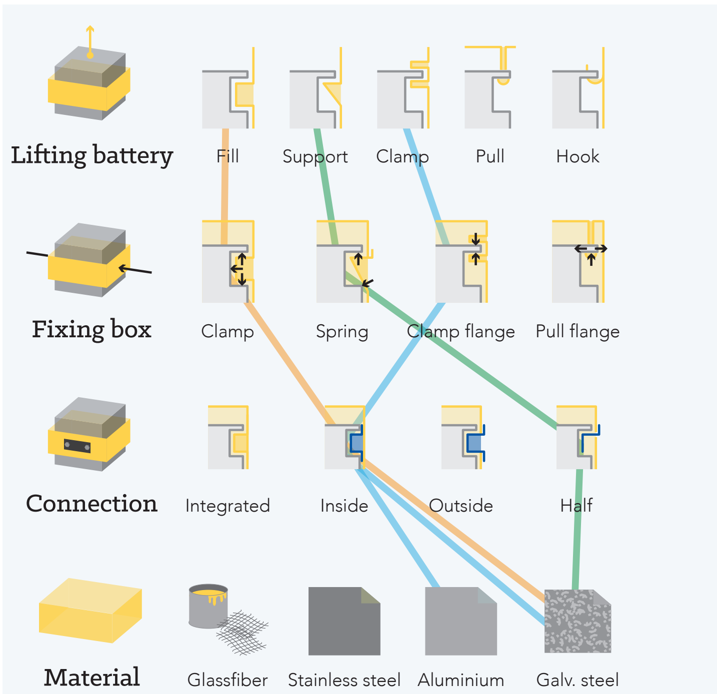


figure 45. Morphological chart for box-battery connection

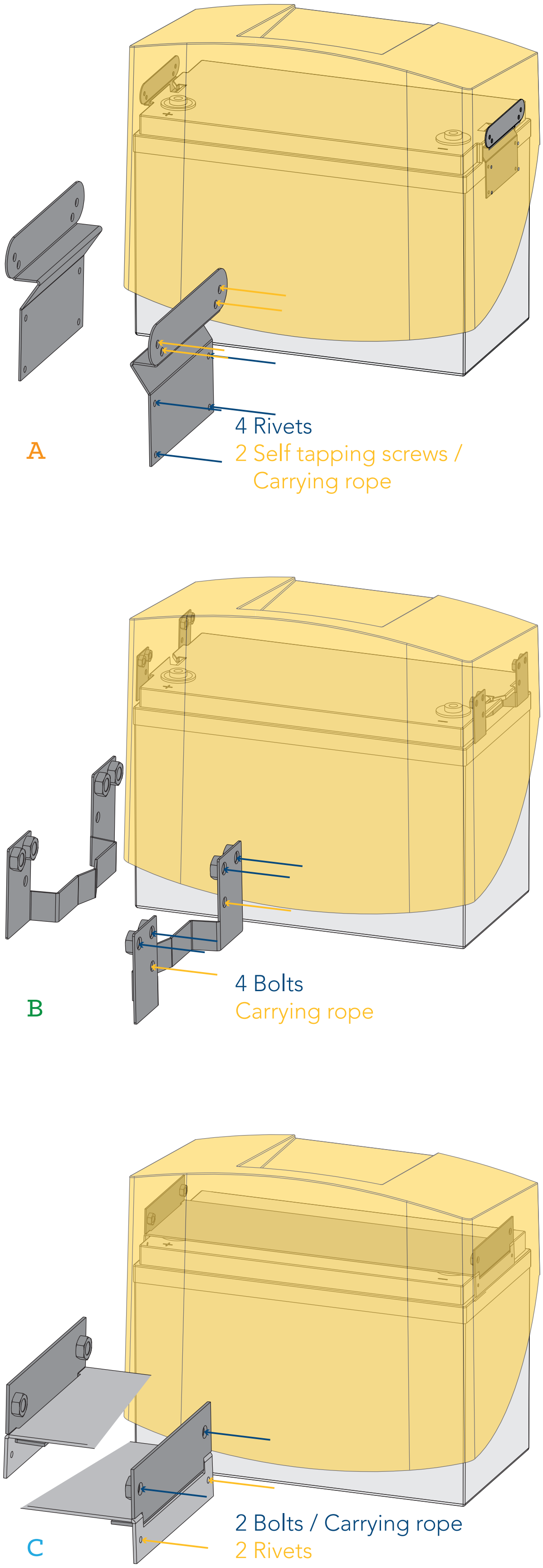


figure 46. Three possible solutions for the box connection

Clips (A)
Two clips are attached to the sides of the box with blind rivets. When placing the box onto the battery, the clips are pushed outward until they snap into position. This position is secured by self tapping screws and/or carrying ropes.

An advantage of this concept is that the box does not disconnect from the battery when the self tapping screws and/or carrying rope are removed: the clips have to be pushed outward before the box is disconnected. A disadvantage however is that the self tapping screws need to be mounted directly into the fibreglass: the screws may loose their grip. Moreover, the visibility of the metal strips require a smooth finish and may affect the coherent appearance.

Brackets (B)
These brackets will be placed into the cavities of the battery before the box is put into position. Then the brackets are secured by four bolts on each side.

This solution is the only one where the fixture is not directly mounted onto one of the two parts. It might be difficult to get the box aligned with the brackets. Knotting the carrying ropes through the brackets may allow easier positioning, by pulling the box into position. The advantage is that these parts are easy to produce in the workshop of Sre Ampil.

Clamp (C)
One sheet of aluminium is mounted with rivets to the short sides of the box. Two hooks are placed in slots in the aluminium and used to clamp the battery. The hooks are tightened by two bolts on each side, mounted from the outside.

The aluminium sheet has a function that is not integrated in the other concepts: cooling the power board. This heat sink can not be used in the regular battery box however. An advantage of this concept would be that the box can be clamped to the battery very tightly, but production needs to be very precise to make this concept work.

Concept selection
The concepts were assessed to several criteria (see table), after which they were discussed with the design team.

Concept C was the first concept to be rejected because of the material use, the need for precise cutting and possible complications during assembly. The fixed aluminium sheet would position the box in the right height, but makes the accessibility of other components hard.

Concept A and B are valued with the same score. After the discussion with the design team, concept A was rejected due to aesthetic values (the visible metal strip). Concept B was chosen for its simplicity and concealment. The bends, that are needed to make a tight fit, can be made with the manual sheet metal punch (and the adjustment of an unused punch and die) owned by Kamworks.

	A	B	C
Fixation	+	+	++
Concealed fastening	-	+	+
Hard to disassemble	+	-	+
In-house production	++	++	+
Easy to produce	++	++	-
Total	+++++	+++++	++

4.2 Assembly

With the shape for the large battery box determined, the contents for both battery boxes can be further developed. In figure 36 (page 47) and figure 42 (page 51) the design proposal's configuration of the contents is shown. This configuration is evaluated and adjusted with the modularity for both systems and the accessibility for repairs in mind.

Since there is less space available in the regular battery box, the assembly of this box is more critical than the large battery box. Issues mentioned throughout this section may only occur in the regular battery box. The improvements that were made are split up in two parts: the power board and the assembly (sockets, battery, fasteners and wiring).

4.2.1 Power board

In close collaboration with the electronic engineers, thorough changes were made to the power board (figure 47). The changes most relevant to the total design are elaborated below.

1 - Orientation

The components on the power board are rotated 90 degrees. Since the power board of the design proposal was almost twice the size than estimated, a reconfiguration was required.

The new configuration positions the long side of the PCB to the back, creating space for additional components (on the board) that need to be accessible from the back of the box. The heat sink of the power board, which is used to mount the power board in the battery box, will be attached to a side and the back of the box instead of the front and back. This change allows the use of the same sheet in both boxes and avoids the need of precise bending.

Besides the reconfiguration of the board, which is elaborated hereafter, the orientation of the power board has also changed. By mounting the power board upside down, it becomes accessible when the battery box is opened. In this way small repairs can be executed without having to remove components (figure 48).

2 - Display connection

The Ethernet connection that is meant to power the display and SIM board caused problems during testing. They were replaced by two 9-pin SUB-D connectors. Although these connectors are a bit larger, they are low in price and solved the issues that the electronic engineers experienced.

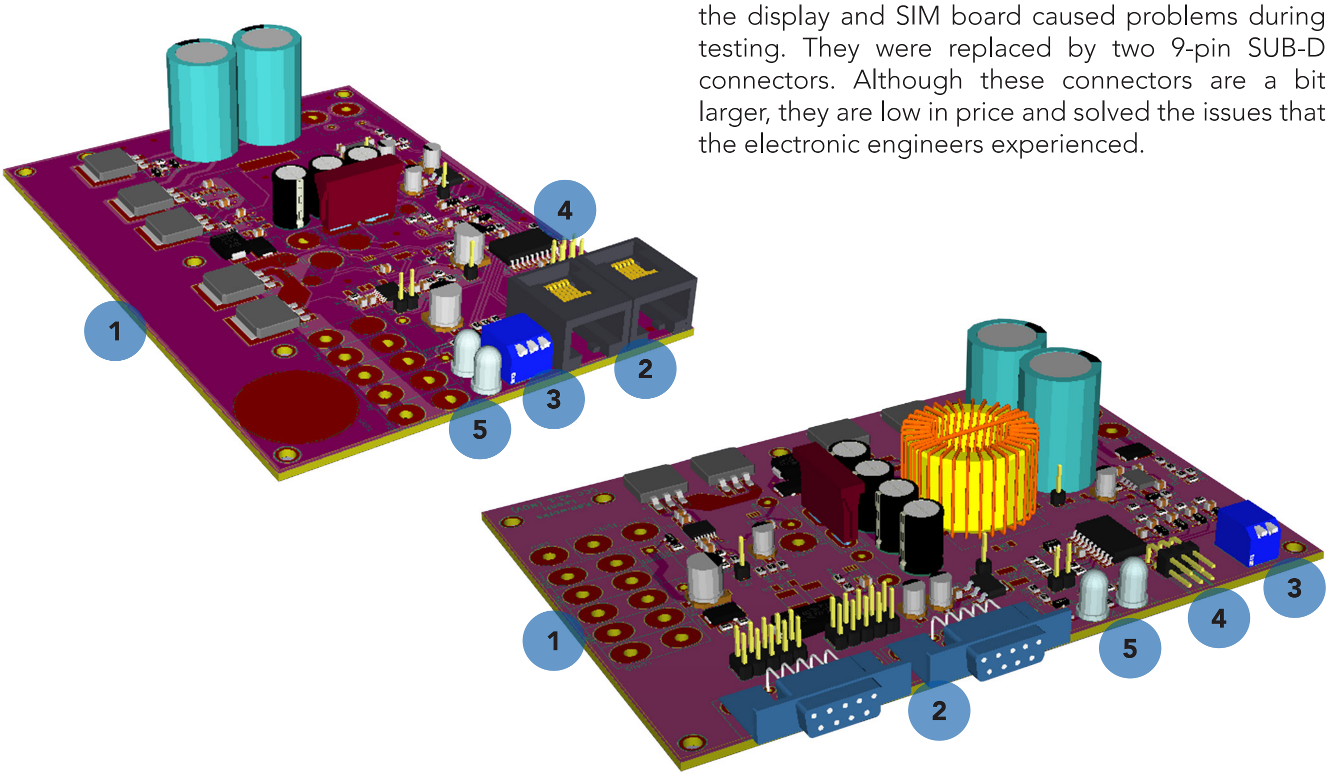


figure 47. The power board from the design proposal (left) and the redesign (right)

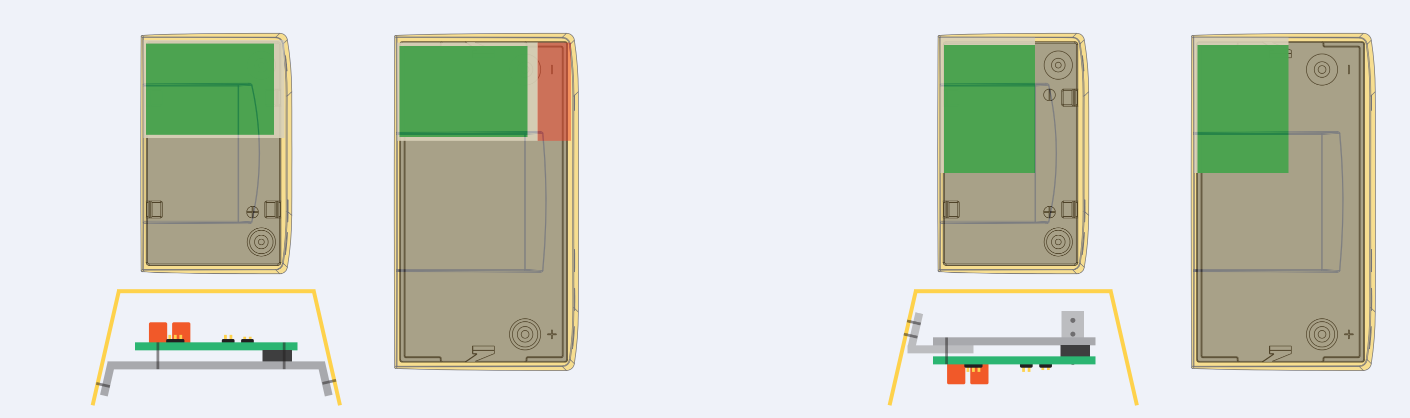


figure 48. The position of the power board in the design proposal (left) and the redesign (right)

3 - Switch for expandability
A 1,2,3 switch would determine the position of a Solar Home System within a multiple sized system. When the battery box is transported together with the battery, a fourth "standby" mode is needed to store the boxes. This mode prevents the battery to drain energy when it is stored for a longer period.

Theoretically, the circuit breaker can activate this mode, but to enable this option, each circuit breaker would need to be purposely overloaded, which is not desirable. Moreover, there would be a reasonable risk of the circuit breaker being deactivated by accident, activating the system. Eventually it was decided to not involve the circuit breaker.

Instead of a 1,2,3 switch, a piano DIP switch with two pins can be used. The combined position of the two pins (up or down) wil provide the system with four modes. Looking at simplicity and costs, this would be the best option.

4 - Software
A 6-pin connector is used by technicians to install software updates or analyse data (about the system's performance) during service visits. Since these actions are often executed apart from repairs inside the box, this connector should be accessible when the box is closed.

5 - LEDs
When a repair visit is needed at a household that owns multiple Solar Home Systems, the LEDs indicate which systems do (and do not) function properly. In this way, technicians know which system needs to be repaired. For this, both LEDs need to be visible from outside the box. Therefore, they are postioned next to each other.

4.2.2 Assembly
With the redesign of the core of the battery box (the power board) finished, the rest of the battery box can also be developed. The similarity in components of both boxes, and the ability to access all individual contents were influential to certain decisions. The changes and improvements that were made in order to come to the final design (figure 49), are explained below. A set of technical drawings, showing the detailed assembly with dimensions, can be found in appendix H.

Mounting the power board
By changing the orientation of the power board the way of mounting it to the battery box also changes. The requirement of making it impossible to dismount the power board from the outside would mean that screws or bolts cannot be used. Instead, blind rivets can be used for example.

One of the options is to fix the heat sink directly to the box. Since the power board may need to be replaced over time, it would be assembled while the heat sink is already in position. There are seven M3x3 spacers and a set of self-tapping screws, that all need to be tightly fixed. If this is not done properly, the PCB has too little contact with the heat sink and will overheat, causing malfunctioning and possible irreparable damage. Although the spacers can be glued to the power board or the heat sink, checking the quality of the fixation is a fairly inconceivable task.

Instead of fixing the aluminium sheet, three brackets are mounted into the box first. In this way the power board can be attached to the heat sink first, before it is put in place. This sub-assembly is fastened with three screws, after which the contact surface of the heat sink with the MOSFETs (the components that need to be cooled) can be checked before it is mounted in the box. The last four screws secure the sub-assembly to the brackets. Since the brackets are fastened with blind rivets, the power board cannot be unmounted from the outside.

Available sockets
As can be seen in figure 52, the available space in the regular box is limited. Where the design proposal of the regular box has three cigarette sockets, the final design only has two (which is also the amount

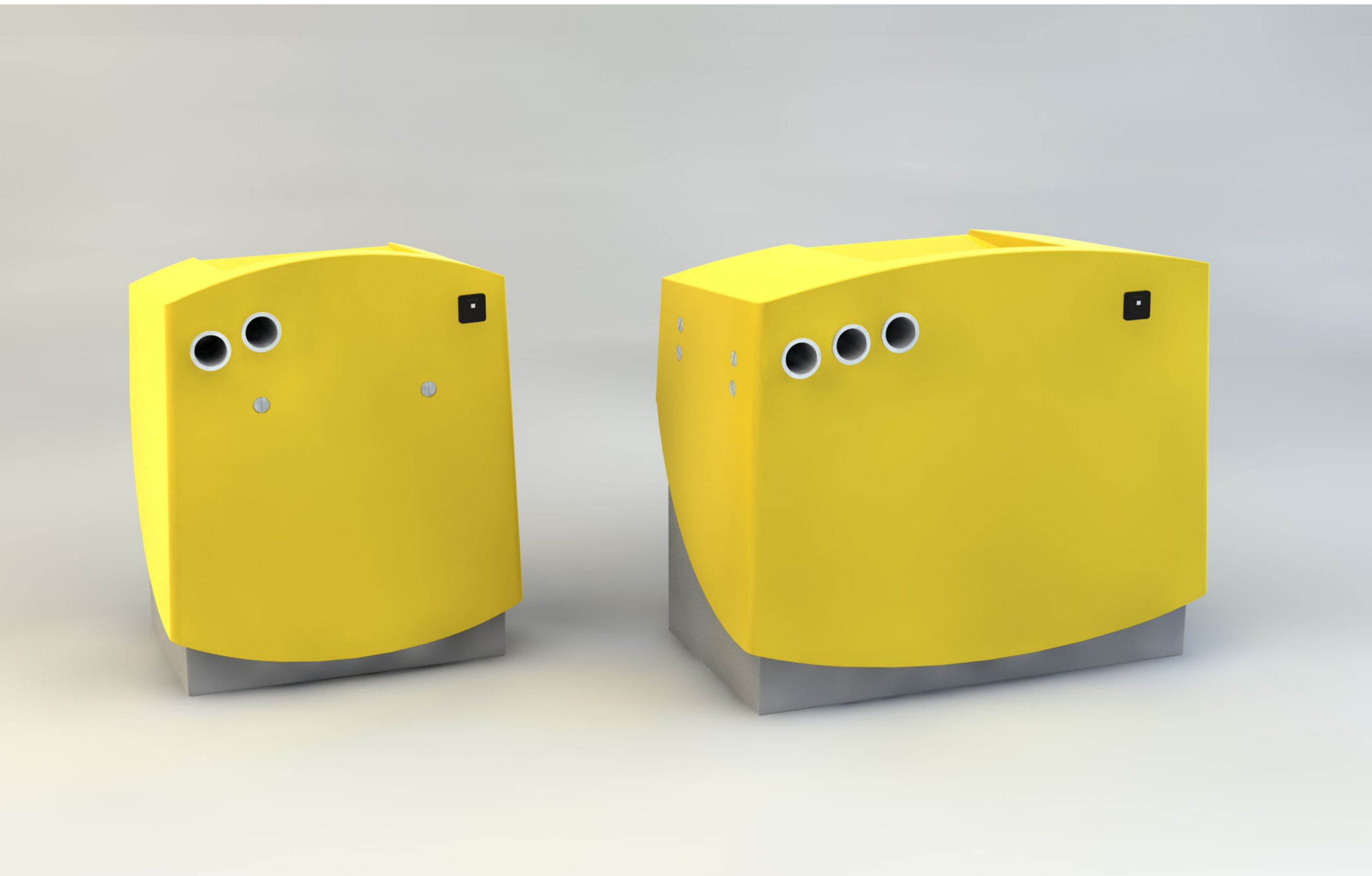


figure 49. The front view of the regular (left) and large (right) battery box

figure 50. Exploded view regular battery box

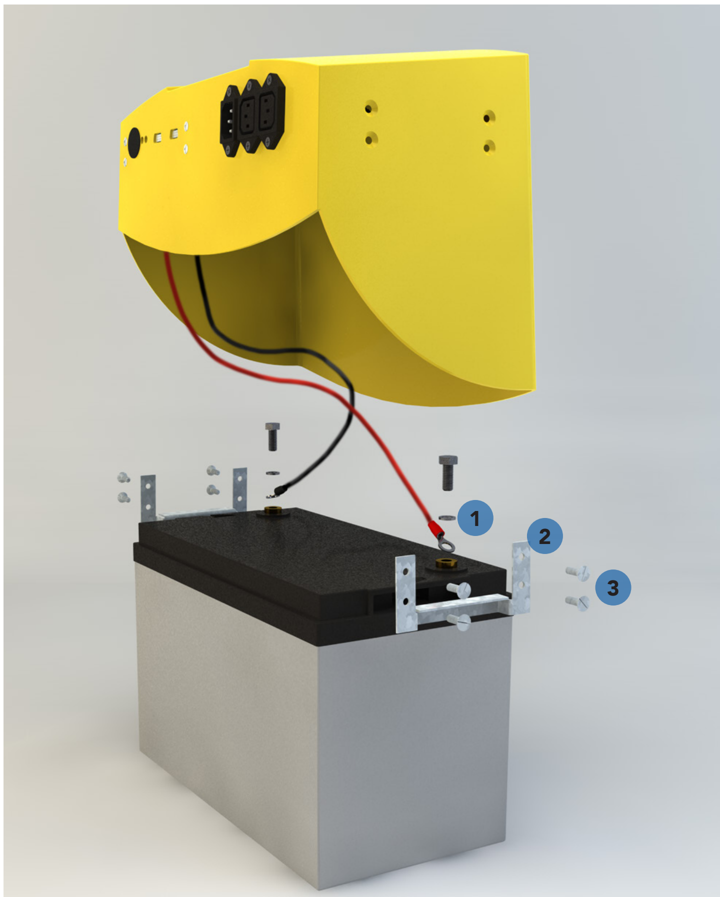


figure 51. Exploded view large battery box

of sockets in the current regular battery box). By providing the large battery box with three sockets, the difference in capacity is emphasized.

The USB sockets increase the amount of available sockets. Since a single PCB contains two USB sockets, both systems have two USB sockets. While these sockets can be used for charging a mobile phone or other small appliances, the cigarette sockets can be used more efficiently.

Position of the IEC sockets

The IEC sockets–used to receive the energy generated by the solar panel, power the lamp kit and connect the batteries of different Solar Home Systems within a household–were horizontally positioned in the design proposal. In that orientation the power board would at least obstruct the accessibility of one IEC socket. When placed vertically, this issue is resolved.

Wiring

The current battery box has a power board with all wires soldered to it. When the board needs to be replaced, all cables are too. If a single wire is broken (e.g. if a young, hungry gecko found its way in) a technician needs to reconnect them by stripping the insulation and taping them together, or replace the whole power board, which both are not the best thinkable solutions.

In order to allow small repairs of the individual components, the wires are provided with faston terminals. This allows all wires to be connected easily and replaced individually. Except the wires that connect the power board to the battery box (which have a ring terminal on one side), all wires have the same size and length.

Closing the box

The exploded views in figure 50 and figure 51 explain how the battery boxes can be closed after they are fully assembled. The first step is to connect the power board to the battery [1] and test the functioning. The box is configured as a core system by adjusting the piano switch (accessible from the back, figure 53) and attaching a test display and solar panel. If the display shows the box is charging and the green LED on the power board illuminates, the battery box is approved. In that case, the battery boxed can be closed, switched back in standby mode and stored.

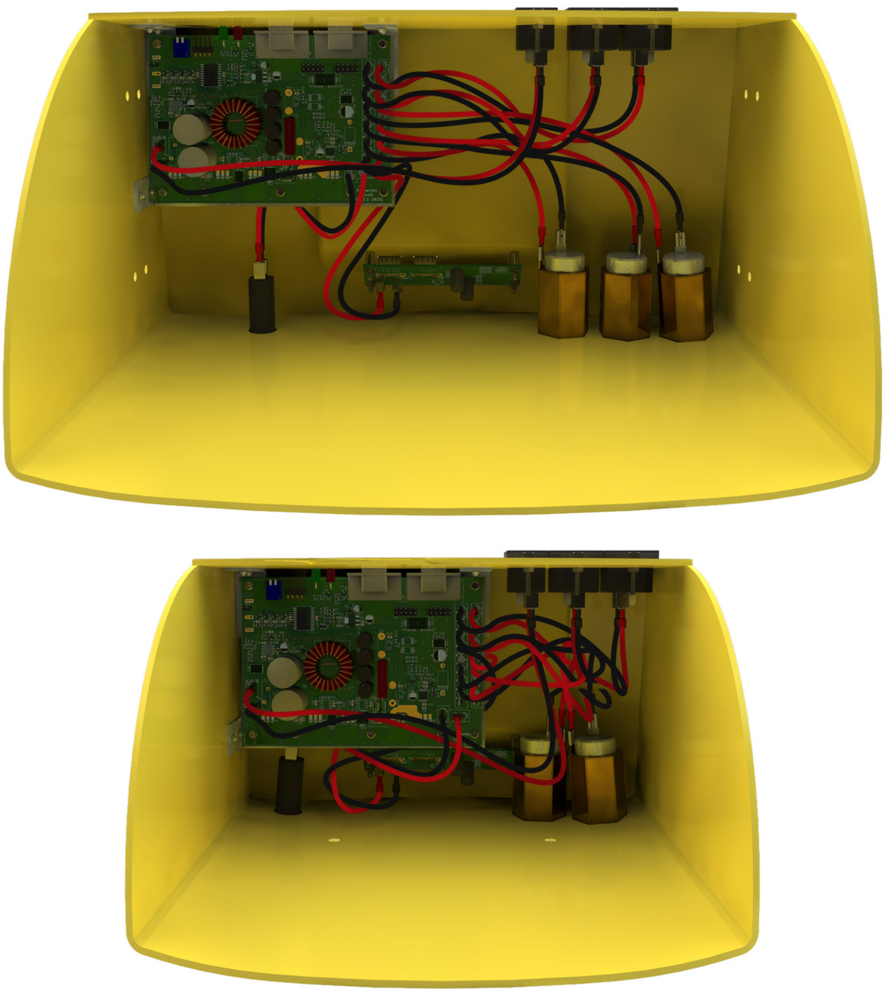


figure 52. Bottom view of the opened boxes (without the wiring to the battery).

There is a small difference in closing the regular or large battery box. The regular box can be directly mounted to the battery: with four countersunk bolts, the box can be attached to the battery [2]. For the large battery box, two brackets need to be placed in the battery's cavities first, after which the box is attached to the brackets with eight of the same bolts [2,3]. To prevent users from opening the box, the bolts should be covered with warranty seals.

Initially, the battery boxes would be provided with carrying ropes: two ropes on both sides of the box that allow a technician to move the box around and put it the preferred place of the customer's home. These ropes could be removed after installation, so that the boxes cannot be moved; or they could stay so that customers could move it around themselves: a desire of Kamworks' customers (Siebinga, 2016).

After evaluation, it is decided that the carrying ropes will not be included at all. Giving customers the possibility to lift and move the battery box is risky: with multiple wires (from the solar panel and display) attached to it, dropping the heavy battery box, or even moving it around carelessly, could easily damage the system. The technicians do not need the carrying ropes. The battery box will be transported in a cardboard box that protects the box from damaging during transport. During installation, this cardboard box can be moved close to the desired position in a customer's home, before getting the actual battery box out of its packaging. This can be done without the carrying ropes. Leaving them out gives the box a more solid and clean appearance.

4.3 Implementation

With the completion of the final design for both battery boxes, the first steps towards production can be taken.

4.3.1 Production

Most parts are imported or purchased in Cambodia. The brackets and the boxes will be produced in the workshop of Kamworks, while the power board and the USB board are custom parts that will be imported. These parts need extra attention to make the design ready for production.

Sheet metal

The brackets, made from galvanized steel, and the heat sink, made from aluminium, are produced in Sre Ampil. Sheet metal is widely available throughout Phnom Penh and its surroundings, while the required production steps can be performed with the tools that are available in the workshop. Since Kamworks is not able to invest high amounts of money in new

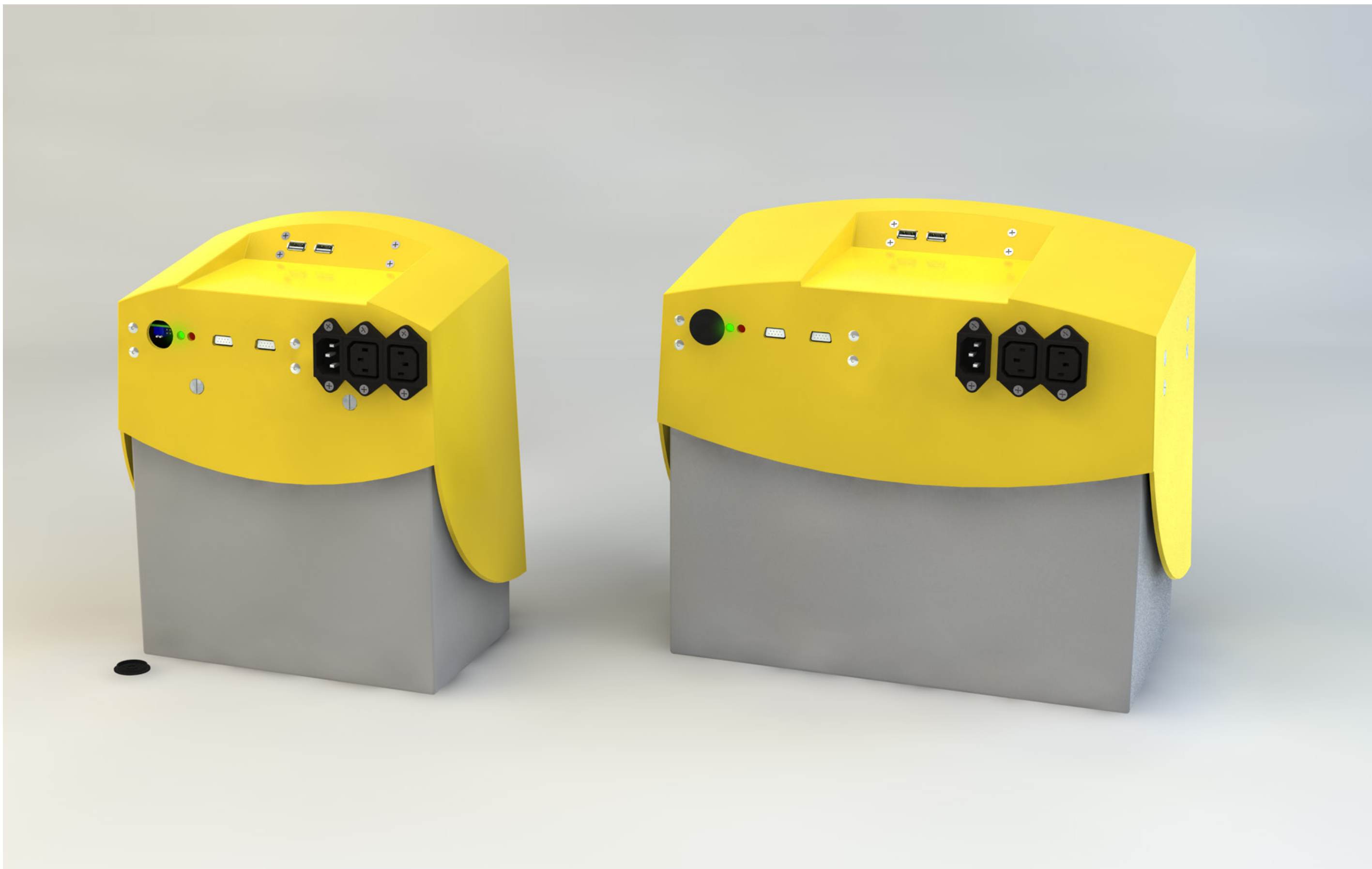


figure 53. The back of both boxes, with the opened lid at the regular box for access to the piano switch and 6-pin connector

production techniques or tools, improvisation and choosing low tech solutions is inevitable. In order to make the bends for the brackets, for example, an unused punch and die can be used (figure 55) in combination with Kamworks' sheet metal punch (figure 54). To make the bends, three millimetre of the die's top surface should be removed. This can be done by a local workshop that has a milling machine. This will cost approximately $30 (Kamworks, personal communication, January 25, 2017).

Battery boxes
As mentioned before, the battery boxes are produced through vacuum resin transfer moulding. The exact method is a simplification of the traditional VRTM process (Composite Integration ltd., 2008), based on Kamworks' previous experiences. A brief description is given below, supported by the images of figure 57. An elaborate description of the process can be found in appendix I.

A production mould for a single box consists of a positive and negative mould. The positive mould is made first. The shape of the product is converted into a solid block, with a flange around the eventual partition line of the mould. In order to make this block, the shape was divided in slices of six and twelve millimetres. The slices were cut out of MDF sheets, glued together and sanded [1]. The block is then finished with a layer of polyester putty and then is spray painted.

The positive mould is made by applying multiple layers of glass fibre and resin onto the plug [2]. To avoid the mould sticking to the plug, the plug is waxed before. When the fibreglass is hardened, the positive mould is separated from the plug and used as a basis for the negative mould.

The positive mould is covered with three millimetre foam: the thickness of the final product. Edges are smoothed and rubbers and inserts, needed for the vacuum and resin transfer, are applied [3]. Just like the block, this layer is waxed, after which multiple layers of glass fibre and resin are applied. When the fibreglass is hardened [4] and the foam is removed from the first mould, the two mould parts are ready to produce battery boxes.

The boxes are made by applying a gel coat in the moulds, followed by the right amount of glass fibre mats. The moulds are closed and resin is added. The end product is a battery box with a rough edge. By removing the edges, the box is finished.

PCBs
One battery box contains two PCBs: the power board and the USB board. They were developed by Kamworks' electronic engineers and will be produced in China. A pilot run of ten PCBs was ordered (figure 56). With minor adjustments of component types and configurations, the last errors were removed.

For the final product, the USB and power board will be printed on one PCB. When the PCB arrives in SA, it is separated by breaking the board along pre-made slots (appendix H), after which they are mounted in the box separately.


figure 54. The manual sheet metal punch in Kamworks' workshop


figure 55. Punch and die that can be recovered

4.3.2 Pilot

After the first battery boxes were produced, two prototypes were manufactured in order to perform a pilot (figure 58). Holes were cut, the electronics were assembled and a display was mounted into an electronic box. Through the network of Kamworks' Khmer employees, a customer was found that wanted to test the systems. The goal of the pilot was to test the collaboration of multiple systems, evaluate the data transmission of a combined system and analyse the performance of the electronics.

After some start-up problems (e.g. accidentally a rejected, used battery was installed that needed to be replaced after two days), the system was up and running. The first data showed promising results with an increased efficiency of the system (Kamworks, personal communication, February 2, 2016). These two battery boxes, the first of Kamworks' next generation Solar Home Systems, are still being tested so that the long term performance can also be evaluated.

The two solar panels that belong to the battery boxes were installed with a provisional mounting system, since the mounting system is yet to be developed. The next chapter is the start of this.

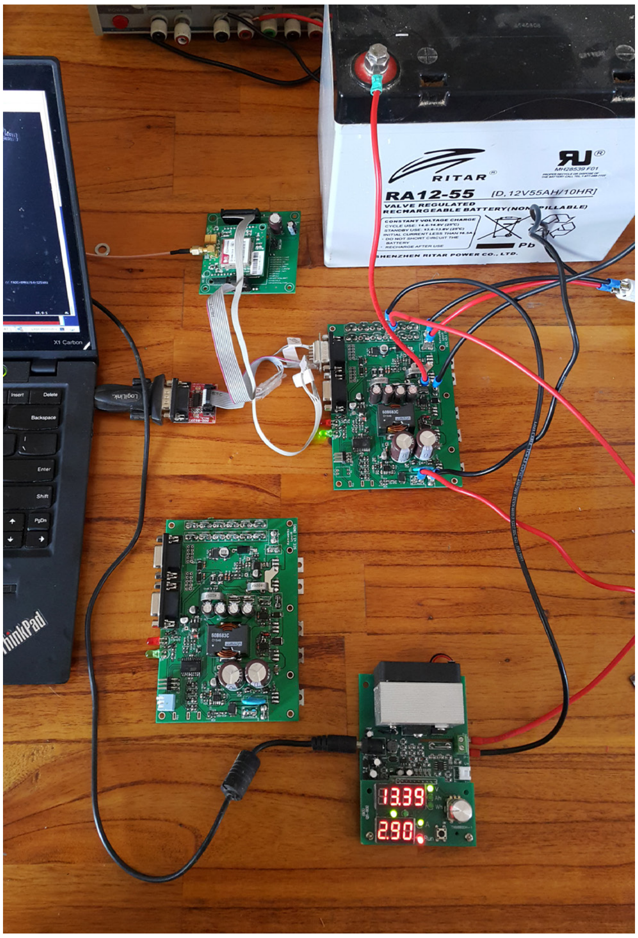


figure 56. First simulations with the new electronics

figure 57. Producing the battery boxes

figure 58. A brief overview of the pilot

4.4 Conclusions

Throughout this chapter the battery boxes were developed. Several changes and improvements resulted in a final design that is close to production and is currently tested by a user. An overview of the most significant improvements is given below.

Production costs

Looking at the whole SHS, the battery box is the part of the system that can impact the cost reduction the most (§2.3.4). The biggest cost reduction was realized by combining the power board with the charge controller. Other cost reductions were made by combining the PCBs in one print, using only one fibreglass part and removing the 4-wire connector from the design.

Excluding the costs for the accessories, the display board and SIM board (approximately $25), the production costs for the regular battery box would be $131,70 (appendix B), while the production costs for the redesign are estimated on $117,44 (appendix L). This means a cost reduction of 10,8%. For the large battery box the production costs drop from $188,20 to $144,75: a reduction of 23,1%.

Transportation

The current battery box is transported in a separate box than the battery, taking up a lot of empty space that needs to be transported. By enabling storage and transportation of the fully assembled battery box, a reduction in transportation volume was realized. The reduction in volume is an important step towards transportation by motorcycle instead of transport by TukTuk (§1.2.3, 3).

The two boxes of the current regular battery and battery box have a combined volume of 46,9 litre. With the new design, only one box of 26 litre is needed, reducing the transportation volume with 44,4%. For the large battery box, the total volume is reduced even more: a reduction of 55% (from 86,2 litre to 38,8 litre).

Besides making transportation easier, the reduction in the amount of boxes simplifies the logistics too. Currently, the battery and the box are labelled with unique codes before transportation. The codes are used to track the box and the battery in the SHS journey, link the SHS to the user and monitor the system's health and usage. By assembling the box to the battery before putting it into stock, only one unique code is needed per SHS (and thus per customer). This simplifies the registration and stock management.

Assembly

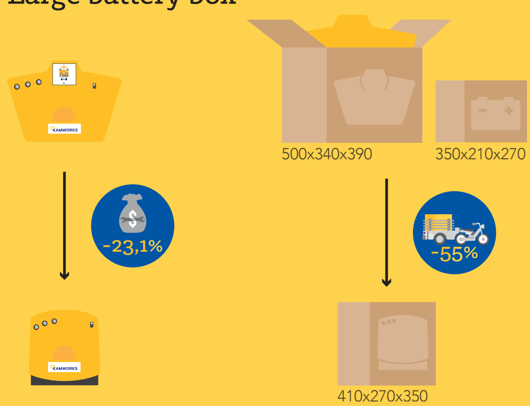
The total production time of the redesign is approximately two hours (§3.2.1); half of the four hours needed for the current box. This reduction is mainly achieved by only using one fibreglass part.

The production steps of the redesign are not very different than the design proposal. However, with the reconfiguration of the components, the sequence of assembling is not fixed anymore. This simplifies both the assembly and repairs.

An advantage from the redesign is that both production lines are very similar. The current design has bigger differences in production/assembly steps and unique parts. By having similar parts and production lines, the chance of production errors is reduced. Besides, it is more viable to optimize the layout of the workshop for the production line.

Regular battery box

Large battery box



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5.

5 Product analysis: Mounting System

The battery box was analysed and developed in the previous two chapters. The coming two chapters dedicated to the second part of the SHS: the mounting system. The mounting system is the supporting structure that positions a solar panel in the right angle and direction. It is placed on top of the roof, as shown in figure 59.

The (current) regular and large SHS both have a different solar panel as well as mounting system. One mounting system is capable of supporting a single solar panel. The goal of this project is to design a universal mounting system for the two solar panels that can support up to three panels. Although Siebinga also proposed a design for this part of the SHS, the lacking amount of research regarding her proposal, asks for a more critical attitude towards this part of her design proposal. The redesign should be compact, easy to install and easy to expand (§1.2.3). This chapter will analyse both the current mounting systems and the design proposal. The insights are summarized in a list of requirements and wishes.

The assemblies of the current mounting systems (without panel) are shown in figure 60. The physical properties of these mounting systems are analysed first. When the production and installation of both mounting systems are analysed separately, the differences between the systems are discussed.

figure 59. An installed solar panel of the large SHS (© Kamworks)

5.1 Regular mounting system

The regular mounting system is produced in SA. They are produced in small batches (5-20) and are bundled (unassembled) before they are stored. The mounting system is assembled at the customer's home, during the installation of the SHS.

5.1.1 Production

The production of the parts was observed and documented (figure 63). Thereafter, the design was evaluated with the SA staff and the design team.

The regular mounting system exists out of six unique parts (ten parts in total, fasteners excluded). For these parts, five different profiles/sheets are needed: the supporting rod is made from a steel profile and is spray painted to prevent rusting, while the rest is made from galvanized steel. Although the materials are widely available, collecting a high variety of specific material sizes make the stock supply challenging.

Generally only three production steps are performed: cutting, forming and drilling/punching. The limited amount of steps make the production easy to perform. For bending the two parts forming the mounting clamps, two punch and die sets are used. The sheet metal is cut with a manual corner notcher (figure 62), after which they are formed with a small hydraulic press (figure 61).

The profiles for the mounting pole are cut with a chopsaw. When needed, an angle grinder is used for finishing rough edges. Small holes, from three to seven millimetre, are drilled with a regular or pillar drill. For bigger holes, the manual sheet metal punch (figure 54, p.64) is used.

Holes are misplaced sometimes resulting in the solar panel not fitting on the mounting system (Kamworks, personal communication, November 8, 2016). This is mostly discovered during installation and solved by the technicians drilling additional holes. Misplaced holes can also cause the panel being placed in an inefficient angle. This problem is rarely identified by the installers and thus left unsolved. This lowers the performance of the solar panel and may cause customer complaints.

5.1.2 Installation

Nearly all traditional Khmer houses are built with a similar wooden frame (figure 64). In order to mount the solar panel on the roof, the mounting systems are attached to this frame. The regular mounting system is usually positioned at the top ridge of the roof. The

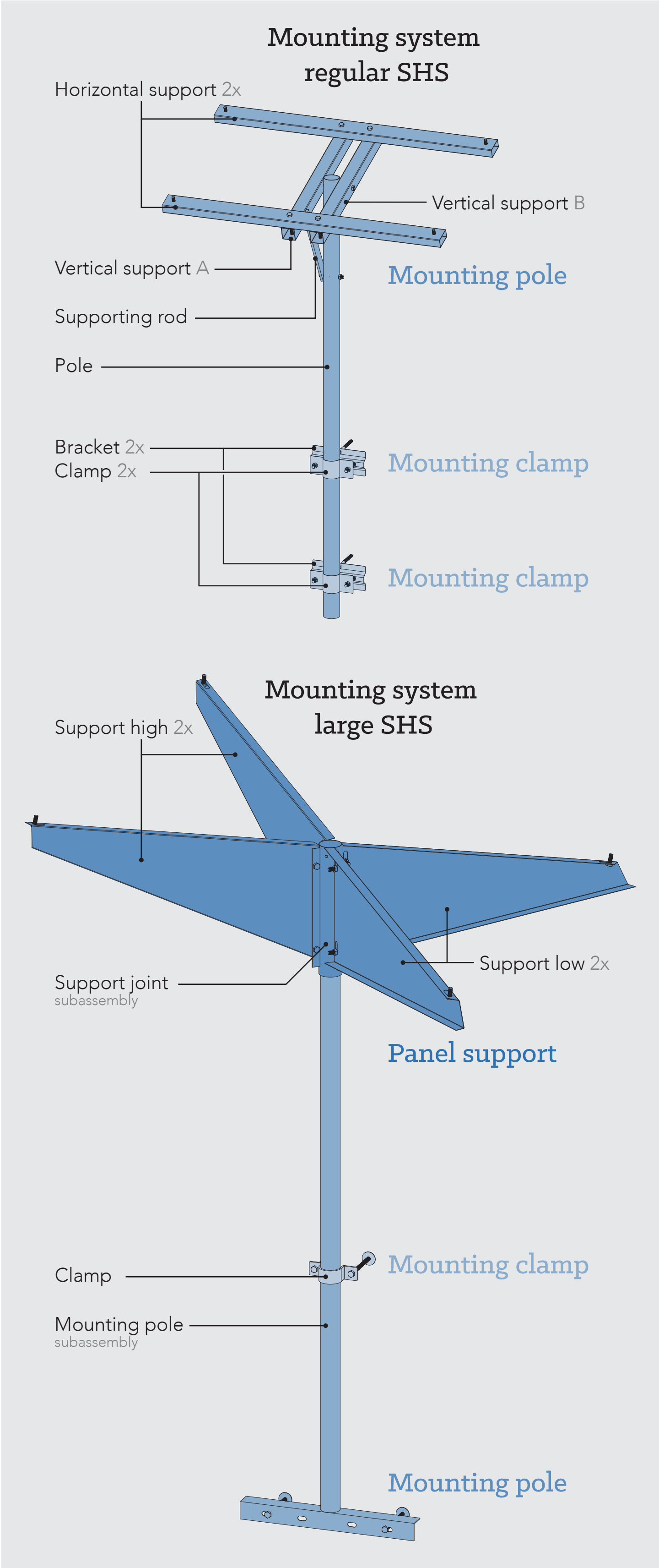

figure 60. The regular and large mounting system

installation steps, obtained through observations, are visualized in figure 65.

The first step of the installation is assembling the mounting pole [A]. The mounting pole can be assembled in any sequence as long as the solar panel is mounted last. The varying fasteners, however, all have a specific position. Assembling the mounting pole can be done within 4 minutes (observation, November 1, 2016).

Next, a hole is made in the roof and the brackets are mounted on a pole of the wooden frame of the house [B]. Depending on the type of roof, an angle cutter, a drill and/or cutting pliers are used to make the hole. These tools are powered by an inverter connected to a car battery (note: one of the conditions for the warranty is that customers cannot use an inverter themselves). When two technicians do the installation, this step is performed while the mounting pole is assembled. It takes about 10 minutes to complete this step (observation, December 16, 2016).

The next two steps [C, D] are performed simultaneously. One technician is climbing the roof with the assembled mounting pole, while the other technician goes inside. The technician on the roof will face the solar panel to the south (using a compass) and hold it in place, making sure the supporting rod and solar panel do not get damaged or damage the roof. The technician inside pulls the solar cable through the hole and will tighten the clamps to fix the mounting system.

When the mounting system is fixed, the hole in the roof is closed [E]. Currently this is done with plastic bags and cement: two materials that can always be found around the house (figure 66).

5.1.3 Pros and cons

After the observations of the production process and installations, combined with the evaluation with the design team, several strengths and weaknesses were identified.

Strengths of the design

› Each part can be produced within a few, simple production steps. With the limited amount of space in the workshop, the production of multiple simple parts can be executed more efficient than complex parts. Moreover, the simple parts make production errors unlikely.

› Except for the pole, all parts can be mounted the other way around without affecting the assembly. The technicians can therefore quickly assemble a mounting system, without making mistakes.

› Because all parts are straight beams or small in size, the regular mounting system can be stored and transported compactly.

› Since the mounting system can be produced in-house, the stock and production of the mounting system can be controlled more easily. Only raw materials (and batches of fasteners) need to be purchased.

› The small solar panel is lightweight and the assembled mounting pole is relatively easy to carry. This makes carrying it up the roof less dangerous.

figure 61. Kamworks' hydraulic press

figure 62. Kamworks' manual corner notcher

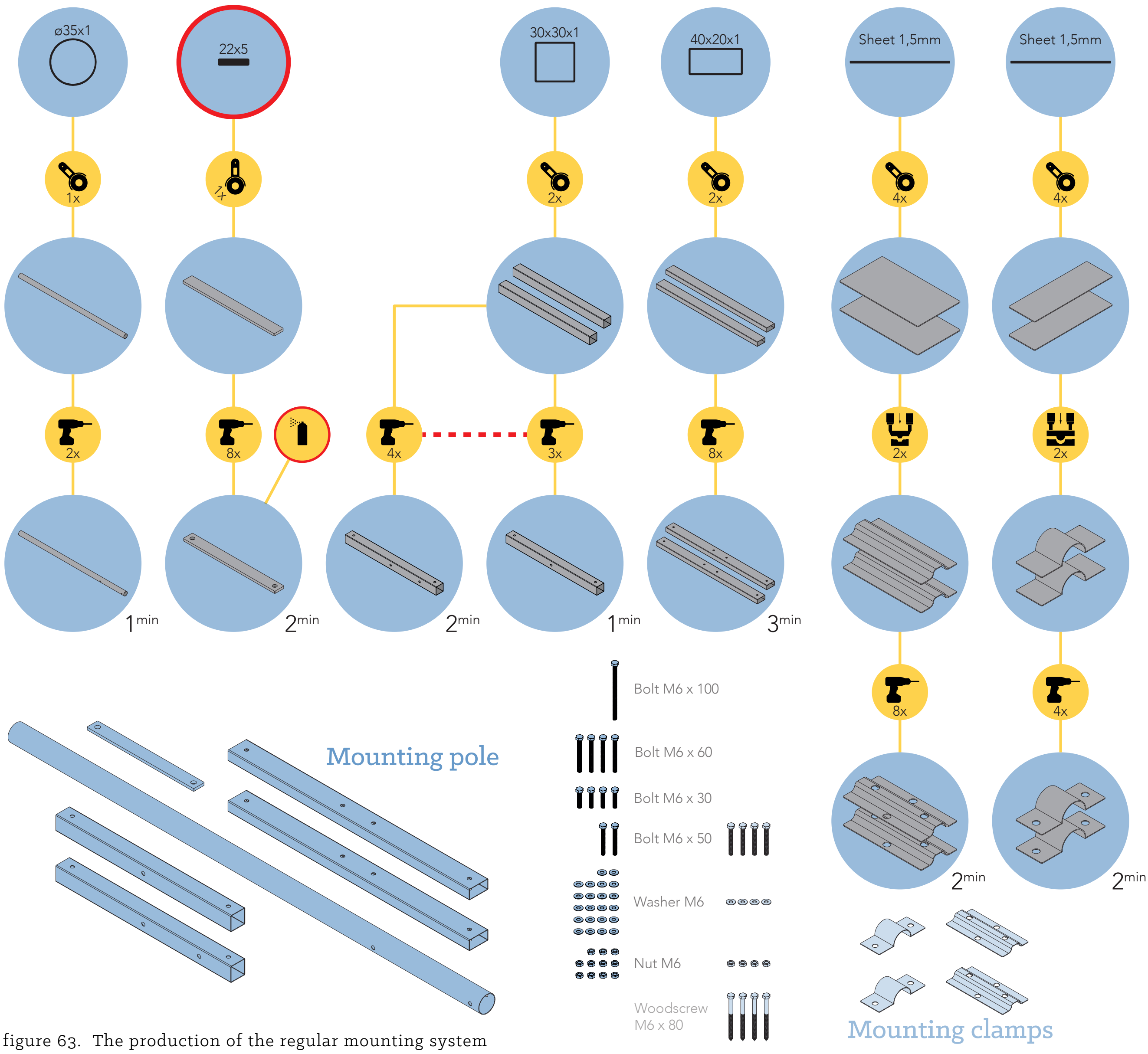

figure 63. The production of the regular mounting system

figure 64. Khmer house (in construction)

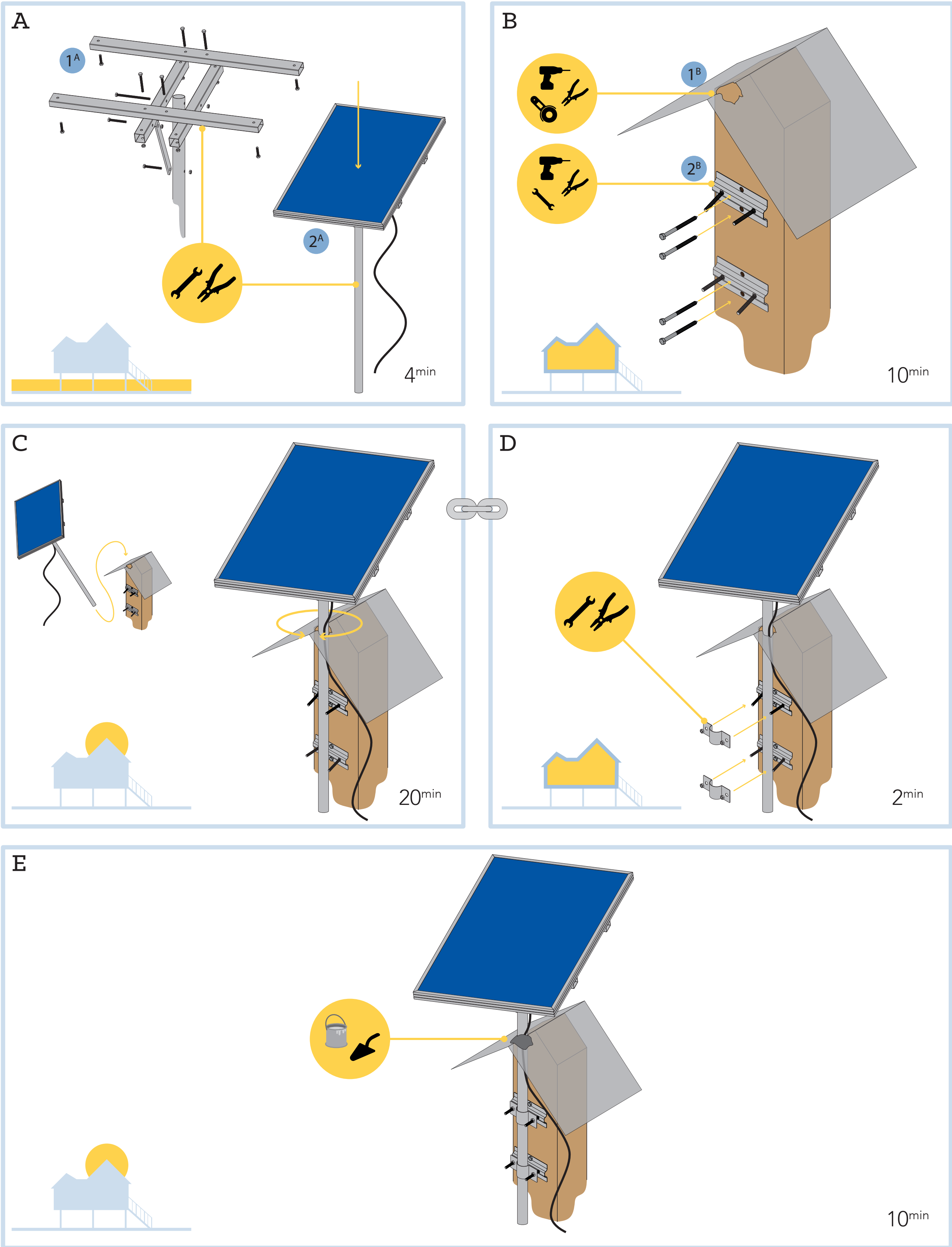

figure 65. Assembly and installation steps of the regular mounting system

figure 66. A Kamworks technician making cement

Weaknesses of the design

- There is a relatively large variety in profiles/sheets and fasteners, compared to the simplicity of the design and the total amount of parts. Less variety would make the stock supply easier and more reliable.
- There is no consistency and precision in drilling the holes. Some holes are drilled by hand, some are drilled with the column drill and some are punched. Without consistency, the position of the holes are vulnerable for deviation.
- The angle of the solar panel is determined by the distances between drilled holes on the mounting pole, the supporting rod and vertical support.
- The vertical supports, support A and support B, differ by one hole only. It happens that two A (or B) supports are bundled instead of one of each. Avoiding minor differences can prevent packing the wrong parts.
- One of the goals for the redesign is that one technician can install the system. Although a customer can help when needed, step C and D (figure 65) would be hard to execute by a single technician.

5.2 Large mounting system

Contrary to the production of the regular mounting system, the mounting system for the large SHS is being produced in a factory in Phnom Penh. Large batches (100+) are produced at a time, after which they are picked up and stored in SA. Subsequently, smaller batches are brought to Kampong Chhnang. Just like the regular mounting system, the large mounting system is transported unassembled and assembled during the installation of the SHS.

5.2.1 Production

The production of the regular mounting system could be observed, but, as sales rates are low, the large mounting system is not being produced (at the moment), due to having a sufficient amount in stock (figure 69). To obtain an overview of the production, the factory where the mounting system used to be produced was visited. The design was evaluated with the factory workers, production steps were explained and production times were estimated (figure 67).

The large mounting system is made out of five unique parts and sub-assemblies (seven in part count, fasteners excluded). They are made from a variety of steel profiles and sheets. The parts are produced through a combination of large, precise machinery and (imprecise) handicraft (observation, December 13, 2016).

The supports are made from 1,5mm steel. The outline is drawn on the sheet metal by hand first. Then, a hydraulic metal shear (figure 71), puncher and press brake (figure 72) are used to respectively cut the outline, make slotted holes and bend the edges.

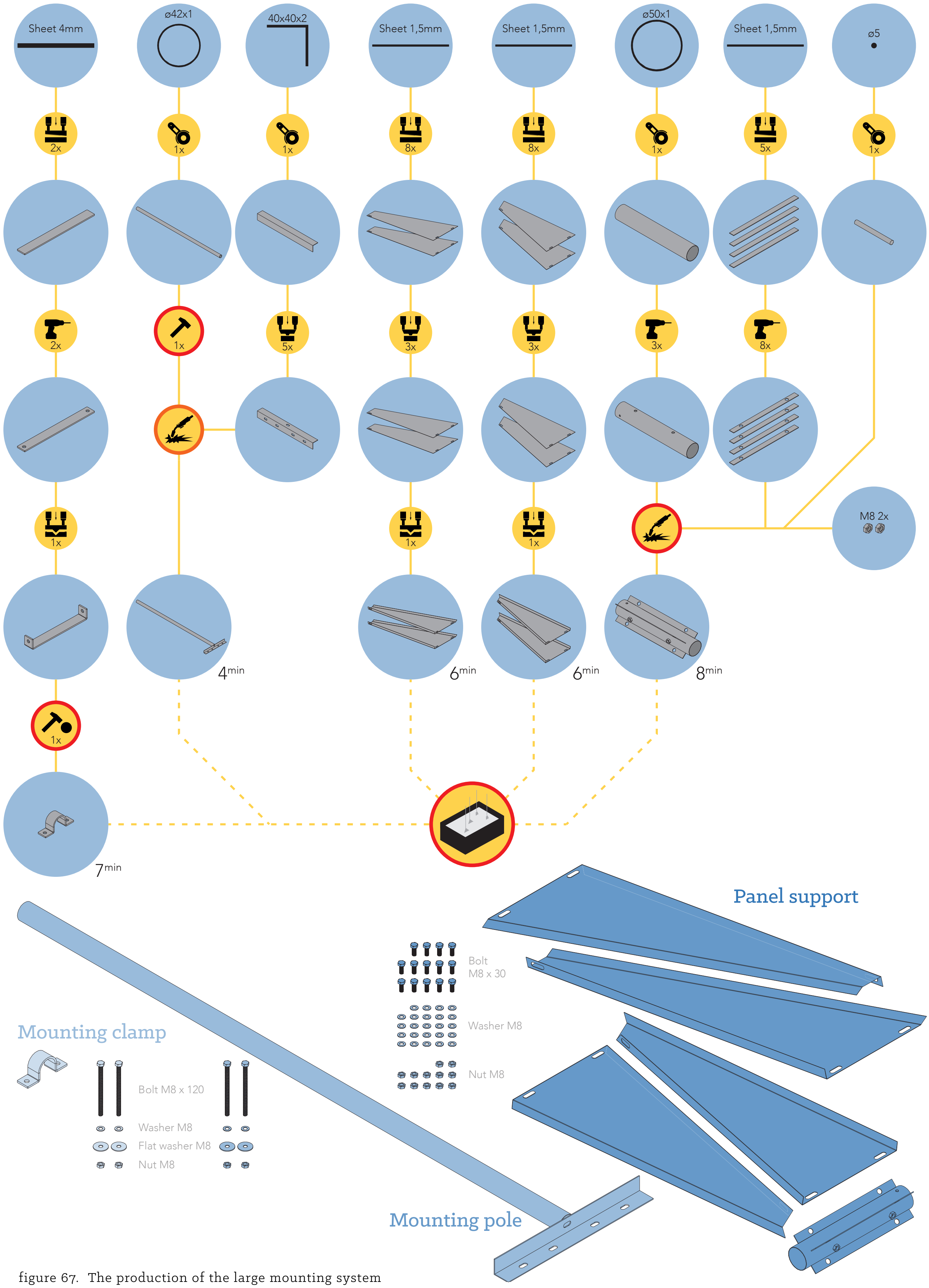

figure 67. The production of the large mounting system

In contrast to the supports, the clamp and the support joint are mainly hand-crafted. The first production steps of the clamp (cutting the four millimetre steel sheet and bending the 90˚ bends) are done by machinery, but eventually a hammer is used to create the round shape. The flanges of the support joint are inaccurately positioned, while the welding is ragged. These procedures result in two parts that look like they are produced without care and precision (figure 68).

The 'finished' mounting systems need to be picked up from Phnom Penh by a Kamworks employee. Then, they are brought to a factory in Sihanoukville (approximately five hours south of Phnom Penh) for galvanization. Galvanization is needed because of the amount of welding (of the support joint and mounting pole) and the thickness/production method of the clamp. In total, the process of picking up the products can take up to one week, depending on the speed of the galvanization factory. Drips from galvanization are not removed and contribute to the poor appearance of the products.

5.2.2 Installation

Multiple installations were observed so that differences with the installation of the regular mounting system could be identified. An overview of the installation steps can be found in figure 70.

The first installation step is assembling the panel support [A]. All connections are made with the same bolts. Two of them are placed in the welded nuts of the support joint and will be tightened later on. The supports have a lot of tolerance and can be

figure 68. Uncarefully finished parts

figure 69. A part of the large mounting systems in stock (Sre Ampil)

figure 71. The hydraulic shear in the Phnom Penh factory

figure 72. The hydraulic press brake in the Phnom Penh factory

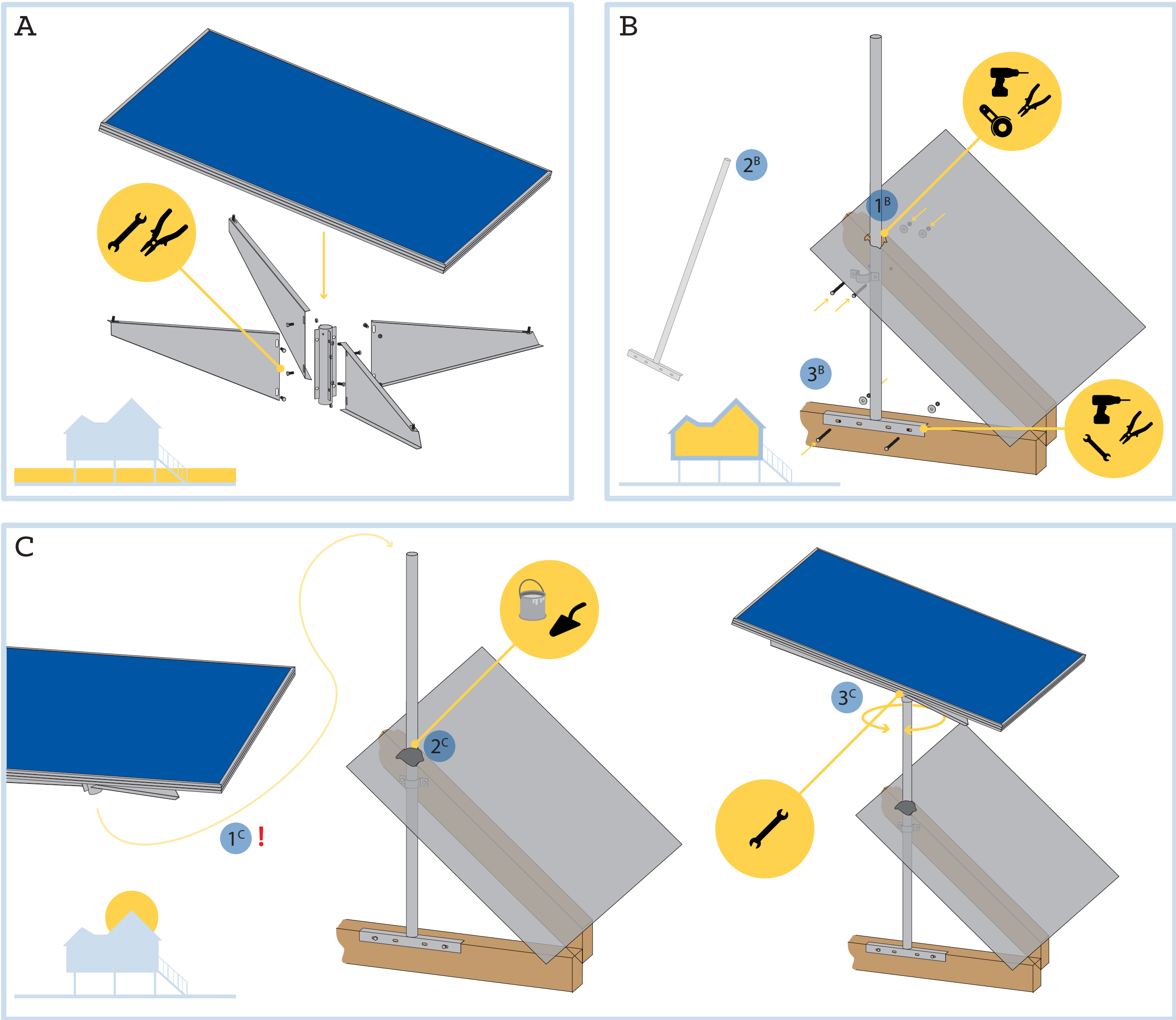

figure 70. Assembly and installation steps large mounting system

assembled in a random sequence, as long as the two front- and back panels are assembled the right way. Assembling the mounting pole can be done within 3 minutes (observation, November 1, 2016).

The large mounting system should be mounted on the side of the roof, since it needs to be attached to a horizontal and diagonal beam (figure 75). A hole is made in the roof, after which the mounting pole and the clamp are fixed [B]. Also with the large mounting system, this step takes about 10 minutes (observation, September 12, 2016).

The last step [C] is performed by two technicians. Before the panel is placed, the hole in the roof is closed by one technician. It is difficult to get the panel up on the roof because of the panel's weight (20kg) and the design of the panel support. The panel is carried up the roof by two technicians: one is pulling a rope tied to the panel support, while the other technician takes the panel and pushes it up the ladder (figure 73). After this, the solar panel, with panel support, has to be placed on the pole, which requires precise handling (figure 74). When the panel is placed on the pole, it is pointed south and secured with the two bolts on the support joint. Placing the large solar panel is a dangerous activity because of the weight, the required precision and the position of the mounting system (although the side of the roof is lower than the top ridge, it is harder to reach because of the roof's overhang).

figure 75. Making a hole in the roof and mounting the pole

figure 73. Getting the panel with support on the roof

figure 74. Placing the panel support on the pole

5.2.3 Pros and cons

Also for the large mounting system it is possible to list strengths and weaknesses based on the acquired information.

Strengths of the design

› The bolts for the panel support are all the same. The bolts for the clamp and mounting pole are much larger, making distinction easy.

› The mounting pole can be fixed from inside the house, without climbing on the roof first. By doing so, the technicians have to climb up the roof one time during installation. Moreover, the fixed mounting pole allow the technicians to easily position the solar panel south.

Weaknesses of the design

› Because of the welded mounting pole and the supports, the large mounting system requires a lot more transportation space compared to the regular mounting system. With the addition of the large solar panel, the total package becomes fairly impossible to transport by motorcycle.

› The high tolerances of the mounting system can cause the support to be unstable when not all fasteners are tightened.

› The front and back supports seem similar and can, because of the high tolerances, be mounted in a wrong way easily. This can cause the panel to be positioned in an angle that is not optimal.

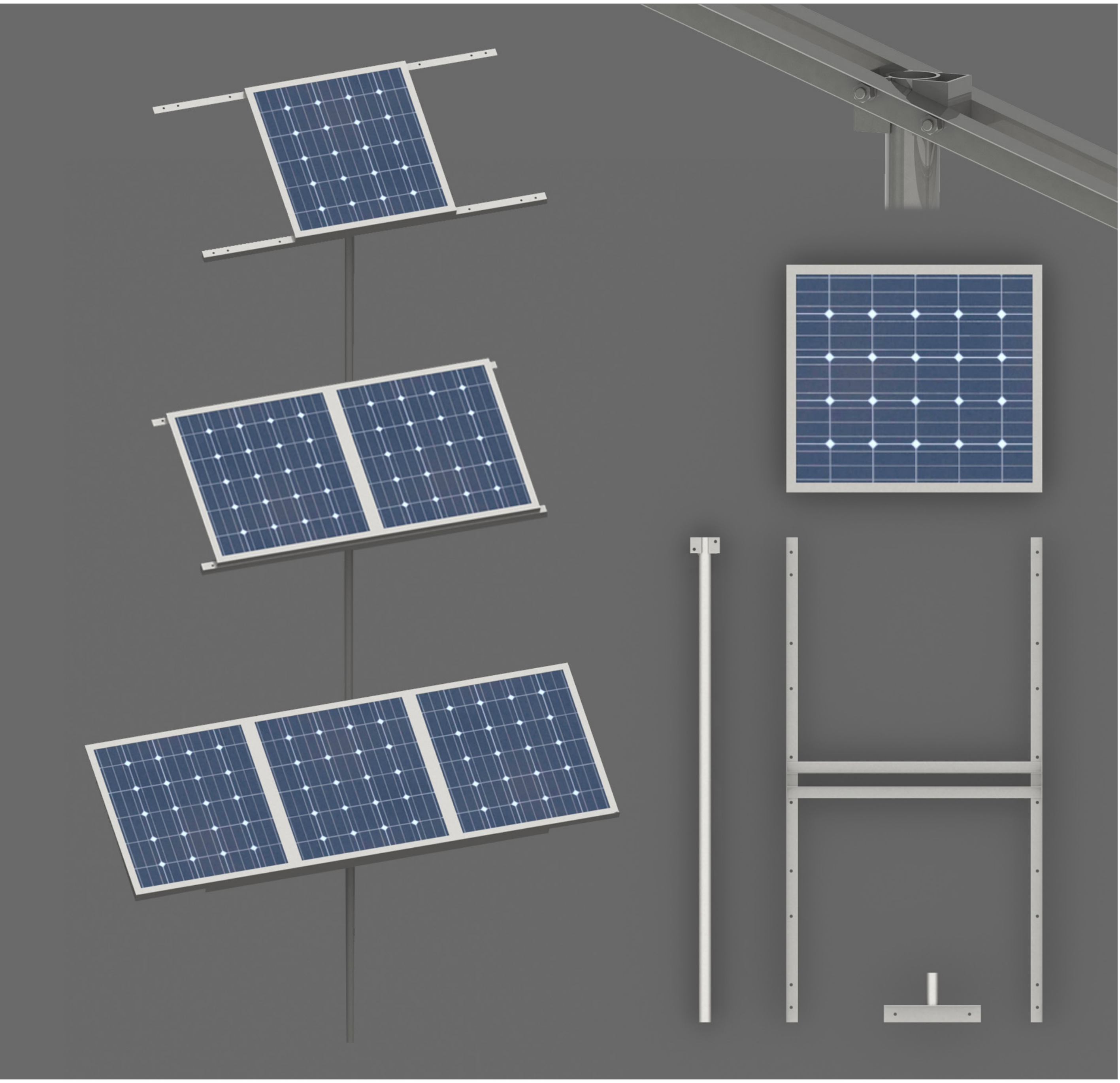

figure 76. The mounting system of Siebinga's design proposal

› The contrast in the use of heavy machinery and handicraft, results into an end product with a poor finish.
› Due to the thickness of the clamp's material and the amount of required welding, galvanization is inevitable. The price for galvanizing is high in Cambodia (1USD per kg, Kamworks, personal communication, December 19, 2016). Besides, factories for galvanization are far away and increase the delivery time when no stock is available.
› The welding is done without care or precision, which lowers the qualitative appearance of the product.

5.3 Mounting system V3

Before the mounting systems are compared and discussed, the design proposal for the mounting system is introduced (figure 76). The design proposal contains elements from both the regular and large mounting system. Little research was done to get to this proposal and its viability has not been proven through a prototype or simulations. Based on the research that was done in this project and an extensive evaluation of this design, some remarks can be made.

The mounting pole of the design proposal is based on the current large mounting pole. The mounting pole is separated in two parts: the pole and the foot. The support that is separated from the bottom can be mounted in the house first. When the pole is placed through the roof, supporting on the base, it can be pointed south and fixed inside the house with, supposedly, an additional clamp (that is not included in the design proposal). Siebinga mentions that the mounting system only consists out of three welded parts, but without a clamp, the pole cannot be locked facing south. Without the use of a clamp, the mounting system will be extremely unstable.

The motivation behind the separation of the mounting pole and its foot is not specified in Siebinga's thesis. It may be perceived as an attempt to enable a more compact transport, but the welded panel support contradicts to this idea. Another reason for the separation could be that the panel support is bolted to the pole first, and then placed on its foot from the outside. The current large mounting system, however, shows that these kind of precise actions are dangerous to perform on the roof. Especially with the design proposal's dimensions–both the pole and the panel support have a width of 1,5 meter–this becomes very risky.

Where the regular mounting system uses a supporting rod to place the panels at the desired angle, the design proposal uses two U-profiles, welded to the mounting pole. To get the panel in the right angle, precision is needed. U-profiles are very hard to find in the Cambodian factories however. An alternative could be to fold the profiles from sheet metal or to use a rectangular tube that fits around the pole. However, early prototypes turned out that connecting the vertical supports to the pole without lateral supports is not strong enough to support multiple panels. Especially when more panels are attached the mounting system will break easily.

The parts of the design proposal are mainly made of L-profiles. The availability of L-profiles is not an issue in Phnom Penh, but they are not galvanized (figure 77). With all the required welding, galvanization, or another surface treatment, is inevitable. As stated before, galvanization is expensive. L-profiles that do not rust, like stainless steel or aluminium, are available as well, but they would increase the material price of the product.

A last remark can be made regarding material use. When a system is not expanded, two meters of material is left unused. When the design proposal, that can only support regular panels, would be adjusted to make it suitable for both solar panels, the material use will increase.

Without an elaborate explanation of the design proposal, it seems impossible that this mounting system can be produced at low cost, installed safely, transported efficiently and/or function properly. With so many remarks and uncertainties, the design proposal will not function as a starting point for further development.

5.4 Discussion

In the previous sections, both mounting systems that are currently used and the design proposal were analysed and evaluated. With the doubtful feasibility of the design proposal, the regular and large mounting system will be discussed here.

Structural support

The regular and large mounting system differ in their (structural) way of supporting the solar panel. The main reason for this is the size and the weigh of the panels.

Since the regular panel is small (50x80 cm) and lightweight (5kg) the design is simple with little material use. When a bigger (and heavier) panel would be mounted on the regular mounting systems, problems may occur when the wind picks up or the weight of the panel is not centred: the supporting rod would stop the panel from rotating forward and backward, but connection of the supports with the mounting pole is not strong enough to withhold rotations to the left and right.

Because of the size (110x140 cm) and weight (20 kg) of the large panel, the support is X-shaped. In this way the mounting system has rigidity in all directions.

With production and easy install in mind, the simplicity of the regular system is preferred, but the geometry of the large mounting system is more suitable for carrying the weight of multiple panels. Based on the panels that are going to be used, a balance in simplicity and rigidity should be found.

Installation
The regular solar panel is mounted onto the mounting pole before it is put through the roof from the outside. The mounting pole needs to be kept in position while its mounted inside.

The pole from the large mounting system is first fixed from the inside before the panel is placed onto it. This makes the installation steps easier. However, placing the large panel on the roof still seems to be more dangerous, caused by the required precision, the weight and size.

Eventually the difference between putting the mounting pole through the roof from the inside or the outside (with or without panel) will not be that relevant. The tolerance and complexity of the installation steps on the roof should be taken into account to avoid dangerous situations.

Production
The regular mounting system is produced in-house and the large mounting system is produced in a factory in Phnom Penh. The products from the factory do not have a higher quality than the in-house production. The only advantage of the factory is that they have more metalworking tools. The disadvantages are the dependency and a higher production price. In-house production is possible when the need for big sheet metal parts, or parts that require a lot of welding is eliminated. In-house production is preferred since a reliable supply chain and cost reductions are important elements in this project.

Avoiding outsourcing does not mean that production processes should be fully eliminated. Facilities that are not available to Kamworks yet, might become available in the future. Without the possibility of investing in new machines and the goal of designing a SHS that can be implemented on the short term, however, the facilities and tools that are currently available at the SA workshop will influence the design process.

Where both the regular and large mounting systems have their pros and cons, the design proposal shows that problems occur when combining the wrong elements. In the next chapter, the design of the mounting system will be fully reconsidered to come up with a suitable solution.

figure 77. Steel rods and L-profiles in a regular metal shop in Phnom Penh.

5.5 Conclusions

The redesign of the mounting system should be suitable for both the regular and large solar panel. The transportation size and ease of installation (of expansions especially) are the main topics that need to be improved: they contribute to making clean energy more accessible to rural Cambodia. This chapter showed that structural stability, material use and simplicity are important factors, that need to be taken into account throughout the development of the mounting system.

Assuming that the redesign will not be radically different to the current mounting systems, the following requirements and wishes can be listed:

5.5.1 Requirements

Modularity & Expandability

› The mounting system can support the regular, as well as the large solar panel.
› The mounting system (+possible expansion systems) can support up to three panels, in any configuration of regular and large panels.

Production

› The mounting system can be produced with in-house facilities. §5.4
› The used materials do not rust or are protected against rust.
› There is no need for galvanization. §5.2.1

Assembly & Installation

› There are no installation steps that require two technicians. §1.2.3
› The mounting system allows orienting the panel 360° around the vertical axis. §2.3.3
› If the panel is oriented from inside the house, the mounting pole should indicate what direction the panel is facing.
› The mounting system can be fixed in a certain direction.

Performance

› The new solar panels have a higher Wp than the current solar panels. §2.4.3
› The mounting system places the solar panel at a 12,35° angle, with a maximum deviation of 2° in both directions. §2.4.4
› When multiple panels are installed, they do not overshadow each other.
› It is possible for users to clean their solar panel(s). §2.4.3
› The mounting system can support two times the total weight of three panels (SF=2).

5.5.2 Wishes

› There is no superfluous material use when a SHS is not expanded.
› The mounting system is recognizable as a Kamworks SHS. Kamworks
› There is little variety in materials and profiles. §5.1.1
› The parts can be mounted the other way around without affecting the assembly. §5.1.1
› The transportation size of the mounting system and solar panel is minimized. §2.3.5
› An expansion panel can be easily attached to the mounting system.

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6.

6 The mounting system

The battery boxes were developed based on the design proposal, but the mounting system will not be. The requirements and wishes on the previous page form a basis for the development of the mounting system. Reducing the transportation size and simplifying the installation will contribute to the accessibility of the SHS the most.

The development will start with an idea generation. The ideas will not be discussed specifically yet, but several considerations are explained. Based on the insights of the research, some decisions will be made during this phase. This will create understanding of the selected ideas that are developed into concepts.

After a concept is selected, the development is continued. Several prototypes were made to test (sub-)solutions, which contributed to the final design. After the design is explained, the final design is introduced. An overview of improvements will conclude this chapter.

Several criteria are taken into account throughout the development of the mounting system. They will influence the decisions that are made during the design process.

Modularity
One of the goals is to design a universal mounting system. This means that it can support both the regular or large solar panel. Parts may slightly vary per panel, but with expandability in mind, the need for two different mounting systems should be prevented.

Expandability
It is preferred that the mounting system can support up to three solar panels. Another option could be that a first mounting system is installed by a technician, after which a customer can replicate the installation when a system is expanded. When the mounting system can support multiple panels, it can be any configuration of large and/or small solar panels. Assuming the first panel is installed by a technician and expansions by the user, the design should especially allow easy installation of expansions.

Transportation
With reducing the size of the mounting system (and solar panels), it will be easier to transport the SHS. Especially an expansion SHS should be compact, since it will be transported by the customer. For the core system the transportation size can be slightly bigger, where the motorcycles of technicians can be provided with (customized) luggage carriers.

Availability
For a reliable production of the mounting systems, the availability of materials (on the local market) is of great importance, since the whole mounting system is locally produced.

Safety
There are several safety aspects relevant to the mounting system. On the one hand, the solar panels

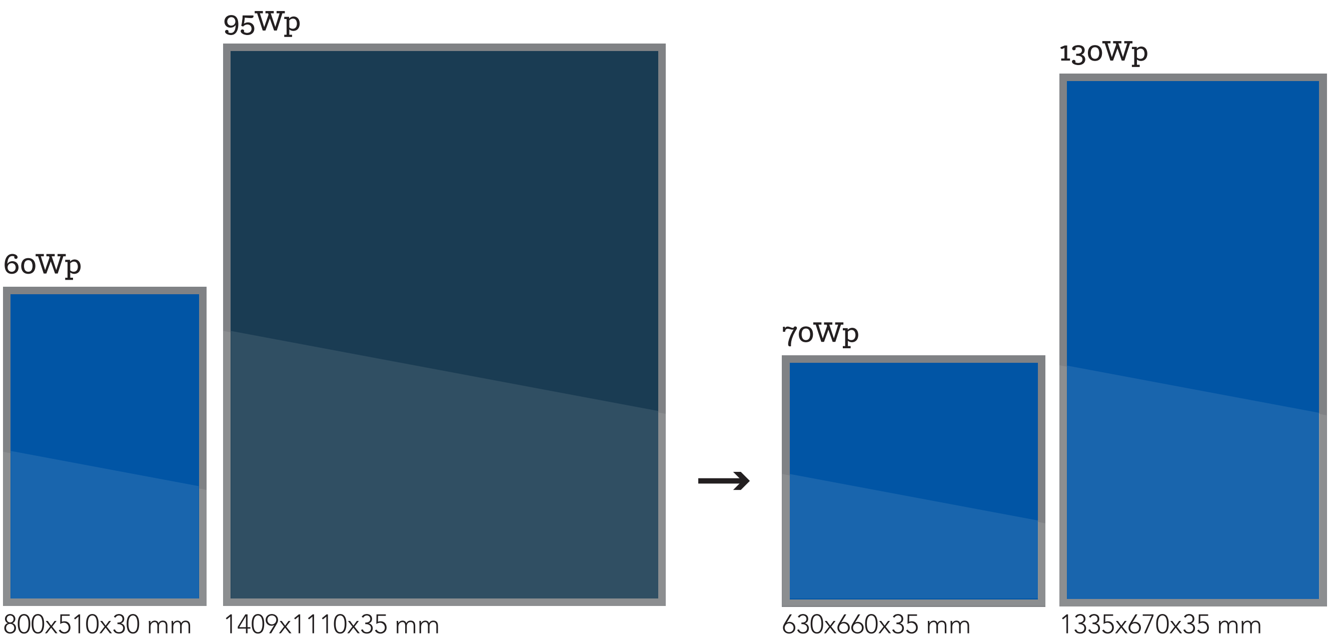


figure 78. The current solar panels (left) and the new solar panels (right)

should be secured on the roof without having the chance of falling of. On the other hand, the installation steps should be safe. This is especially relevant as an expansion can and should be, self-installed. During the research, it turned out that users already install their own solar energy systems (§2.2.2), showing the viability of self-installation.

6.1 Idea generation

Many solar panel sizes are available and they can be mounted in or around the house. For the idea generation this would mean a broad range of possibilities. In order to guide the design process, some decisions were made before ideas were generated. After the idea generation (figure 80), three ideas were selected that appear most viable to the earlier described criteria.

6.1.1 New solar panels

Solar panels with a higher Wp are needed (§2.4.3). To respond to the problem of the battery slowly running out of energy due to too little energy output, the electronic engineers redetermined the ratio between the capacity of the battery and the required Wp of the panel (Photovoltaic-software, 2016). Instead of the 60Wp regular solar panel, a 70Wp panel will be used, while the large 95Wp panel is replaced by a 130Wp panel.

The 95Wp is an amorphous solar PV panel. Although this type of panel is cheap, it also needs a large projection surface to generate electricity (Energy informative, 2016). Sticking to the same technology would mean an even larger (and heavier) solar panel, making the installation and transportation of a SHS difficult, if not impossible. Changing to the same technology as the regular panel (polycrystalline solar PV panels) will increase the price, but allow the large panel to be smaller. With the design goals in mind, the reduction in weight and size are perceived as more important.

The new panels are smaller than the current ones (figure 78). They were selected for their (nearly) similar width; providing opportunities for modularity.

6.1.2 Position of the solar panel

The average Khmer house allows the solar panels to be mounted at several locations (figure 79): on the roof [A], the wall [B], a pillar [C] or the floor[D]. They can be evaluated on several criteria relevant to the performance and functioning of a solar panel:

	A	B	C	D
360° positioning	++	-	--	++
Low chance of theft	++	+	-	--
Little chance of shading	++	-	--	-
Stability	-	-	++	++
Easy to clean	--	-	+	++
Low chance of damaging	++	+	-	--
Total:	+++++	--	---	+

Mounting the panel on the wall or a pillar are the least desirable options. There is little freedom for positioning, while there are no real advantages compared to placing the panel on the roof or the floor.

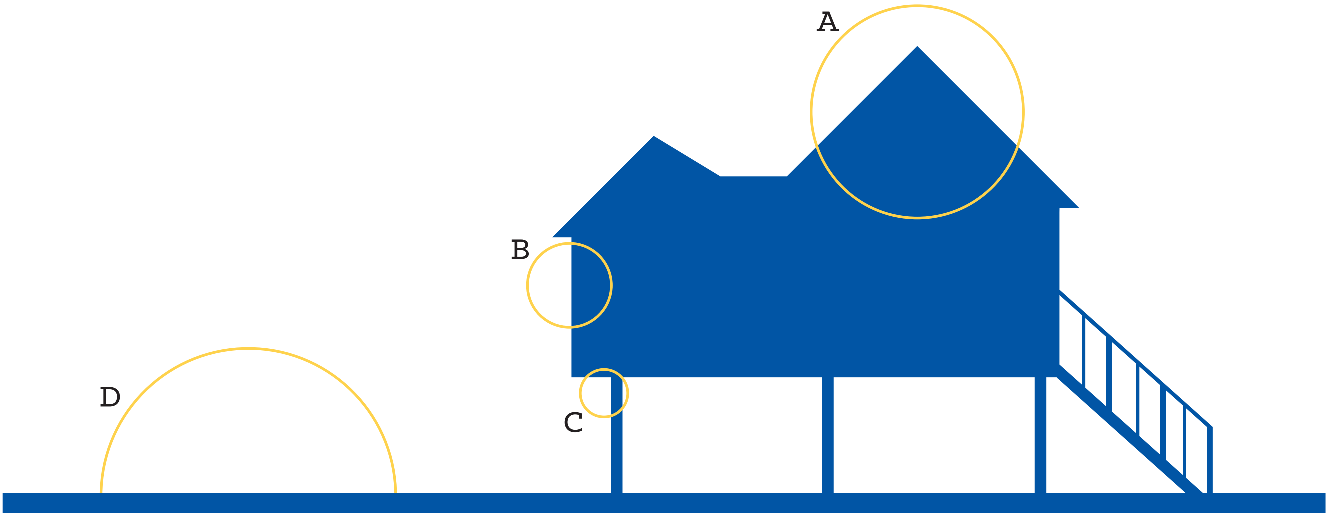


figure 79. Possible positions for the solar panel(s)

When placing the solar panel on the floor, the chance of shading (by trees) is high, while it can get damaged, or stolen, easily. When theft needs to be avoided, the design (and also the installation) will become more complex. Therefore the idea generation will focus on a mounting system that can be placed on the roof [A].

The current regular and large mounting system are respectively mounted on the top ridge and the side of the roof. The top ridge of a roof is easier to reach than the sides (§5.2.2) and has an additional advantage: free space. When two additional panels are supposed to be attached to the mounting system, this freedom is needed. Placing the mounting system on the side of the roof may cause the roof obstructing expansion panels (e.g. when the roof is facing west and the mounting system is mounted too close to the roof). Also, making sure the hole is waterproof can be done easier on the top ridge. All together it is preferred to mount the solar panel on the top ridge of the roof.

6.1.3 Other considerations

Besides new solar panels and their position, other topics, relevant for the development, are discussed below. These topics do not result in a final decision, but give an idea of the possibilities regarding the design.

Adding panels

Although self-installation can save costs, it has been decided that the core system is installed by a Kamworks technician. If not, a solar panel can be easily installed the wrong way, resulting in an inefficient power output and eventually customer complaints. One way could be to let the technician install an easy to assemble mounting system, with the solar panel facing the correct way. When a system is expanded, a customer just has to make sure the additional panel is faced the same direction.

Another way could be that the core system has a core mounting systems (with one panel) onto which panels can be added. The design proposal shows one mounting system that is suitable for three panels. When an additional solar panel is installed, only fasteners are needed to add a panel. To avoid excessive material use (i.e. when customers do not expand their system at all) , the core mounting system can be made expandable too. Expansions could be added with a simple construction.

Availability materials

It is important that the product is produced with locally available materials. This makes the production and stock supply reliable. Throughout the idea generation, numerous markets and shops were visited to verify the feasibility of solutions. As turned out from the analysis, square, rectangular and round galvanized steel profiles are widely available (figure 81). U- or L-shaped profiles are available in aluminium or stainless steel, but they do raise the production costs. An advantage of these materials is that they could be welded without the need of a surface treatment.

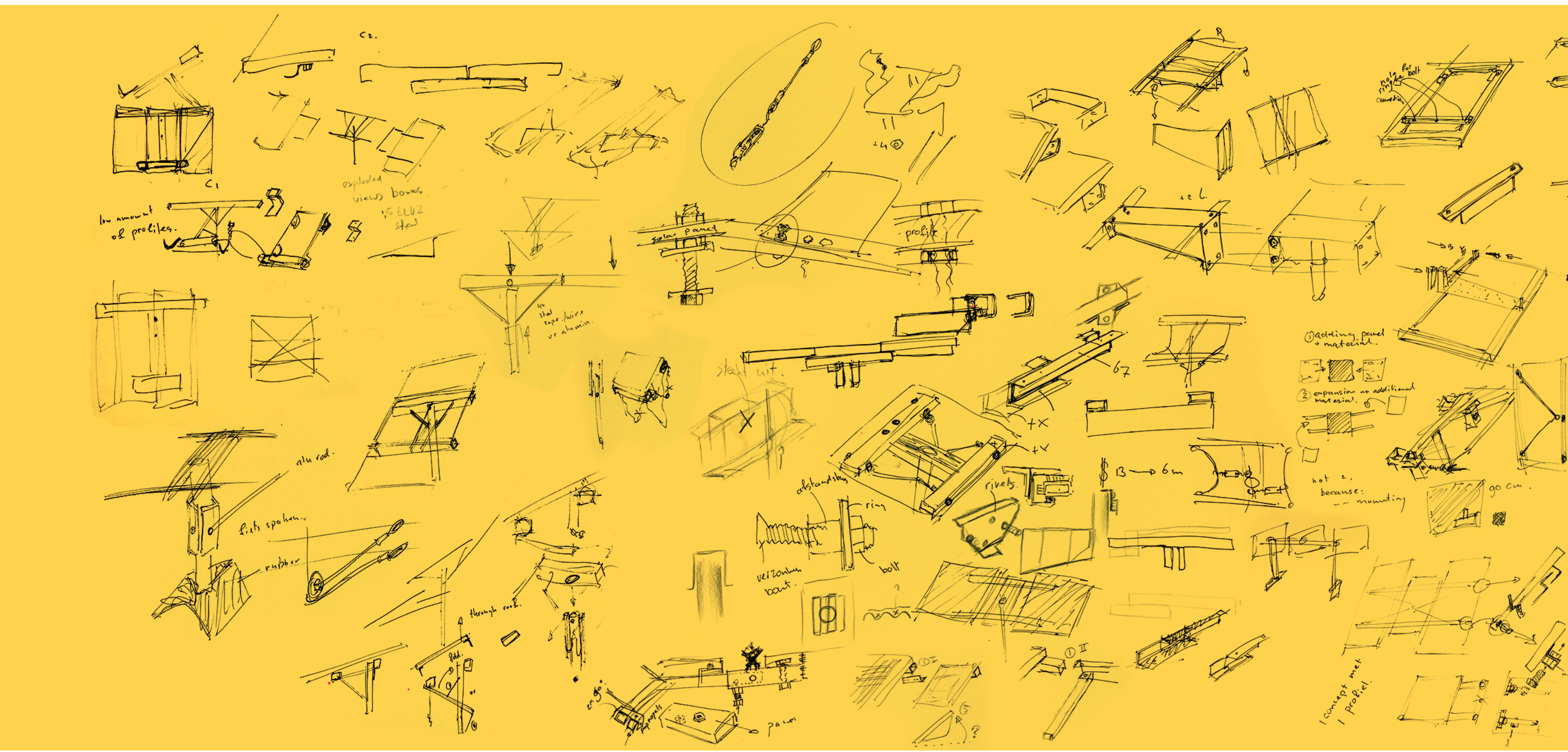
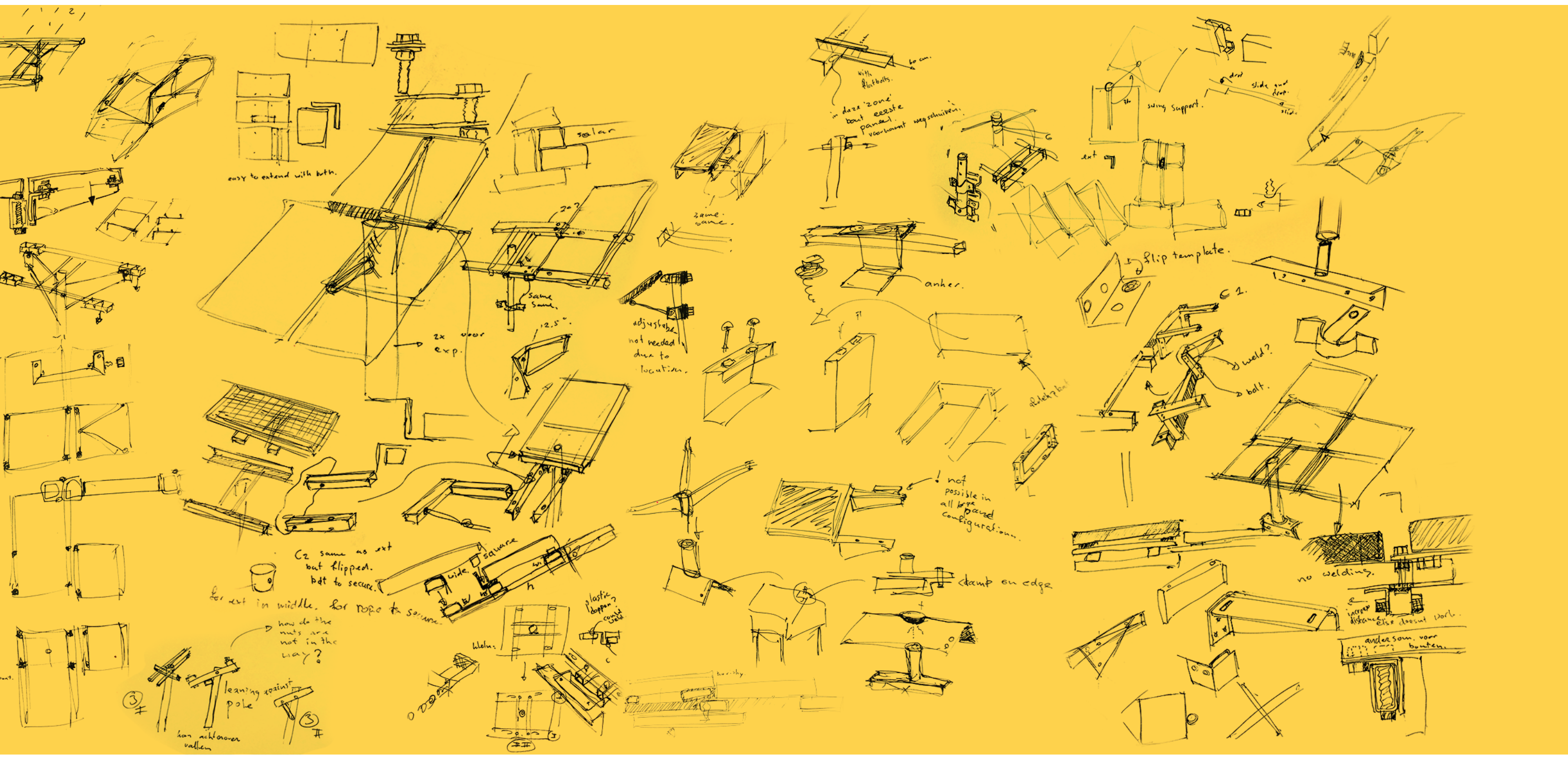


figure 80. Idea sketches


figure 81. Widely available galvanized steel profiles in Phnom Penh



Sheet metal is widely available in several thicknesses. There is sheet metal of all common materials (aluminium, steel, galvanized steel and stainless steel). The production costs will be estimated based on the local material prices, since it will be the source of the stock supply.

Although there are an innumerable amount of hardware stores and markets selling tools and fasteners, the variety of their products is low. The range of available fasteners is limited and should be kept in mind throughout the development. Some special fasteners can be found in electrical and maritime industry shops.

6.2 Concept development

The coloured lines in the morphological chart (figure 82) show the combination of solutions that led to the concepts. These concepts, visualized in figure 83, were designed to suit both panel sizes. For the ease of understanding, the visualization shows configurations with the regular panel only.

Concept 1

This concept comprises a central mounting pole that can support up to three solar panels. The panels can be are attached to the long horizontal support, while they rest on the L-profile at the bottom. This is done so by mounting two brackets at the top corners of the solar panel and a small rectangular profile at the bottom.

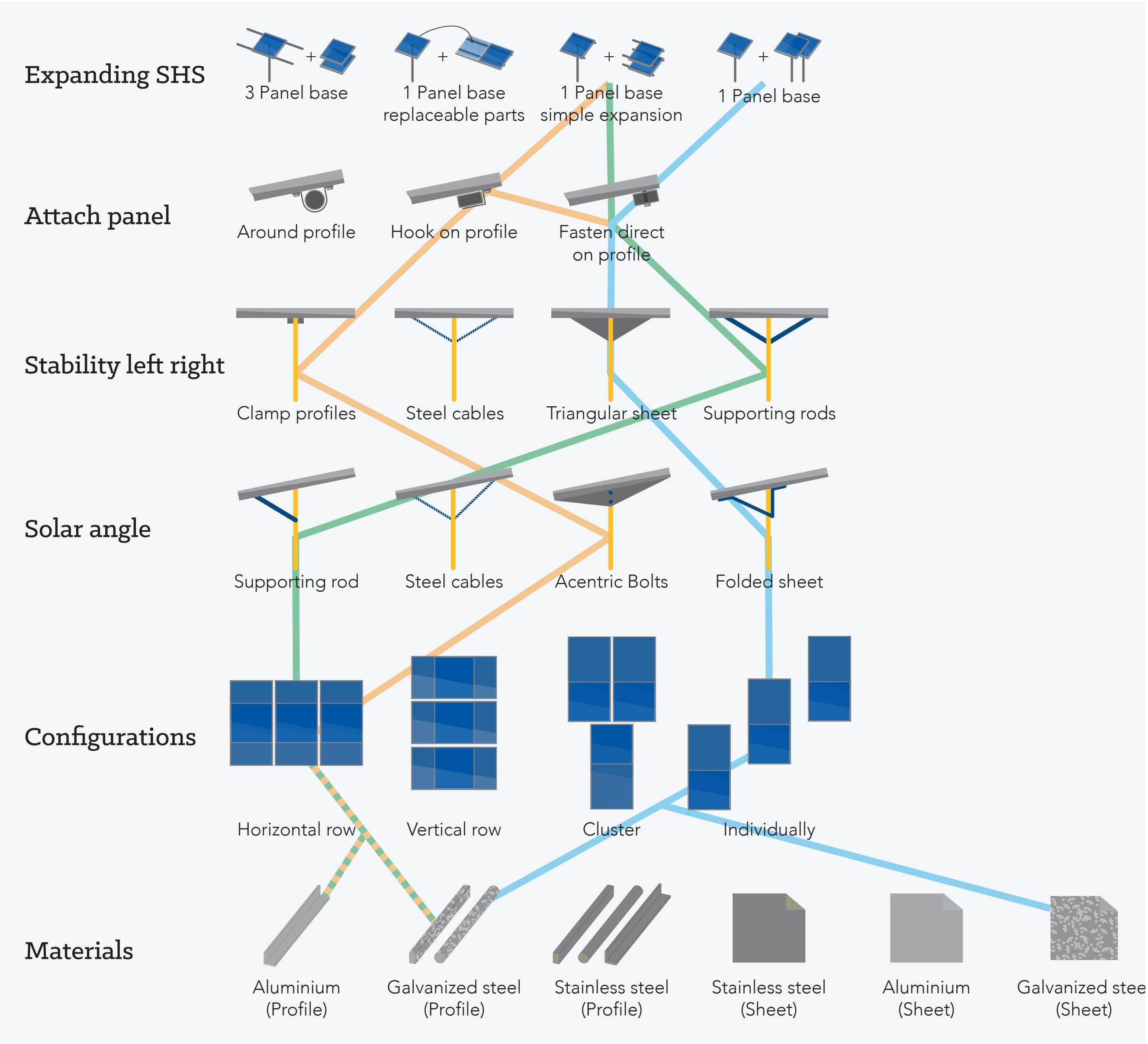
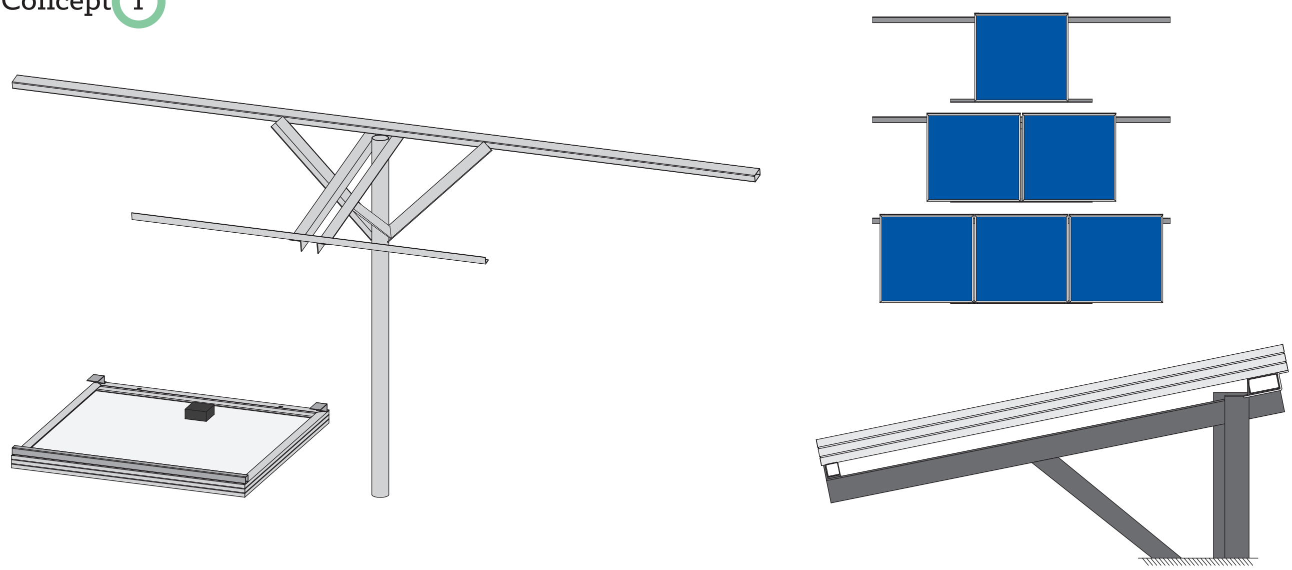
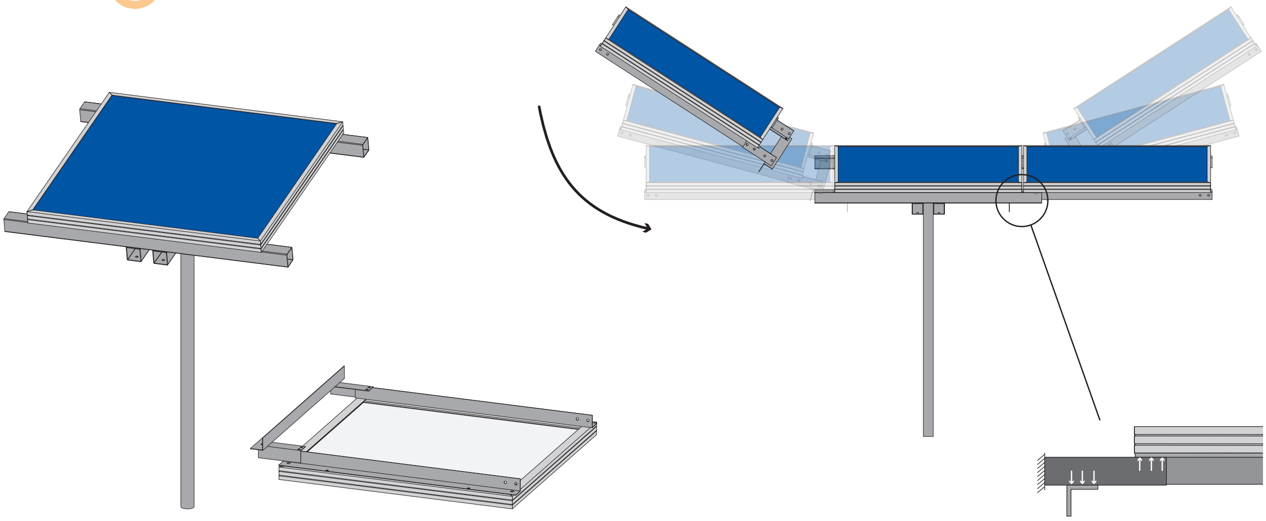


figure 82. Morphological chart mounting system

Concept 1



Concept 2



Concept 3

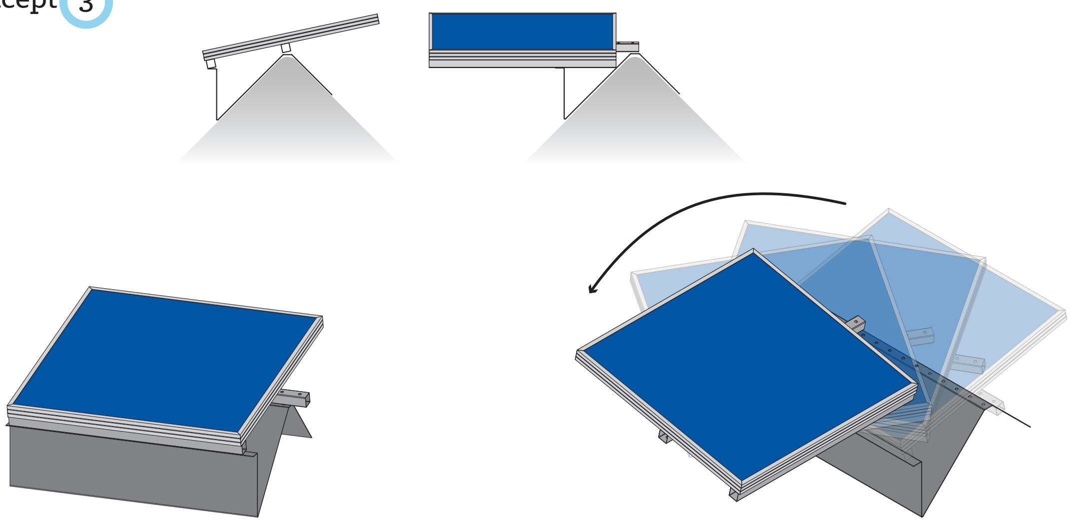


figure 83. Three concepts for a universal mounting system

When a second panel is added, the positions of the panels can be adjusted to balance the load. The same goes for adding a third panel. As proposed now, the outer two panels would rest on three small surfaces (the brackets and a small part of the bottom of the panel) when all panels are attached to the mounting pole. It should be evaluated if this support is sufficient, or if additional support or fastening is needed.

The long horizontal support mainly keeps the panels in place. To provide this support with extra stability, it is mounted directly to the pole and supported by cross-beams. The left/right stability should not be an issue with this concept, but the weight of the panels are positioned in front of the mounting pole. Therefore, the dimensioning of the pole and the supporting rod (of the vertical supports) will be critical elements for further development.

Concept 2
Also this concept uses a core mounting system, but in this case the first panel is attached to it. A second and third solar panel can be attached to the mounting system with an expansion kit. The expansion kit is made from three beams that are bolted together.

The mounting system is basically the current regular mounting system with extended horizontal supports. The extra length of the horizontal supports is used to attach the expansions to. The weight of the solar panel clamps the expansion to the mounting pole. Also for this concept it should be evaluated if fastening is needed for safety reasons.

When a second panel is attached to the mounting pole, the load is unbalanced. Although larger profiles will be used, it might be needed to add one or more supporting rods. It can also be considered to make it possible to move the horizontal supports so that the load is better balanced.

Concept 3
Instead of installing a mounting pole to the frame of the house, this concept uses the roof as support. Each solar panel has its own mounting system that is placed on the top ridge of the roof. To secure the mounting system it can be fastened to the roof. This concept is inspired by observations from the first field trip: self installed panels are often balanced on the top ridge of the roof, stabilized by only four thin metal rods (figure 16, p.29).

The solar panel can be rotated 90˚ on the support. By allowing the support to be assembled as a left or right variant, a 360˚ orientation is achieved by placing it on one side of the roof. The orientation of the panel is fixed by bolting the top beam to the sheet in the correct position.

The folded metal sheet obstructs compact transportation, while the balance of the mounting system might also be an issue. The angle of the roof will not be consistent and would require more adjustability. It might be possible to split the sheet in three parts that can be assembled during installation, but too many adjustable parts also increase the chance of installation errors.

6.2.1 Concept selection

The concepts were compared using the Datum method (figure 84) and these were evaluated within the design team. The criteria that need explanation are briefly mentioned below.

Compact Base & Expansion
For these criteria, the concepts were compared on transportation size and the size of the assembled mounting system. The base of concept 2 can be most compactly transported.

Easy to install
Concept 3 would be most easy to install, since there is no need for cutting holes or getting large objects up the roof. Concept 1 and 2 would be more difficult to install: the assembled mounting system of concept 1 is large in size, while the second concept will be heavier to carry up to the roof because of the mounted solar panel.

Material variety & Use
During the analyses, it turned out that it is challenging to resource a high variety in materials. For this, reducing the variety would make the supply of materials easier. Concept 2 has the lowest material variety and can be produced with widely available materials. Moreover, the use of a compact core system that can be expanded with an expansion kit reduces the material use.

Balanced load
Although the construction of the first concept should be evaluated on its strength, the adjustability of the panel positions is interesting. Where concept 2 is out of balance as soon as a second panel is added, the adjustability of all panels can improve this concept.

Recognizable
Concept 3 seems to be the most distinctive when comparing it to Kamworks' current mounting systems, but as a recognizable design it should compared to mounting solutions of competitors and self-installed solar energy systems. Therefore, concept 1 and 2 are rated more recognizable.

Possible self-install
Remarkably, concept 3 scored best at easy to install, but is weakly rated here. This is because the installation by a skilled technician is different than the installation by a user. The adjustability of this concept makes it vulnerable to mistakes.

Conclusion
It can be concluded that concept 3 is the weakest concept. The required degree of adjustability, and the transportation size, make this concept unsuitable for further development. Assuming a user will carefully imitate the 'settings' of the first SHS, installed by a technician, is not realistic. This concept will lead into wrongly installed solar panels and, subsequently, complaints.

The adjustable solar panels of concept 1 seem promising, although the large mounting system is a major disadvantage. Concept 2 is rated best, but with a fixed (first) panel, a balanced load cannot be realized. Possible changes to the design, that allow a better distribution of the solar panels' weight, need to be evaluated. Because of the low material variety, material use and the possibility to transport the mounting system compactly, concept 2 will be further developed.

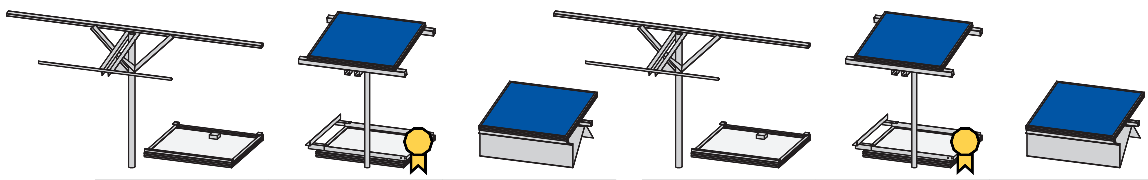
6.3 Materialization

The concept needs adjustments to allow a better distribution of the load. The stability should also be evaluated. Multiple prototypes helped to verify changes in the design. With the limited availability of materials and fasteners, the sourcing of materials for the prototypes helped to explore the feasibility of ideas. A prototype of the chosen concept was made to identify the concept's weaknesses. After the evaluation of this prototype, the mounting pole and the expansion kit are developed separately. Since the first solar panel should be adjustable too, it is included after the mounting pole is developed. The insights throughout this section will lead to the introduction of the final design.

6.3.1 The initial concept

A prototype of the initial concept (figure 85) was made in order to evaluate the stability of the mounting pole, the precision of the orientation and the action of adding panels. With the expandability (i.e. the mounting pole supporting multiple panels) in mind, larger galvanized steel profiles were used for the vertical and horizontal supports. Steel L-profiles were welded together to create the expansion arms. When the expansion arms are bolted together, they clamp onto the ends of the mounting pole.

The supporting rod, currently used for the inclination of the regular mounting system, is left out in this prototype, since its production impairs the simple production process (figure 63, p.73). Instead, two bolts connect the vertical supports with the pole at the correct angle. After testing, however, it can be concluded that the two bolts cannot ensure the panel's position: even with both bolts tightened, the angle of the supports could be easily changed with (approximately) 5° in both directions. Since a maximum change of 2° is determined, this is too much.



Compact base	-	.	-	.	+	+
Compact expansion	+	.	-	.	-	-
Easy to install	s	D	+	D	s	+
Material variety	-	A	-	A	+	+
Lightweight	-	T	+	T	+	+
Balanced load	+	U	s	U	-	-
Material use	-	M	-	M	+	-
Recognizable	s	.	-	.	s	-
Possible self-install	s	.	-	.	s	-
∑+	2	.	2	.	4	4
∑-	4	.	6	.	2	4
∑s	3	.	1	.	3	1

figure 84. The Datum method to determine which concept has the best potential

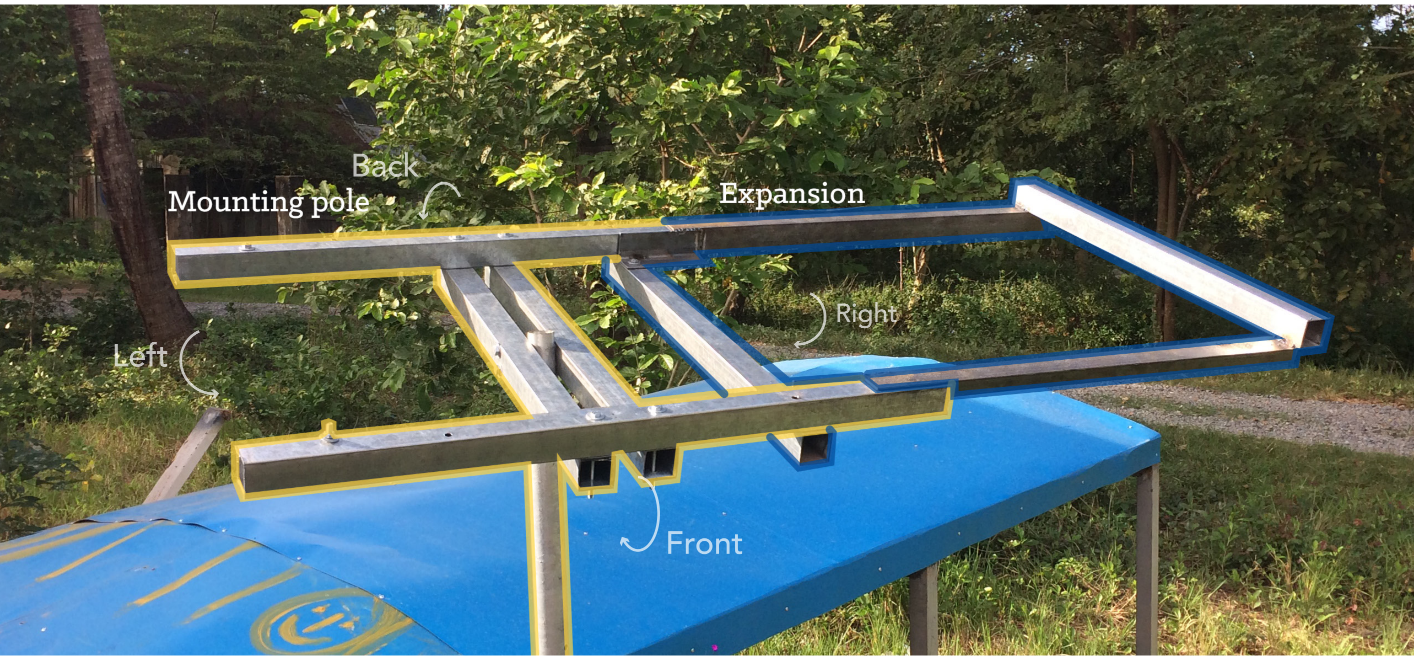


figure 85. Prototype of the concept

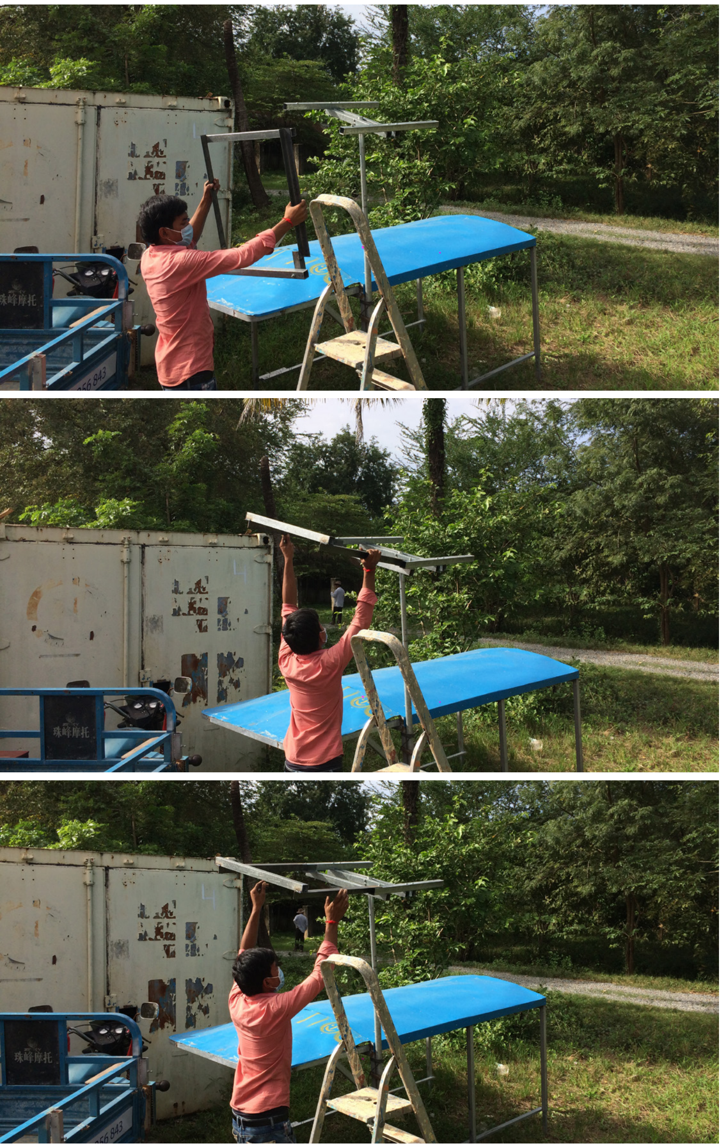


figure 86. Applying the expansion kit to the mounting pole

The mounting pole was mounted to a frame, after which an expansion kit was attached to it (figure 86). Immediately after attaching, the mounting pole became unstable: when applying the slightest load, the connection of the supports with the mounting pole would show signs of deformation. This would mean that a panel, especially when not balanced properly, would cause this prototype to collapse.

Before the separate elaboration of the mounting pole and the expansion (kit), several conclusions can be drawn:

› Two bolts (that are positioned two centimetres away from each other), cannot ensure the panel's position.
› The connection of the support with the pole is not strong enough. Without applying a load, the mounting pole is already unstable and can bend sideways easily.
› Apart from the unstable mounting pole, the way of expanding is feasible. When the extension is clamped onto rigid profiles, the load of a panel can be applied easily.
› Both the dimensioning of the mounting pole and expansion seem oversized: besides the weak connection, tests with the material showed that a heavy load can be applied to them.

Before the panels can be involved into the design, improvements should be made regarding the stability of the mounting system. When a bracket or a supporting rod would be added to the mounting pole (allowing the bolts to be positioned further apart), the inclination's accuracy can be increased. However, the left/right stability would still be an issue. Therefore, another solution needs to be developed that supports the mounting pole in all directions.

6.3.2 The mounting pole

The first prototype showed that the construction, similar to the regular mounting system, is not strong enough to support multiple panels. Looking back at both current mounting poles, the large mounting system would be more suitable for supporting multiple panels, due to the sheet metal supports positioned in an X-shape (§5.4). These supports, however, would increase the complexity, material use, and production costs. Moreover, they cannot be produced in-house.

To create a similar geometry, steel cables were used instead of sheet metal (figure 88). Steel cables can be found in local stores, while maritime industry shops provide a broad assortment of cables and accessories too. The advantage of steel cable is that it is low in price, lightweight and compact.

The steel cables noticeably improved the stability of the design. Even when mounted to a long pole, the reinforced mounting pole could support a sufficient load (figure 89). Where a large panel weighs approximately ten kilogram (distributed amongst the expansion kit), this prototype is able to support a load double the size, applied to the end of the expansion (causing an larger moment than the panel would). Optimizing the dimensions can reduce excessive material use.

The connection of the cable with the mounting pole should also be developed. The (drop forged) cable clamps, that are used to allow a connection with the end of the cables, are low end solutions that, together

figure 87. Rolls of steel cable in front of a maritime industry shop

figure 88. The mounting pole with steel cables for increased stability


figure 89. Applying a load of 20kg at the end of the expansion


figure 90. The cables should be professionally connected


figure 91. Cable lug

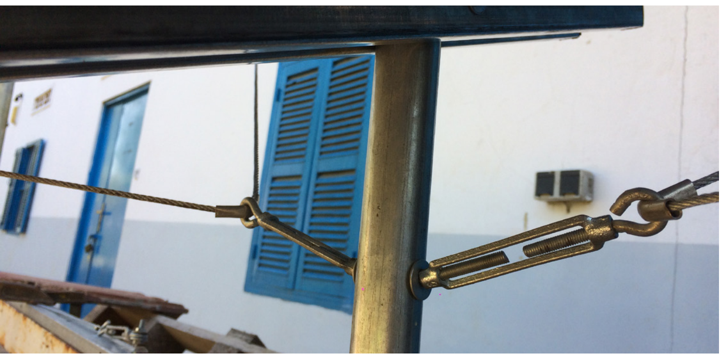


figure 92. Turnbuckle cable tensioner with (bent) butt connector

with its fastening, give the product an unprofessional appearance (figure 90). Without the availability of (small) thimbles and ferrules, the cables cannot be directly mounted to bolts and washers. With a warranty of two years, and a required lifespan of four years, this connection would wear down too fast.

A more durable solution for connecting the cables can be found in Phnom Penh's electrical shops. Cable lugs (figure 91) can be used for the ends of the cable. The advantage of these connectors is that they can be connected to regular bolts. A disadvantage is that they are not commonly used for constructional purposes. A test should be performed to evaluate the quality of the connectors.

Since the cables come together at the pole, this junction is important to the stability of the design. Eye bolts (and nuts) would be suitable for a durable connection, but they are hard to find. Although parts can be imported (if really needed), it is preferred to come up with a design that can be produced and reproduced by local parts only. The cable tensioners can provide a solution for this. By connecting them with a threaded rod through the pole (figure 92), two eyes are created. The bend in the threaded rod ensures the cables are aligned when they are tightened by fastening the cable tensioners.

An additional advantage of the cables is that they can determine the inclination of the solar panel. In order to create the correct angle, the cables for the front and the back should differ in length. Another option would be to use the same cable length, but adjust their position on the horizontal supports.

By applying a butt connector, two cables can be used instead of four. The position of the cable is secured by the bend in the connector (figure 92). The final design steps will determine if two cables (with two butt connectors and four cable lugs) or four cables (with eight cable lugs) will be used.

With the global geometry of the mounting pole determined, the expansion kit should be developed before defining the final details of the design. Since the core solar panel is not attached to the mounting system directly, it is included into the development of the extension kit. Where the extension kit should be a cheap and simple addition to the mounting system, the idea of mounting the first panel with the same kit can be interesting. This would mean that a first SHS has a mounting pole, while panels are always provided with a simple mounting kit. An overview of the conclusions so far:

- The mounting pole, with 40x40x1mm profiles, is oversized and should be optimized.
- In the prototypes, the pole of the regular system was used. A larger pole is desired to reduce the

vibration of the panels, caused by the wind.

› Using a larger sized pole requires a slight adjustment of the punch and die that are used for the mounting clamps.

› The cables provide the required rigidity. They can also determine the inclination of the panel.

› The use of cable lugs (and butt connectors) provide a more durable connection between the cables and the mounting pole.

› The cable lugs should be evaluated on their strength and durability.

› The first solar panel should be moveable and can be preferably mounted with an extension kit.

6.3.3 Expansion kit

With the cables applied to the mounting system, it is not possible to connect both expansion arms with a beam underneath. Where the solar panel can fix the position of both expansion arms, it has been decided to separate them. This enables the arms to manoeuvre around the cables and clamp onto the mounting pole. Two designs were prototyped.

Aluminium expansion arms

The first design comprises two (mirrored) aluminium arms made from L-profiles (figure 93). Two profiles are joined with blind rivets, forming a U-shape that fits around the horizontal supports. Since the U-shape is slightly bigger than the height of the horizontal support, it can move easily along the mounting pole. A leveling screw levels the solar panel. When the profile that is used for the horizontal supports, would have a width (more than) twice the height, a base and expansion could be mounted with the profiles pointing respectively inside and outside. In this way, all panels could be repositioned.

Aluminium was chosen because of the availability and the price. Stainless steel is more expensive, while galvanized steel L-profiles are hard to find. Although this design is compact and simple, there are some disadvantages:

› There is little freedom in the dimensioning of the arms (and thus the mounting pole), since the diversity in L-profiles is low. This makes it probable that the mounting system needs to be oversized, making the product more expensive.

› The L-profiles would easily damage the roof. This turned out during the installation of the mounting system for the pilot test (§4.3.2).

› The U-shape is longer than the panel because it will clamp the panel onto the horizontal support. When the profile of the horizontal support is not twice the width than its height however, a base and an extension cannot be moved close to each other.

› Since there is no (horizontal) gap between the top and the bottom support, it might be difficult to manoeuvre the supports around the cables.

figure 93. Aluminium expansion arms

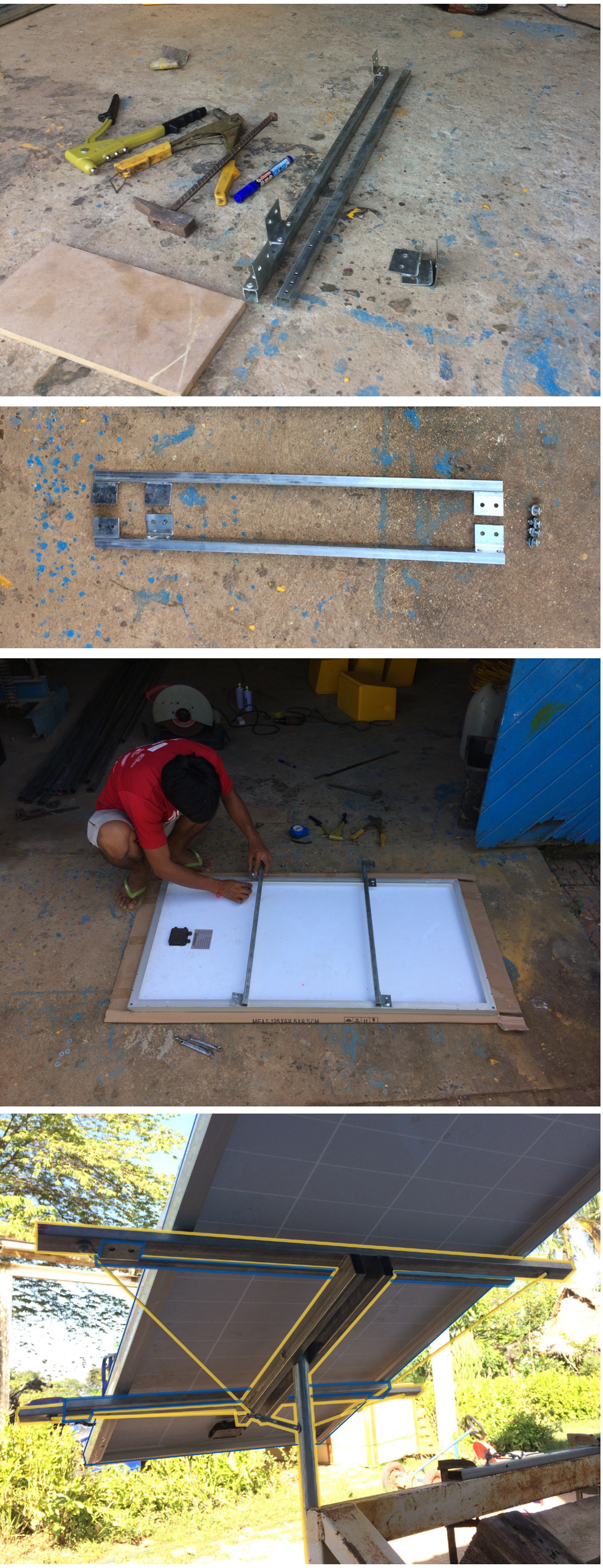


figure 94. Expansion arms made from galvanized steel

Galvanized steel expansion arms
With the insights of the aluminium arms, alternatives were explored. As a result, two arms of galvanized steel were developed. Instead of the long L-profile, a rectangular profile is used. To enable the mounting of the solar panel and clamping onto the mounting pole, three brackets are attached to the arms.

The galvanized steel expansions would be cheaper to produce than the aluminium arms. An additional advantage is that they are easier to install (because of the gap in between the brackets) and that the custom made brackets allow flexibility in the detailing.

Only two unique parts need to be produced to create these arms. For the brackets, the same sheet metal can be used that is needed for the brackets in the battery boxes. When the arms would use the same profile size as the mounting pole, the material variety remains low.

Although calculations showed the profiles of 20x20x1mm would be strong enough, their deformation was unacceptable. This can be explained by the poor steel quality that is sold in Cambodia. The dimensions were optimized (appendix J) for the final design.

6.4 A universal mounting system

After a final prototype was made to verify all changes (figure 95), some last minor adjustments and additions were implemented. The final design will be discussed elaborately in this section, divided amongst several topics. A set of detailed drawings was made, which can be found in appendix K. In this section decisions that were made to come up with this design are motivated. The assembly will be discussed first. Thereafter, the production and installation are described, showing the feasibility of the design.

6.4.1 Assembly

The mounting system can be divided into two parts: the mounting pole (and clamps), and the panel support. A core SHS will have a mounting pole provided, where an expansion will only have the panel support. Since every panel needs a panel support, it can be packed and transported together with the solar panel. The overview of the mounting system's parts can be found in figure 96.

Used materials
The majority of the used material is galvanized steel. The horizontal and vertical supports, as well as the arms, are made from rectangular tube (30x30x1mm). Besides, the mounting pole is made from round tube (ø42x1mm) and the brackets are made from 1,5 millimetre sheet metal.

figure 95. Three large solar panels mounted on the mounting pole (SA workshop)

In addition to the galvanized steel, fasteners and steel cable need to be resourced. Moreover, a roof cover is added to the mounting system that will be made from (recycled) rubber.

Cables
The cables are an essential part of the design. It provides the stability of the mounting system and determines the inclination of the panel.

The previous section allowed discussion to use four cables with cable lugs or two cables with a bent butt connector (dividing the cable in two parts). If the butt connector is not accurately positioned and bent, the panel will be positioned at a wrong angle. The current production shows that the verification of accuracy is hard to implement in the process. Another issue with the use of butt connectors is safety: when a cable snaps for whatever reason, a whole side of the mounting system becomes unstable. This makes the use of four cables (with cable lugs) preferred.

Before the cable lugs were implemented in the design, they were tested on their strength and durability. A test installation (figure 97) was made due to the lack of available data. In this setup, a cable lug was attached to a steel cable. The cable was clamped on a frame and tensioned by a cable tensioner. Their starting position was marked blue to evaluate if (1) the cable lug was properly fixed to the cable and

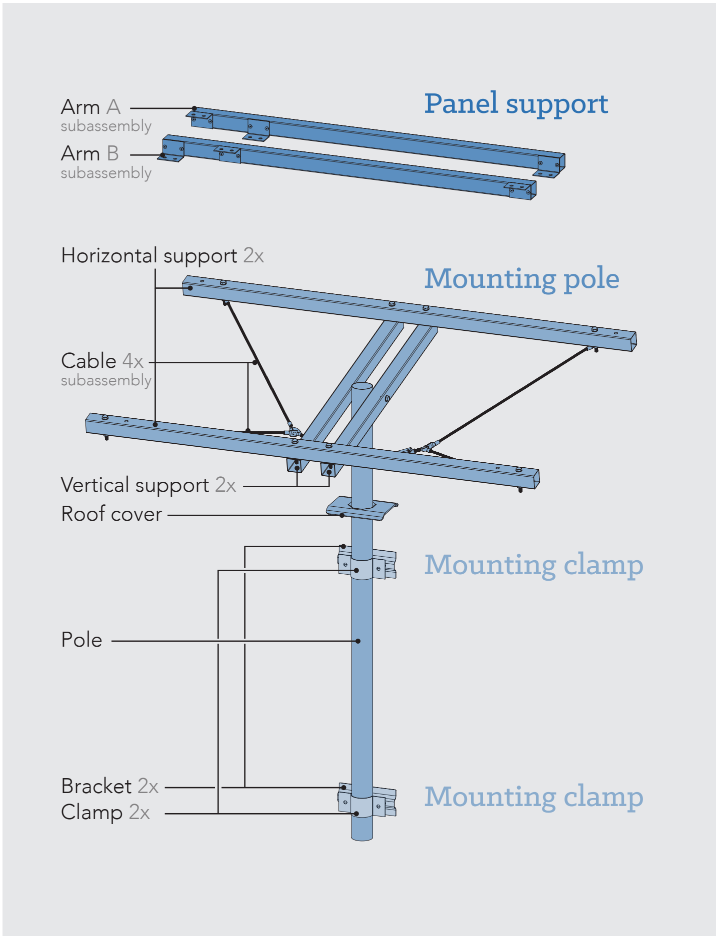


figure 96. The mounting system V3

(2) the position of the clamped cable would remain unchanged. The cable was checked on its tension and position for two weeks. After the successful test, it was decided to use the cable lugs in the design.

There are two options for creating the inclination of the panel: having four cables in two (slightly) different sizes, or using the same cables that are positioned differently on the horizontal beams. Where almost similar parts may lead to confusion and mistakes (§5.1.3), additional holes will be drilled in the horizontal supports and four cables of the same length will be used.

Ensuring that the production of the cables will be precise, a template can be made by mounting two bolts with a (centre to centre) distance of 42,5 centimetre onto a base. Each cable can be made the same length by attaching the cable to the lugs while the lugs are mounted to the bolts.

Roof cover
Currently the hole in the roof, that is made to put the mounting pole and solar cable through, is closed off with cement. This would not allow a second solar cable to be added through the hole when a system is expanded.

The hole will be covered instead of closed. In that way a second (and third) solar cable can be put through the hole as well. Since the mounting system will be mounted on the top ridge of the roof, and therefore does not have to deal with water coming down from the roof, the cover does not need to be fully waterproof.

For the maritime industry, old car tires are being turned into all kinds of parts, while new rubber is also widely available in specialized shops (figure 87, p.95). With Cambodia having major issues regarding waste management, it is suggested that this part (that will be barely visible during use and has no critical qualitative requirements) will be produced from disposed car tires.

Expansions
Both the core and expansion panel(s) will be provided with panel supports (figure 98). They are used to attach a panel to the mounting system.

Although the two solar panels have nearly the same width, the placement of the holes is not ideal. The placement of the hole cannot be adjusted anymore, since the panels are in stock already.

The brackets that connect the support with the panel are positioned in four orientations: left or right, and inside (core) or outside (expansion). A single bracket that is suitable for the existing holes of both panels would be large and complex. With these considerations in mind, it was decided that a connection piece would be provided for one of the panels. With the large panel being heavier, the regular panel is provided with a small connection piece made from sheet metal. This would reposition the holes close to the ones of the large panel, allowing the brackets to remain simple.

The first solar panel will always be installed by a technician. The arms of this support will be mounted to the solar panel with the brackets pointing outward, resulting in the solar support being positioned in between the horizontal supports.

Additional panels are (potentially) installed by the customer. For the expansion panels, the support will be mounted with the brackets pointing inward, resulting in the support clamping onto the outside of the horizontal supports. By mounting the support the other way around, the arms of the base panel and an expansion do not intersect, allowing the panels to be positioned close to each other.


figure 97. Durability test cable lug

With the supports of both extension panels being installed the same way (except the used holes in the brackets), it would make sense to mount the connection parts to the regular panel before placing them in stock. This would avoid differences in installation that might confuse a customer.

Mounting clamps

Where initially the regular pole and mounting clamps (and brackets) would be used, it turned out that a stronger pole was desired. If a pole of the same (outer) diameter, but a thicker material, is used, the mounting clamps could remain unchanged. This pole was found in local shops, but they are sold for five times the price of regular profiles.

Therefore, a slightly bigger pole will be used. The same bracket can be used, but the clamp needs to be adjusted. This also requires the adjustment of the punch and die (figure 100). The investment costs can remain low if a workshop will perform the adjustments of both this set and the other punch and die that needs adjustment too (figure 55, p.64). The total investment is estimated on $75 (Kamworks, personal communication, January 25, 2017).

6.4.2 Production

The mounting system is developed with the production facilities of Kamworks in mind. Also the limited availability influenced the final dimensioning. The production steps of the mounting system are very similar to the current production of the regular mounting system. An overview of the production steps is given in figure 99.

With fasteners excluded, the mounting pole exists out of seven unique parts (total part count of fourteen). For these parts three sizes of galvanized steel, (old) car tire and (galvanized) steel cable are used. With the availability of these materials they can be easily resources, making the stock supply reliable.

All parts can be produced within two or three simple production steps. All parts are cut in the right dimensions first, after which holes are drilled. Only the brackets and clamps have a third production step.

The panel support is made from the same materials and with the same production steps as the mounting system's supports and mounting clamps. The only critical element of this design is that two mirrored versions are provided with every panel. Where the mounting pole is a set of parts that need to be assembled during installation, the panel supports are two arms that only need to be bolted to the solar panel. To simplify (self-)installation, the additional connection parts of the regular panel will be mounted to the solar panel before transport.

The unassembled mounting pole, that is only provided with a first SHS, will be bundled for separate transport. The solar supports can be transported together with the solar panel and cable.

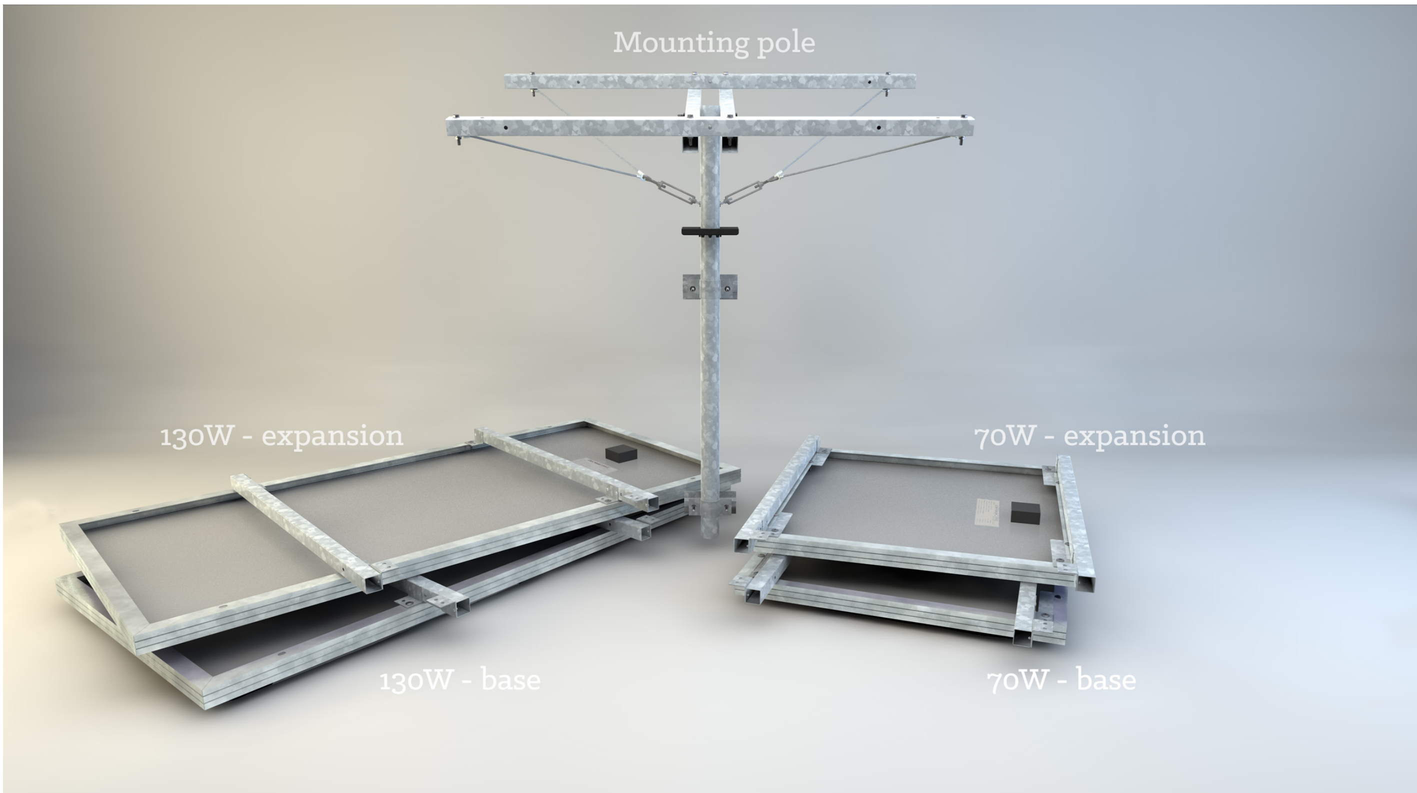


figure 98. The mounting pole and the solar panels (with mounted panel supports)

6.4.3 Installation

Not only the production, but also the installation shows similarities to the installation of the regular mounting system. Both the installation of a first solar panel and an expansion are described below.

Installation of a first system

The overview in figure 101 shows the steps that are performed for the installation of a first solar panel. Assuming that only one technician will install a first SHS (instead of two), the installation is described from this point of view.

The mounting system is assembled at the customer's home [A]. The last step of the mounting pole's assembly (that can be assembled in any sequence) is the tensioning of the cables. This step will incline the support and create the stability. The solar supports are mounted to the solar panel, but will be involved in the installation later on. Due to the simple assemblies, these steps can be performed within a few minutes.

The next step is making a hole in the roof and mounting the brackets to the roof [B]. As mentioned before, the pole will be mounted on the top ridge of

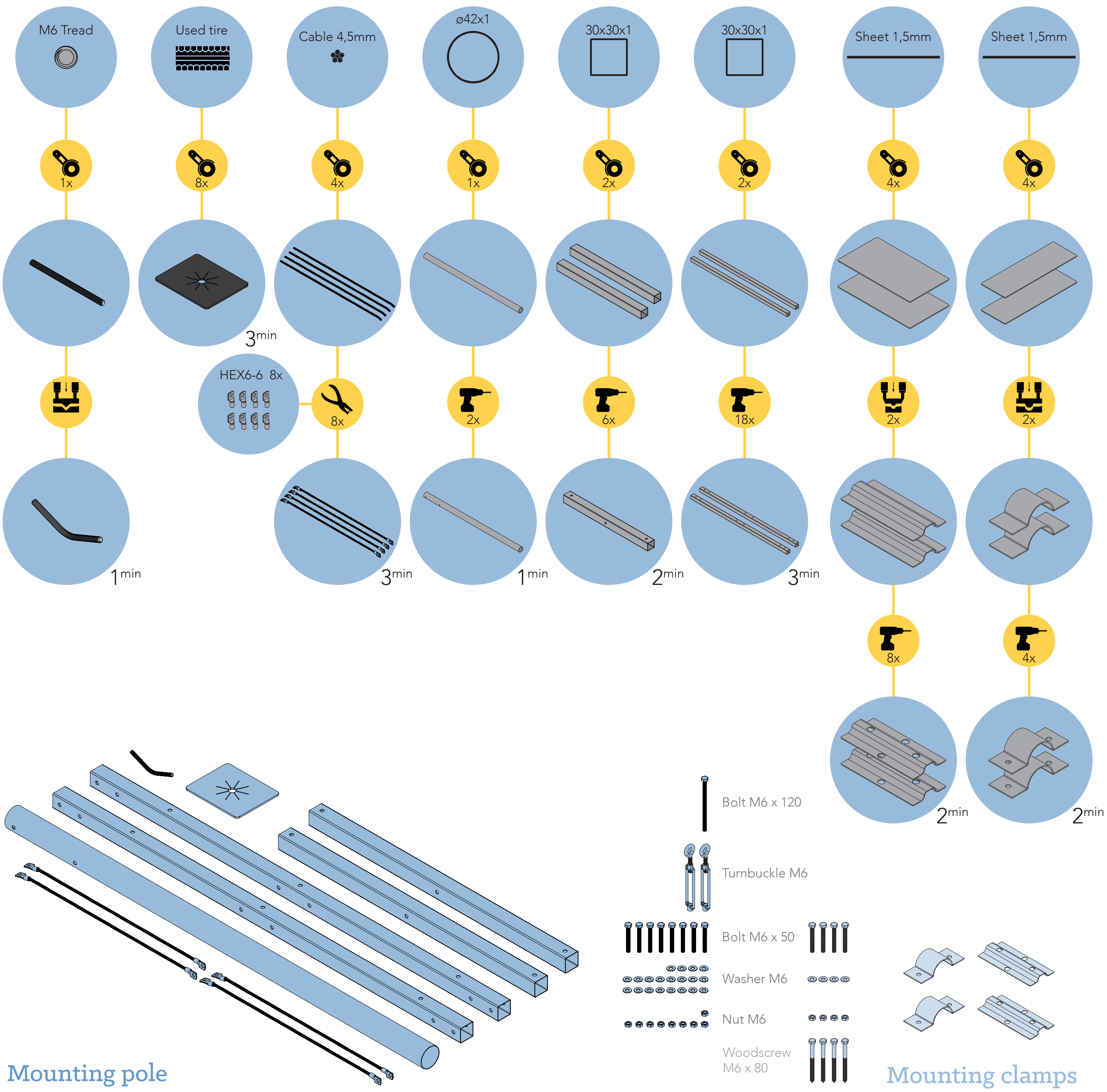


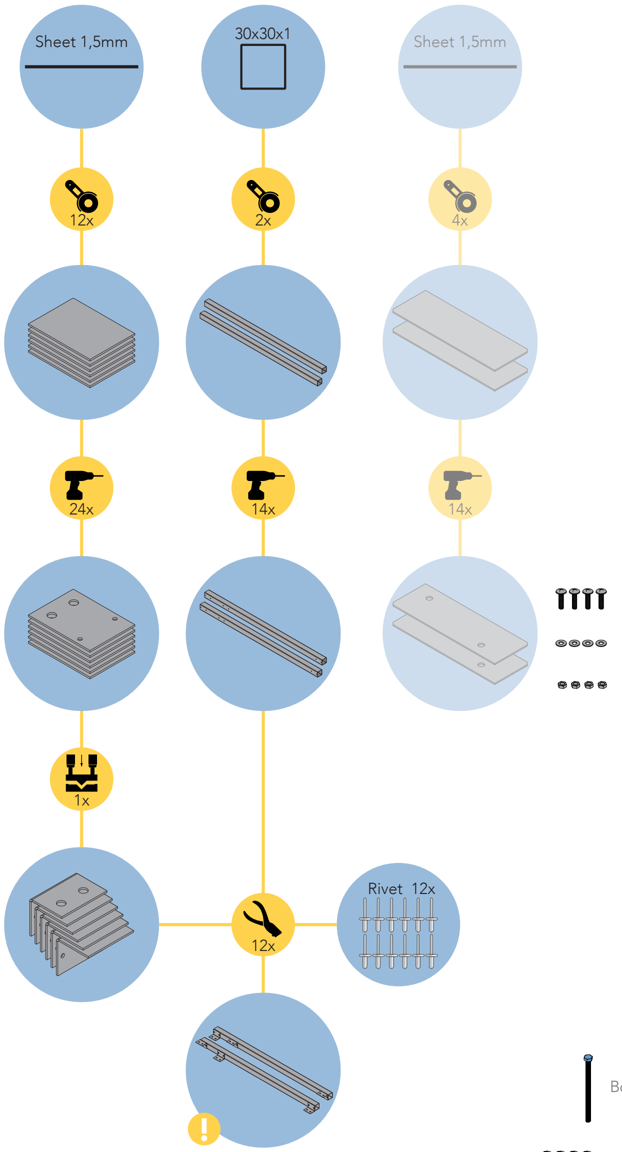
figure 99. The production of the mounting system

the roof. The length of the pole has to be taken into account while positioning the brackets.

When the hole is made, the mounting pole needs to be carried up the roof. Since no panel is attached, this step is less dangerous than the installation of the current mounting systems. The pole is placed in position and faced south [C].

Where normally two technicians would perform step C and D simultaneously, this is not possible with only one technician available. However, since the mounting pole is lightweight it is less probable that the roof will be damaged if the pole rests on the roof. Moreover, the roof cover will protect both the mounting pole and the roof. A customer can be asked to hold the mounting pole for the time it takes the technician to climb off the roof and enter the house. Besides, loosely attaching the bottom mounting clamp in step B might solve the need for holding the pole, but this has not yet been verified.

After the pole is fixed [D], the panel can be mounted on the roof. The difficulty of placing the first panel



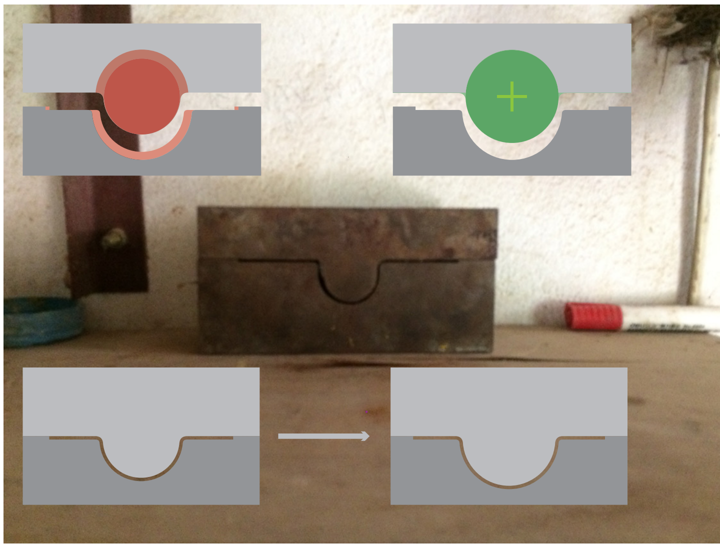
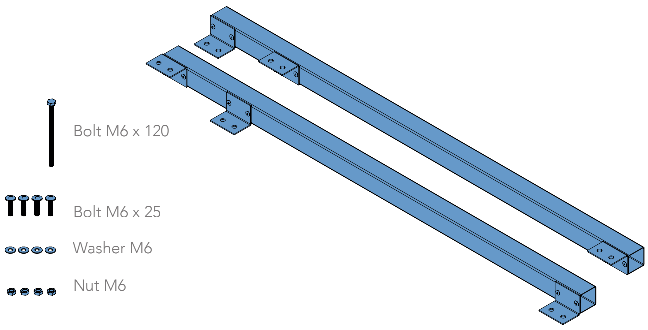


figure 100. The punch and die of the clamp that need adjustment



Panel support

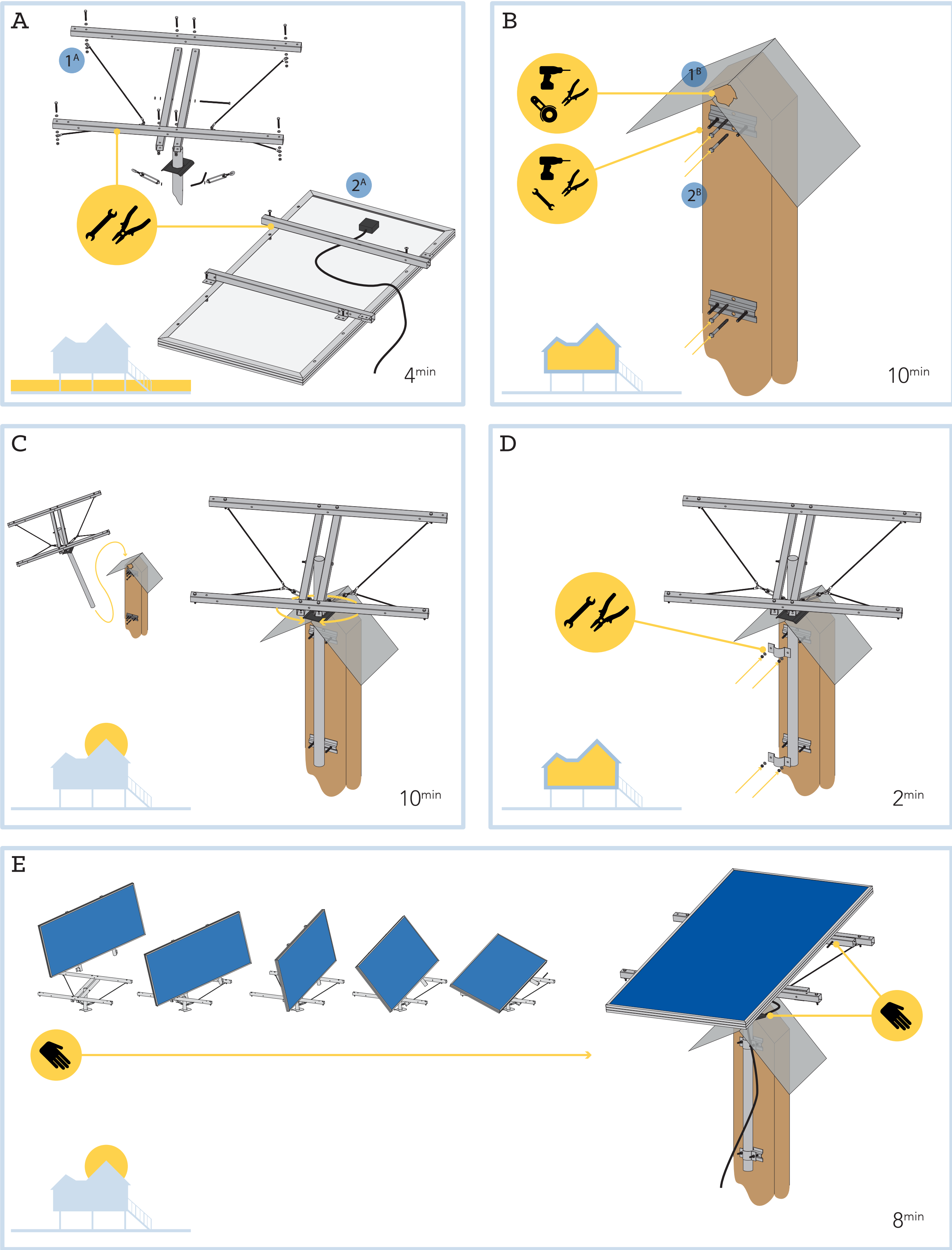


figure 101. The installation of a first mounting system

is slightly higher than an expansion, but that is why technicians are assigned to perform this task. With the correct rotating motion, the solar panel can be slid into place [E]. Although the panel is fixed in place by its own weight, a security pin (M6x120 bolt) is placed through the mounting pole and solar support to prevent it from moving.

Expanding a system
The second panel can be attached to the mounting pole relatively easily (figure 102). After the panel support is fastened, the solar panel can be carried up the roof. The safety pin of the already mounted solar panel [A] is removed, after which the panel can be repositioned by sliding it along the mounting pole [B]. When the panel cannot be moved further (because the brackets hit the vertical supports, figure 104), this panel is in position.

Next, the expansion panel can be attached. As soon as the edge of the panel rests on the horizontal supports [C], it is safe to let the panel rest on the support. By inclining the panel enough, the brackets of the expansion support can pass the vertical supports so that the panel is positioned closely to the first panel [D]. The safety pin then needs to be placed back in position, securing both the first and the second panel to the mounting pole.

When a third panel is added to the system (figure 103), the process of the second panel has to be reversed. The second panel is moved to the side while the first panel is put back into its starting position [E]. The safety pin, again, connects the first and second panel with the mounting pole. Then, the third panel can be added from the other side [F]. With a provided additional safety pin also this panel can be secured.

The goal of the project was to design a universal mounting system that is easy to install and produce. The result is a mounting system comprising a mounting pole that is able to support up to three panels. The panels, that are installed with simple panel supports, can be installed without too much effort. The reduced weight and the allowed tolerance during installation contribute to the ease of installation. The similar way of mounting allows the panels to be mounted in any configuration and sequence (figure 105).

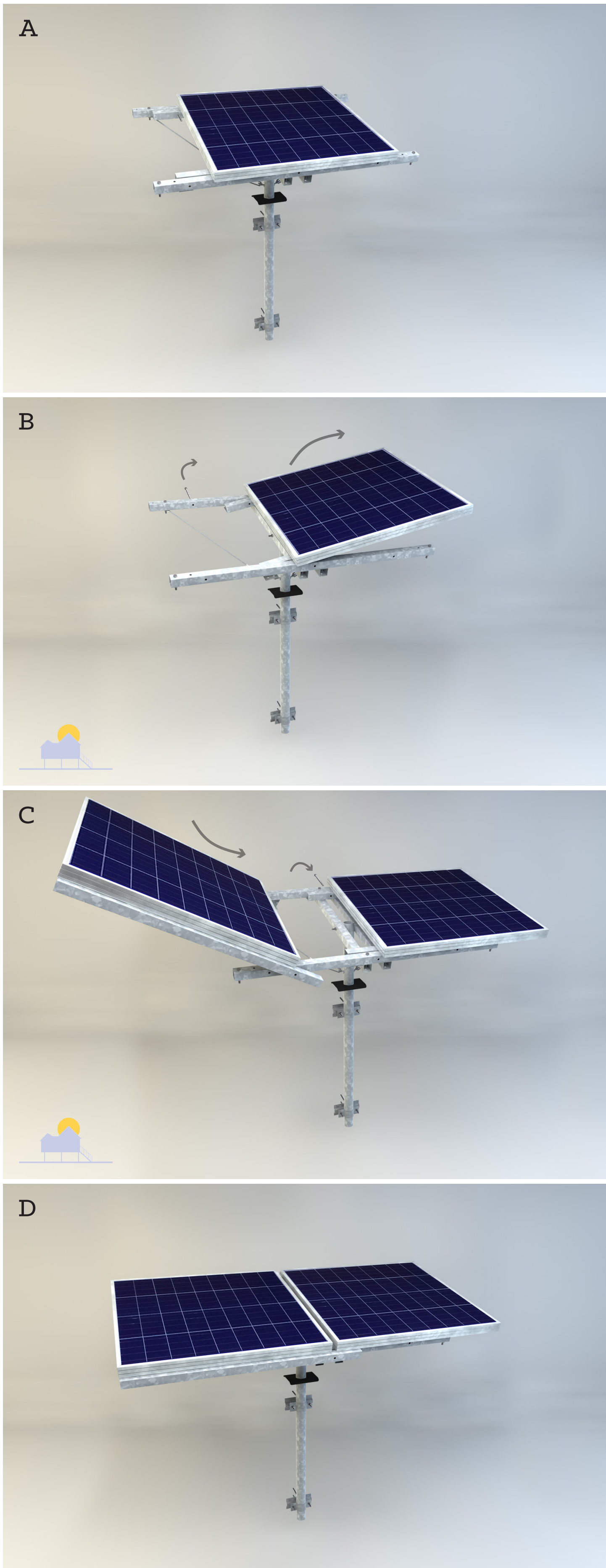


figure 102. Adding a second panel

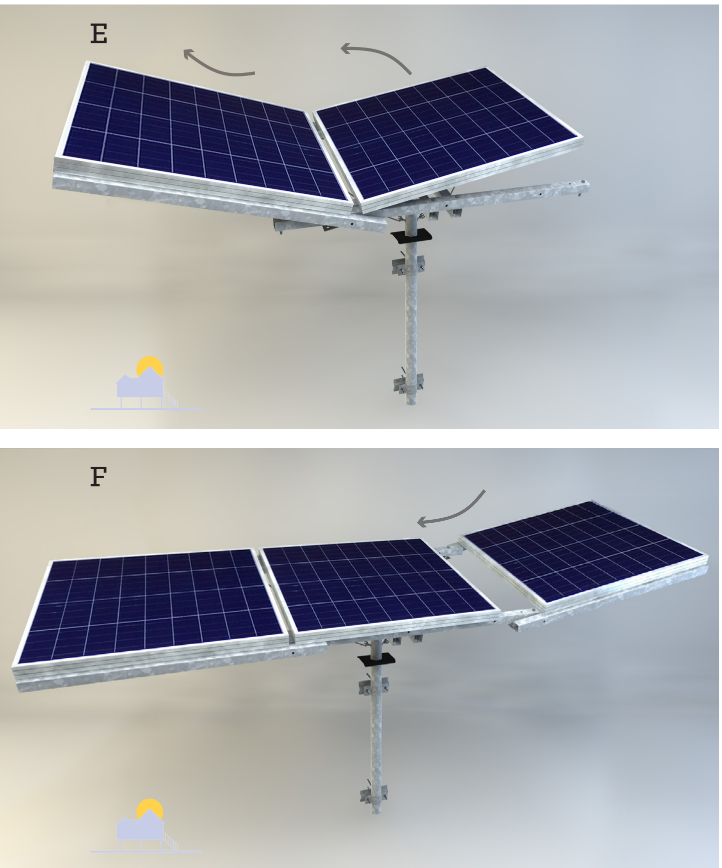


figure 103. Adding a third panel


figure 104. A large panel moved aside for a second panel

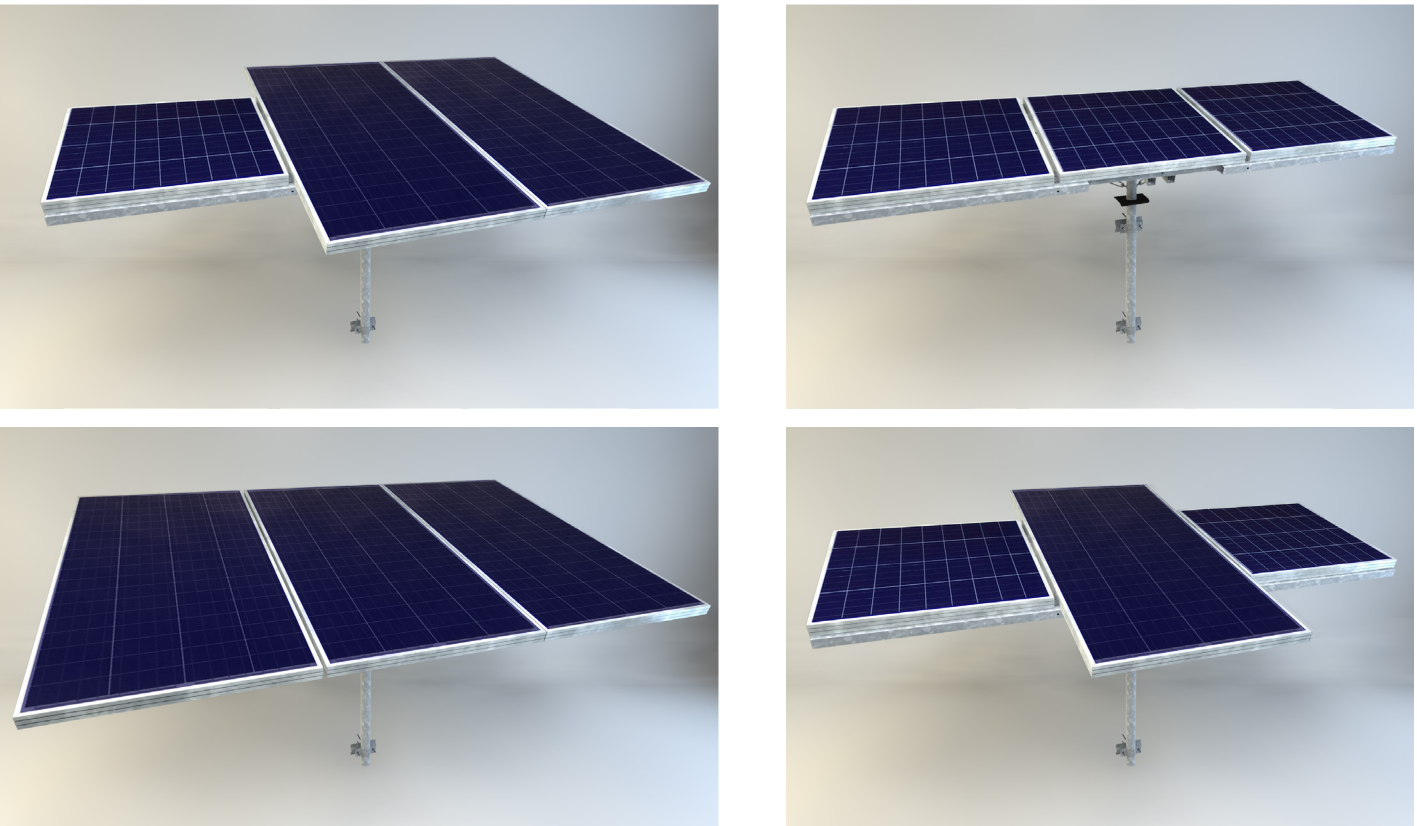


figure 105. Several configurations of the mounting system

6.5 Conclusions

This chapter showed the development of the second major part of the SHS: the mounting system. The main focus was reducing the transportation size and enabling self-instalment. Besides this, other improvements were made. An overview is given below.

Production

The simple production process (of the current regular mounting system) is maintained. Without the need for welding or the use of thick metal, in-house production can be performed efficiently. The material variety is reduced by using the same profiles for the panel supports, the vertical- and the horizontal supports. The higher availability of the used materials make the supply of mounting systems more reliable.

The production costs for the mounting system and panel supports can be found in appendix L. Where the costs for a regular solar panel and mounting system remains approximately similar, the price for a large system increased. This is because the increase in power and reduction in size, that was accomplished by using a more expensive solar panel, was perceived more important.

Transportation

For making self-installation and transportation by motorcycle possible, the transportation size (of especially the large mounting system) needed to be reduced.

The mounting pole is only provided with a first system and requires a transportation volume of 9 litre. The panel supports can be transported within the solar panel's box, making an expansion package even more compact.

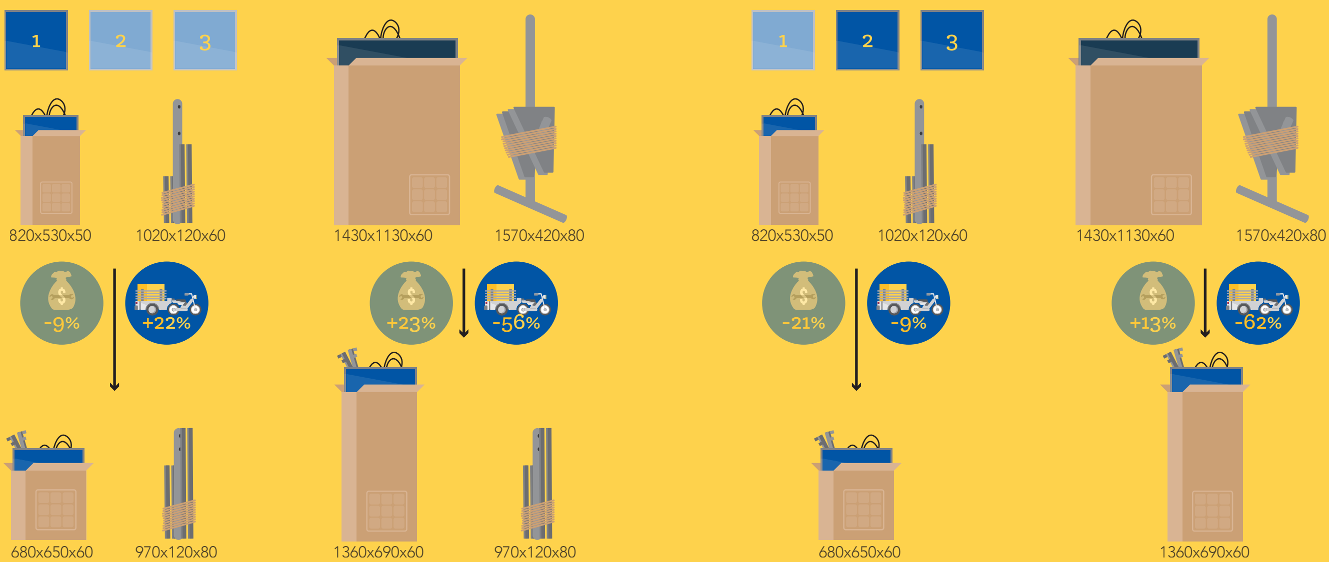
Although the transportation volume of a first regular solar panel slightly increases (35,5 litre instead of 29), an expansion would require less volume (22 litre) since no mounting pole is needed. As mentioned before, the transportation volume of expansions is more important.

More relevant than the regular SHS, is the transportation volume of the large solar panel and its mounting system. With the reduction in size of both the solar panel and the mounting system, the transportation volume is reduced from 150 litre to 66 litre for the first system and 57 litre for an expansion. This reduction in size is an important step towards a self-installable SHS. It makes it feasible to let customers transport their expansion home.

Installation

The installation of a core system, performed by a technician, is comparable to the installation of the current regular mounting system. The installation steps, however, are easier to perform. This is achieved by the reduced weight and the allowance of tolerances in critical installation steps. Moreover, the installation can be performed by one technician.

Expansion panels can be self-installed since the actions that are performed are simple and light. Installing a large solar panel would barely take more effort than cleaning an already installed solar panel; a task that customers already perform.



Delft University of Technology

KAMWORKS

7.

7 The next generation Solar Home Systems

With the completion of the battery box (chapter 4) and the mounting system (chapter 6), the lamp kit is the last part of the SHS that is left undiscussed. After this part of the system is introduced, the comprehensive design of the next generation Solar Home Systems will be presented. This chapter concludes the design project by evaluating the design to the focus topics that were defined at the start.

7.1 Lamp kit and display

The lamp kit, that will only be provided with a core SHS, exists out of four (LED) light bulbs, light switches and the required wiring. The display box will be included in the lamp kit, since only one display (and SIM board) is needed per household.

7.1.1 Light bulbs

An evaluation amongst the technicians showed that the lights are often installed in the same places: the living room, the cooking area, the toilet and the open space below the house. Currently, four 9W LED light bulbs are provided with a Solar Home System, although the lights do not need to be this bright throughout the whole household (i.e. in the toilet and the cooking area).

From a data analysis of user profiles, a quarter of a large Solar Home System's capacity is used, on average, for the lighting (Kamworks, personal communication February 1, 2017). For a regular SHS this implies that nearly half of the capacity (46,4%) is used for the lamp kit, leaving little energy for additional appliances. By providing two 9W and two 5W LED light bulbs, the energy consumption of the lamp kit is reduced by 22%. In this way, more energy becomes available for other appliances (figure 106).

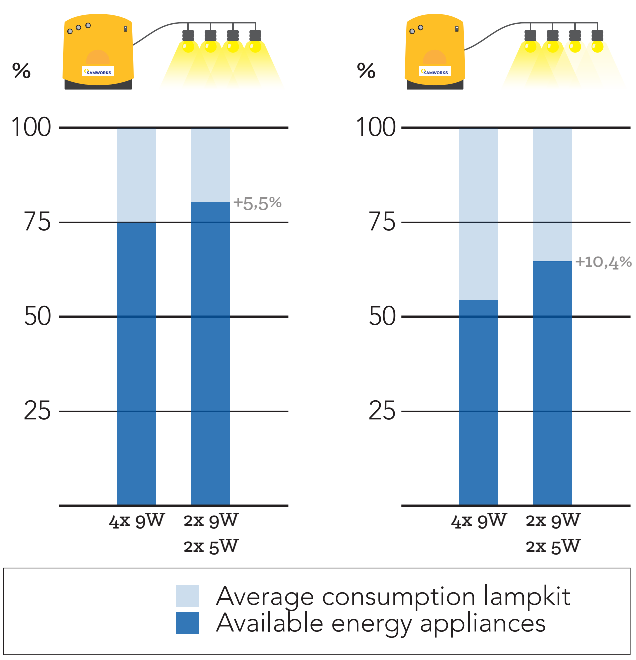


figure 106. Average consumption lampkit

7.1.2 Display box

The use of a locally bought tin box for the display, as it was proposed by Siebinga (figure 107), turned out to not be feasible. Mass produced tin boxes are nowhere to be found, while locally produced boxes have a poor appearance and finishing. Moreover, Kamworks would prefer to use a material that relates more to the properties of the battery box.

A simple (mass produced) box will be cheaper than a box produced with the VRTM process. Since the display box does not need to house exceptional parts, a standard box would be suitable. Based on the dimensions of the two PCBs and the required space for the antenna, a standard box was selected that can be ordered in multiple colours at several suppliers in China (HFJXC, 2010). To create a coherent appearance, the box can be ordered in the same colour as the battery boxes (figure 108).

The front of the box needs to be adjusted to fit the display and SIM board. Holes are drilled in the front of the box for the LEDs and the countersunk bolts that hold the display board in place. The display sticker, designed by Siebinga, cover the bolts. This sticker provides the user with information about the energy consumption, remaining energy, functioning of the SHS and payment status. The screws that mount the display box to a wall (or pole), will be sealed with warranty stickers after installation.

The display box, that also houses the SIM board, transmit the data about the SHS from and to Kamworks. It allows the users to pay their monthly fee and gives Kamworks the possibility to remotely switch off a system. To prevent users from disconnecting the display, a protocol was integrated in the software that immediately switches off all systems when the box is disconnected.

7.1.3 Stickers

Currently, several other stickers are used for the battery box (figure 17, p.30). Their purpose is briefly evaluated, after which the final layout of the battery box is determined.

Kamworks logo
This sticker, that is placed on the front of the box, is mainly for promotional purposes. Both the English and Khmer logo are showed, since not all literate Khmer can read their written language too. Besides, the phone number of Kamworks' hotline is mentioned too.

Cellcard logo
With Cellcard as provider of the SIM cards, this collaboration is very important for the mobile platform. Therefore, Kamworks agreed to promote their brand on the box.

Recently, the Solar Home Systems experienced connectivity issues in certain rural areas, due to the reach of Cellcard's network. Therefore, a collaboration with a second provider (Metphone) was established. Logically, this means that Cellcard's logo will be removed from the battery boxes.

Good solar label
A good solar label is applied to the front of the box, since Kamworks is a certified supplier of the good solar initiative. The label shows the quality of Kamworks' systems.

Unfortunately, the collaboration with the initiative has come under pressure. Employees of Kamworks noticed that competitors, that are also certified, do not comply to the required regulations and guidelines of the label (e.g. only one year of warranty is offered instead of the required two). Although this issue has been brought up to the organisation behind the good solar initiative several times, there are no signs that there will be consequences for these companies.

On the long term, these affairs may lead to a damaged reputation and distrust towards the good solar label. Kamworks decided to dissociate itself from the label by not using it in any promotional tools anymore, to prevent the brand being affected by these worrying developments.

New USB sticker
The yellow colour of the battery box makes Kamworks' SHS recognizable. Where the box will be seen every day by its users, the branding will be implemented more subtle. A new sticker is added at the USB sockets. This sticker covers the USB board's fasteners and will contain the logos of Kamworks, as well as the hotline phone number (figure 109). To create coherency, the colours and layout are based on the design of the display sticker.

figure 107. Siebinga's proposed display box by R. Siebinga

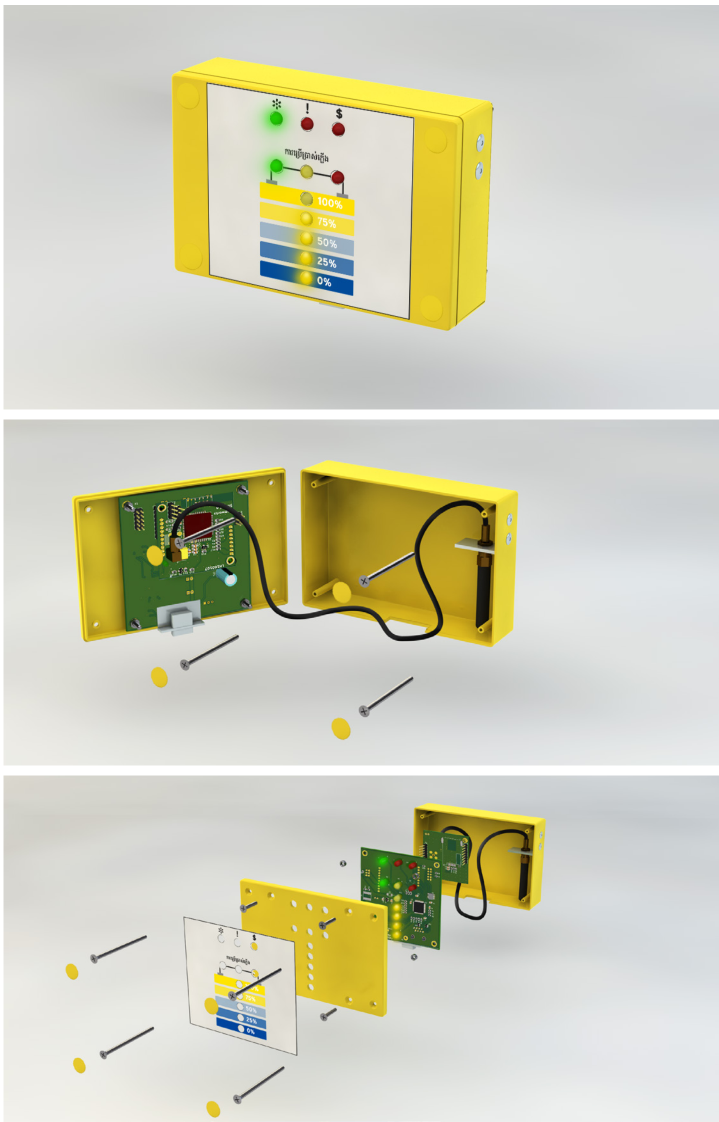


figure 108. The display box

7.2 Overview

At the start of this project, the mission–making clean energy more accessible to rural Cambodia–was divided into four focus topics:

1. Modularity: lower costs and simplified stock
2. Expandability: two SHS sizes and potential self instalment
3. Transportation: reducing the physical size
4. Supply: reliable supply and production

By developing a Solar Home System series that takes these topics into account (figure 110), a design could be presented that contributes to this mission. Each topic will be discussed below, showing how the redesign contributes to the improved accessibility of clean energy in the remote parts of Cambodia.

7.2.1 Modularity: a simplified, affordable product

With the design of two different system sizes, costs were reduced by using standardized parts and less unique components. The integration of electronics, an improved battery box and the design of a universal mounting system contributed the most to the cost reduction. The assembly of the battery box was reconfigured to allow easy repairs, while the mounting system was redesigned for easy installation.

Currently the regular and large SHS are sold for $450 and $595, providing a profit of respectively $180 and $250 per sold system. Kamworks wants to maintain these profit rates, so they will be added to the production costs of the redesign (figure 111). This results in the retail prices for the redesign:

	Core	*Expansion*
Regular SHS	$400	$350
Large SHS	$530	$480

Many Solar Home Systems are sold on credit. On the one hand this is to avoid the upfront investments, on the other hand this is to provide themselves with the guarantee that the system will be repaired when issues occur (§2.4.2). Since the warranty of the current SHS is two years, the loan would be repaid in this period too.

With the simplified design and enabling more efficient service visits, Kamworks decided to extend their warranty period with an additional year. The extended warranty allows the loan to be repaid over a longer period. Although more interest will be paid, the monthly fees will drop. Where the current systems (that are purchased through an MFI loan) would be repaid with a monthly fee of $24,44 or $31 (appendix C), the lower production costs and a three-year repayment schedule lower the monthly fees for a first SHS to $15,22 or $20,17 (appendix M). These monthly fees are approximately half of the energy expenditures of the lower social class (figure 11, p.26), making the systems affordable to them (§2.2.1). This adds a quarter of the rural population to the potential target group (figure 10, p.26).

7.2.2 Expandability: self-instalment for expansions

Two system sizes are developed that convey coherent aesthetics. With the offer of these systems, a customer can decide what capacity they initially need and, when needed, how to expand their system.

After a technician has installed a first SHS, that includes a mounting pole that can support up to three panels, a customer can expand their system through self-instalment. The Solar Home System can be expanded with a plug-and-play system.

An additional battery box is connected to the first box with two cables (one for the batteries and one for the

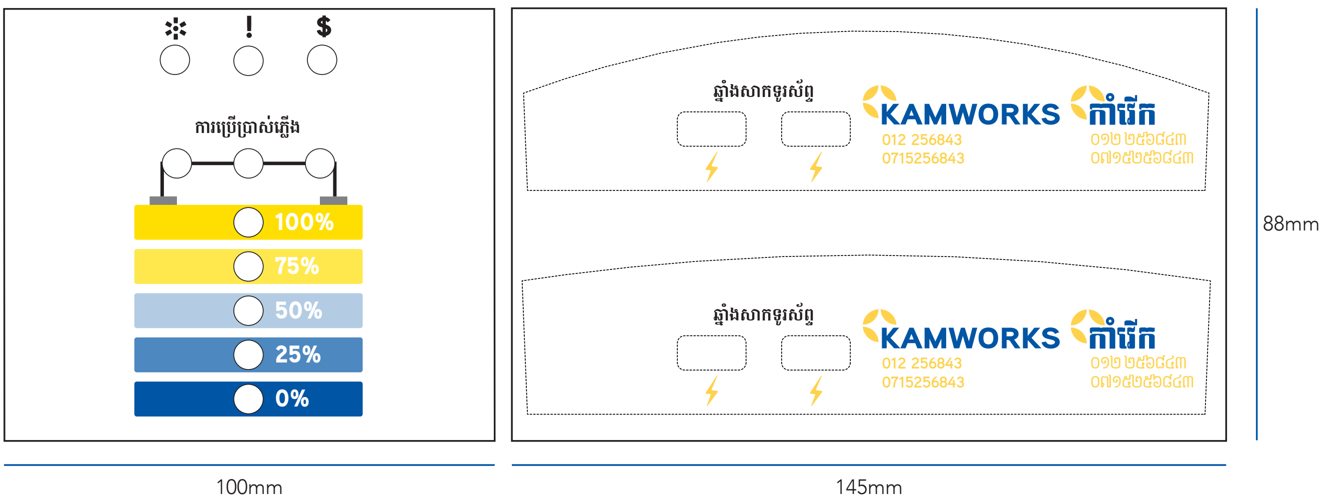


figure 109. Display (left) and USB stickers (regular SHS left top, large SHS left bottom)

display) in order to let them collaborate. The solar panel can be simply installed by sliding the first panel along the mounting pole and clamping the second panel onto it. Eventually, the solar cable is plugged into the box, finishing the installation.

With a technician installing a first system, the correct position of the solar panel is ensured. This also determines the position of additional solar panels. The technician will provide a customer with instructions and a demonstration how to use the SHS. These actions are valuable to the feasibility of expanding through self-installation. Without a skilled technician conveying its knowledge and helping a new customer to start up, the chance of installation errors would be much higher.

7.2.3 Transportation: a compact SHS

In figure 112 the reduction in transportation is visualized. Especially the transportation volume of the large solar panel and its mounting system decreased. With a mounting pole that can support multiple solar panels, the transportation volume of an expansion SHS is even further reduced. Also the transportation of an assembled battery box (instead of separate transportation of the box and its battery) contributed to a compact redesign.

In the first place, the transportation volume needed to be minimized in order to allow instalment by only one technician. With the reduction in size, the technicians can transport a Solar Home System by motorcycle instead of TukTuk. This will increase the

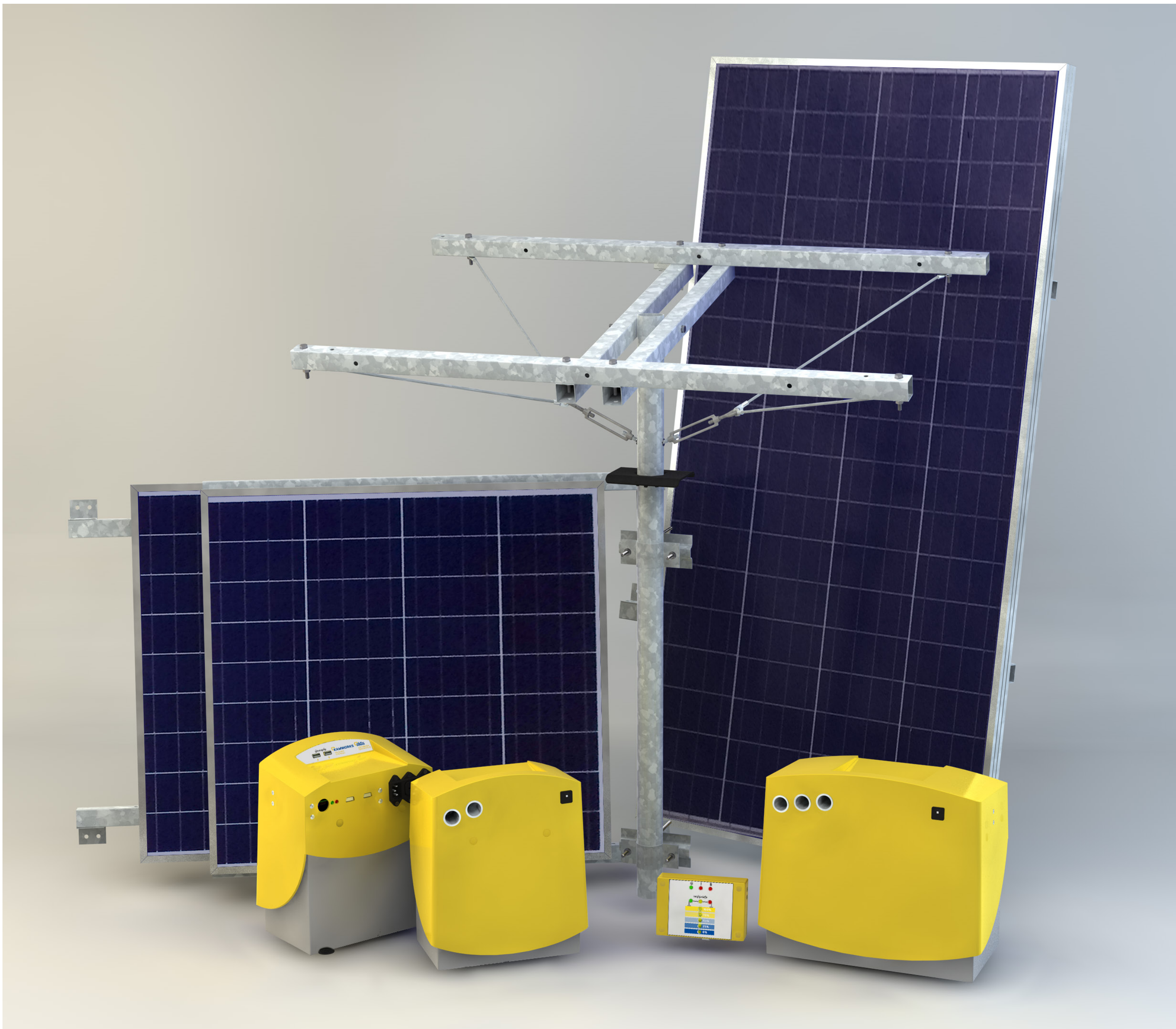


figure 110. The contents of a SHS with three systems (wiring and lights excluded)

reach of Kamworks' sales and make the provision of clean energy in the even more remote areas of Cambodia possible.

The second reason for the development of a compact SHS is the possibility of self-installation. Where the simplicity of the design and its installation would (theoretically) allow self-installation, it should also be possible for a customer to actually purchase the system and bring it home safely. The transportation of large objects by motorcycle is not unfamiliar to the Cambodian population (figure 114), but the transportation of a current (large) Solar Home System would be irresponsible, while damage during transport is probable. With the reduction in transportation volume and the amount of boxes (only two boxes are needed for an expansion), it is possible to let customers bring their own SHS home (figure 113).

7.2.4 Reliable supply and production

The improvements that are made would not have the intended impact on the enhanced accessibility, if the supply of Solar Home Systems is unreliable.

Throughout the development, solutions were evaluated on their feasibility regarding the possibilities of the local market, ensuring that the final design describes a reliable Solar Home System. The material variety is lowered and widely available materials are used, making the resourcing of materials more reliable.

The need for collaborations with workshops and factories was removed by adjusting the design of the mounting system to the available tools and machines of Kamworks. With the relatively easy to perform production steps, the chance of production errors is minimized.

Production costs

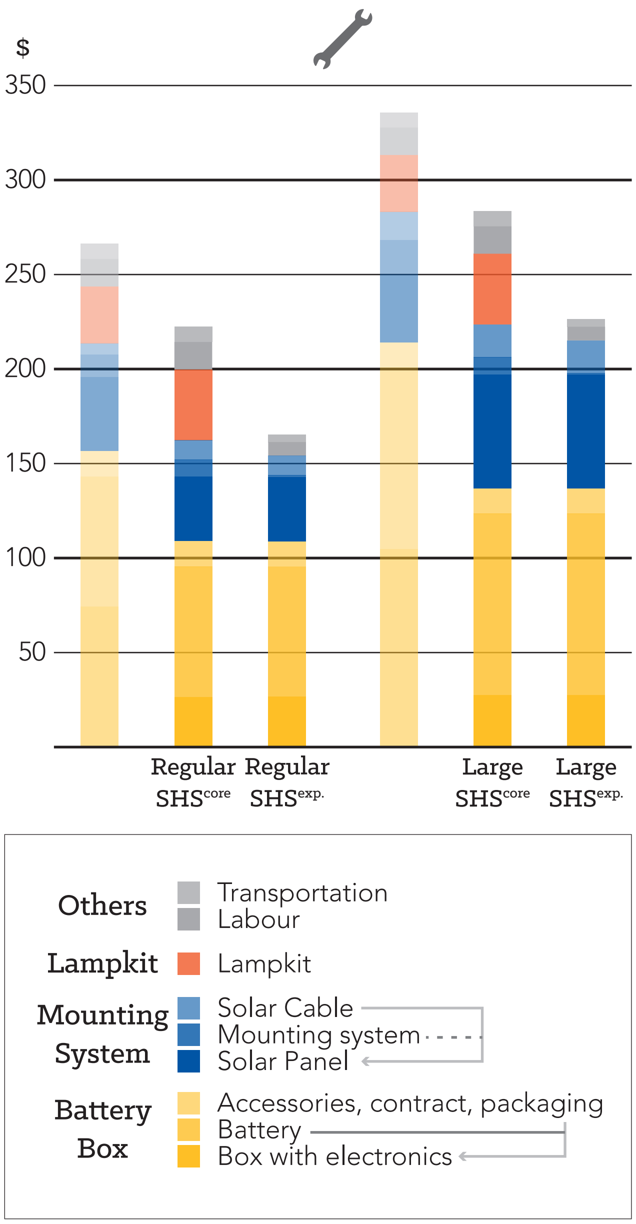


figure 111. Production costs

Transport volume

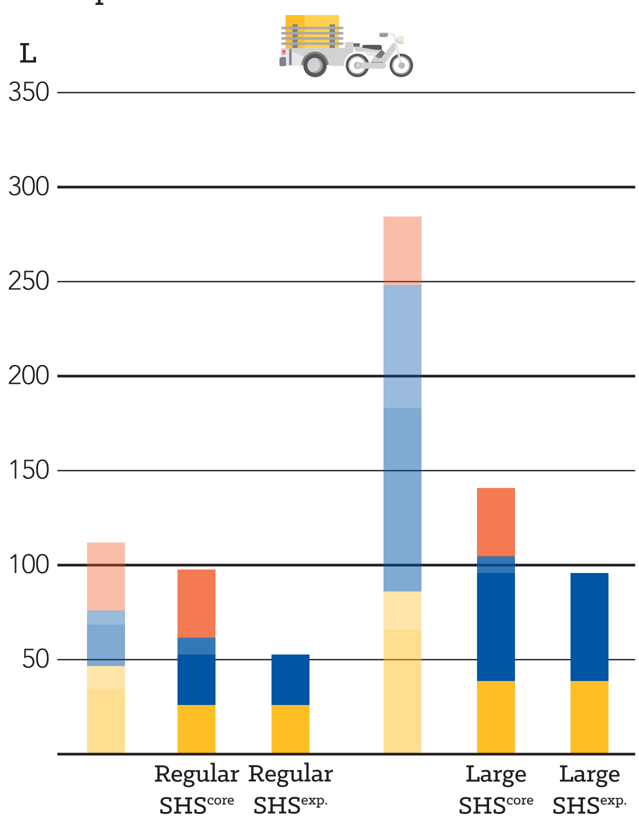


figure 112. Transportation volume

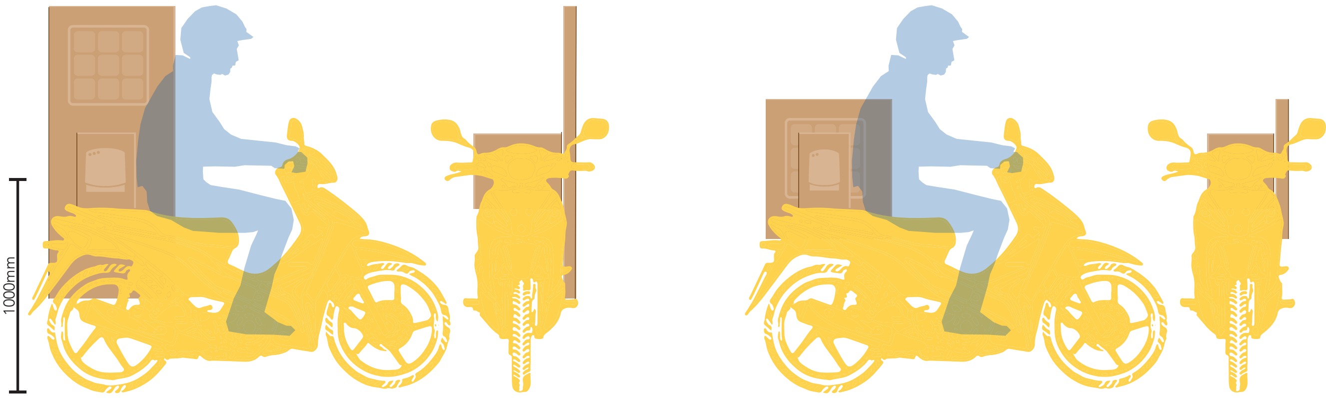


figure 113. Transporting a large (left) or regular (right) expansion SHS

figure 114. Examples of motorcycles being used for transportation in Asia (©Hans Kemp photography - © Freebirdtravelblog)

Also the production and assembly of the Battery box was optimized. The removal of one fibreglass part of the box resulted in a significant lower production (and assembly) time.

Not only the production of the Solar Home System should be reliable, but the service and repair visits need to be too. With the battery boxes having the same fundamental components and the reconfiguration of the wiring, technicians need less unique parts to bring with them during service and repair visits. With the redesign, their knowledge about the electronics apply to both Solar Home Systems.

7.3 Conclusion

In this design project, several improvements were made in order to realize an expandable, compact, multiple sized Solar Home System series.

With the warranty of three years, that is a result of an improved, reliable design, Kamworks distinguishes itself from the (certified) good solar suppliers that lack the regulations and guidelines of the good solar initiative. In this way, the credibility of the brand can be improved. With a system that can be self-installed and transported by motorcycle

With an expandable system that anticipates to the growing energy demand of the target group, a unique solution is offered to rural Cambodia. By reducing the production the costs, and therefore the retail price, the potential group of people that can afford a Solar Home System has significantly increased.

In a BoP market, bringing change is more challenging than in the more prosperous markets. This design does not contain radical changes, but it tackles the required improvements for a sustainable future of Kamworks and Cambodia.

IV Evaluation

With Siebinga's thesis and Kamworks' design brief, a broad basis was created for the project. However, it was hard to create a challenging design project out of it, where Kamworks expected me to simply implement the recommendations of Siebinga without any discussion or additional research. This made the first month quite difficult to get started. The addition of Javier to the design team helped to communicate my intentions and therefore form a proper design goal. By better communicating the intended process and regularly update the planning, the project started to progress more smoothly.

Halfway the project the sales of Kamworks were critically low, forcing Laurent to focus on the sales only. The words "we must raise sales" passed by in meetings countless times, while very little progress has been booked in that time. It seems a utopia that the sales of the Solar Home Systems will increase soon. However, the knowledge that so many people are still living without access to energy kept everyone motivated. The alarming situation of the company caused that sustainable aspects regarding the production processes could not be taken into account in this project. Dealing with reality, it has to be accepted that a product, offering a clean source of energy, is not optimized in its environmental friendliness (yet). Nevertheless, the Solar Home System provided plenty of other challenges.

Without Laurent being involved in the second half of the project too much, but with Arjen and Javier in the workshop every Wednesday, there was a weekly evaluation on the progress anyway. Where the project was very focussed on the development of a tangible end product, a lot of prototyping was done. The possibilities and the limitation of the local market were explored by doing. Riding on a motorcycle through the crowded streets of Phnom Penh, looking for that one specialized shop, to end up in a shop where they would only speak Khmer, is a description of one out of many intriguing experiences.

It could be that this project would have had another outcome if a more conceptual approach was chosen. Especially for the mounting systems, more exploration might have lead to refreshing ideas. Maybe the process has been influenced by the engineering background of Kamworks' management team, that wanted to see concrete results, or maybe it was my eager to make my hands dirty. Anyway, in the past months I have been able to develop a system that will provide a better life to the people in rural Cambodia. No radical changes were made, but important improvements were obtained. There are still steps to be taken, but it makes me happy to see that the two first systems are operating already. In general, I am very pleased with the result.

Working in a context like this (figure 115), especially with a concrete approach that this project conveys, is where my passion lays. For now, I can't wait for more challenges in the near future.


figure 115. The road to the workshop in Sre Ampil

V Recommendations

Not all problems and issues that were identified during the design project could be taken into account. On the one hand because of the limited amount of time, on the other hand because the current situation of the context, company or technologies would not allow certain developments. Although the redesign is nearly producible, some aspects still need to be verified. In addition, several several recommendations are worth mentioning.

› The electronics are up and running for the expandable regular SHS, but they still need adjustment to make it suitable for both system sizes. As soon as this is done, a second pilot test need to be performed before both system sizes can be offered as an expandable, combinable Solar Home System series.

› The brackets to connect the large battery box to the battery are not properly tested yet, since the punch and die were not adjusted yet. A precise prototype needs not be produced and tested.

› Drilling the holes for the display, cutting the glass fibre mats and placing the stickers on the front of the battery box (figure 116) are currently performed with a template. In order to ensure precision in the production process, this way of working should be expanded. For the holes in the front, back, sides and top of the battery box, aluminium sheets can be made that will indicate where the holes need to be positioned. Then, the positions can be traced after which the holes can be drilled. For the mounting system an unassembled set of (example) parts should always be present so that the hole and bracket positions can be compared before putting them in stock. In this way, production (and installation) errors can be prevented.

› It might be possible to replace the cable tensioners by a long bolt that is mounted through a hole 90° rotated from the hole that is used by the thread. Although the cable tensioners make the mounting system recognizable, this change can reduce the costs even more.

› The current SHS is provided with a printed user manual. When systems will be self-installed, additional manuals are needed. Since many customers are illiterate however, the manuals might not be effective. Even when the illustrations are clear, customers might not be interested in following a paper manual. A better way to show how a system can be expanded would be by making instruction videos, where the installation is explained and demonstrated by a technician. Despite Cambodia's poverty rates, most households do have access to internet.

› Since it cannot be checked if customers that buy an expansion SHS transport their system with care, an impact indicator can be applied to the battery box. If Kamworks receives complaints about a broken system, a technician can check if the allowed impact was exceeded. This limit needs to be determined first.

› Where each system is registered with several unique codes, the new configuration will require a rearrangement of the registration too. It should be evaluated how this can be done efficiently, so that the administrative steps will be simple and less sensitive too mistakes.

› The fact that one technician (instead of two) is needed for the installation of a SHS does not mean that they should fear for their jobs. Where the warranty of three years is a first step towards the improvement of Kamworks' customer service, an increase in (preventive) service visits will be the next.

› Kamworks is offering low consumption appliances like fans and DTV. During a field trip it turned out that most households also use inverters or improvised sockets, although this does not comply to the terms and conditions of the warranty. The reason for the ban on inverters comes from the good solar initiative guidelines, but the reason for this is not motivated. With Kamworks considering moving on independently from the label, it might be possible to offer qualitative inverters that are suitable for the systems.

› The way of selling the Solar Home Systems should radically change. Throughout the project the focus already shifted from door-to-door sales to community meetings. With the offering of cheaper, self-installable expansions however, shops should be opened where the SHS can be bought. The KC office can be the first location, but it needs a metamorphosis. When a system is sold, a customer needs to indicate if it is a second or third system so that the battery box can be configured before it is transported.

› To enable transport by motorcycle, a carrying rack should be developed that helps transporting all parts of the SHS. Since the majority of the motorcycles in Cambodia are a Honda Dream or Honda Wave, it is probable that the rack should be mounted on one of these types.

› Besides a carrying rack for technicians, it might be an idea to provide materials for mounting the boxes to the motorcycle properly. Also it should be considered to include some kind of safety gear that can help installing the solar panel securely.
› For the long term, the adoption of alternative technologies for the battery can make the transportation even easier. When other technologies will develop, resulting in more affordable prices, the batteries may be replaced in future SHS generations. Currently (heavy) lead-acid batteries are used, but even this technology is developing. Ritar, the producer of the current batteries, offers high performance lead-acid batteries of half the weight already.

› During the project is turned out that the knowledge within Kamworks about available materials and specialized shops is not well documented. When this would be improved, future development can be performed more easily.

› The technicians will have a software updater (figure 117) that can update or reset a power board. Since this device will be taken into the field, a protective box should be made. During this project a small 3D printable box was provided to Kamworks, but it should still be printed.

› For the installation of the mounting system, a separate battery with inverter is used for the tools used for drilling and making the hole in the roof. Ironically, the SHS is a solution that prevents this way of energy use. It would be good to invest in tools with rechargeable batteries.

› Last but not least, it turned out that technicians receive a lot of information from Kamworks' customers about their opinion about the system or issues they experience now and then. Although Kamworks asks their technicians to fill in a service visit form, this form is left mostly blanc. It is clear that this way of communication does not work and result in the lost of possible valuable insights. By putting more effort into the communication with technicians, the service can be improved.

figure 116. A template for positioning the stickers

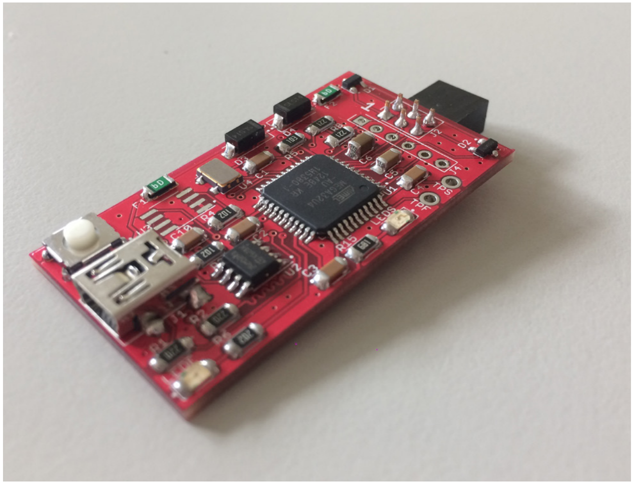


figure 117. Software updater for the new power board

VI References

1. Cellcard, 2016. "Kamworks sponsorship.", Retrieved August 19, 2016, from http://www.cellcard.com.kh/en/press-release/post/kamworks-sponsorship/
2. Central Intelligence Agency (CIA). "The World factbook." Retrieved September 15, 2016, from https://www.cia.gov/library/publications/the-world-factbook/geos/cb.html
3. Composite integration ltd., 2008. "Composite Mould Building for Vacuum RTM"
4. Energy Invormative, 2016. " Which Solar Panel Type is Best? Mono- vs. Polycrystalline vs. Thin Film." Retrieved December 21, 2016, from http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/
5. Good Solar Initiative, 2016. "About." Retrieved August 19, 2016, from http://www.goodsolarinitiative.org/
6. Good Solar Initiative, 2016. "PB-SHS80-V1." Retrieved August 19, 2016, from http://www.goodsolarinitiative.org/pb-shs80-v1.html
7. HFJXC, 2010. "Shen Zhen Hong Fa Shun Da Mould Co.,ltd Product catalogue."
8. Knoema. "Poverty and Equity database 2015." Retrieved September 5, 2016, from https://knoema.com/WBPED2016/poverty-and-equity-database-2015
9. Lighting Global, 2015. "Off-grid Power and Connectivity - Pay-As-You-Go Financing and Digital Supply chains for Pico-Solar." Market research report.
10. NASA Langley atmospheric science data center, 2017. " NASA Surface meteorology and Solar Energy: RETScreen Data." Retrieved March 22, 2017, from https://eosweb.larc.nasa.gov/cgi-bin/sse/retscreen.cgi?email=rets%40nrcan.gc.ca&step=1&lat=11.544873&lon=104.892167&submit=Submit
11. People in Need, 2016. "Cambodia improving lives with solar energy." Retrieved August 18, 2016, from https://www.clovekvtisni.cz/en/articles/cambodia-improving-lives-with-solar-energy?src=42
12. Photovoltaic-software, 2016. " How to calculate the annual solar energy output of a photovoltaic system?" Retrieved December 19, 2016, from http://photovoltaic-software.com/PV-solar-energy-calculation.php
13. Siebinga, R., 2016. "The redesign of a Solar Home System - An expandable and understandable solar home system for rural Cambodian families." TU Delft
14. SNV Netherlands Development Organisation, 2015. "Quality Charter: Technical & Service Quality Standards for Accredited Solar Suppliers"
15. Solar Electricity Handbook 2016 Edition. "Solar angle calculator". Retrieved December 9, 2016, from http://solarelectricityhandbook.com/solar-angle-calculator.html
16. The Worldbank group, 2012. "Access to electricity, rural (% of rural population)." Retrieved September 4, 2016, from http://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS
17. The Worldbank group, 2012. "Access to electricity (% of population)." Retrieved September 4, 2016, from http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS
18. USAID Private Financing Advisory Network-Asia, 2015. "The business case for: Solar PV in Cambodia." Private Financing Advisory Network (PFAN) – Asia Program
19. UNCDF, 2016. "About SHIFT." Retrieved August 23, 2016, from http://shift.uncdf.org/
20. UNDP Cambodia, 2008. "Residential Energy Demand in Rural Areas - An empirical study for Kampong Speu and Svay Rieng."
21. WWF, 2016. "Power Sector Vision - Towards 100% Renewable Electricity by 2050". Greater Mekong Region Cambodia Report.