ESTONIAN ACADEMY OF ARTS

1918 TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

BATTERY FOR OUTDOOR USAGE IN COLD TEMPERATURES

Karl Annus

MAY 29, 2014
TALLINN UNIVERSITY OF TECHNOLOGY

TABLE OF CONTENT

INTRODUCTION

Current paper is dealing with the problem that outdoor photographers are facing with when they go to shoot photos during winter. Performance of the battery inside the camera is dropping significantly as it is affected by the low temperature. This project is trying to solve this problem for photographers.

This project was initiated by Start-up Company of two young men. This company is so fresh that it hasn't even been registered jet. One of these two entrepreneurs is Sander Jahilo who has graduated MA in Environmental Technology at Tartu University and who is also passionate hobby nature photographer and photo enthusiast. His partner is Ardi Mäesalu who has graduated in electronics engineer at Estonian University of Life Sciences.

Problem for nature photographers is the longevity of their cameras' battery when they are out in the nature on their photo shooting trips during the winter. The colder the weather is, the shorter is the durability of the battery. Some photographers are dealing with this issue by carrying always two batteries. When one is in use, the other one is in the warm inside pocket of their warm winter jacket or some photographers hold the extra battery in their left-hand glove, so it is near to reach when battery needs to be changed. From this user behaviour these two men got the idea of designing this sort of battery that would be close to photographers' body and in the use at the same time. So it would be around the arm and connected to the camera with the wire.

To develop their idea further, they were looking for designer and they approached to the author of this paper. They needed designer to design this external battery – to give form and appearance to it. Author of this paper does not take their idea blindly, but takes one step back and starts with wider background research. Section **1 Setting the Ground** author defines the problem and describes the design methods that he follows in this project. Section **2 Discovery** consists of battery history and technology part, where brief overview of history of battery technology is given and batteries working principles are described. Also, new battery technological achievements are described in battery technology part. In Discovery section, there is also Market Research part that takes into focus existing products that could be used in solving this cold problem. And also some existing applications, where devices with batteries that have to work in cold temperatures, are described. In section **3 Define**, three alternative concepts to solve the problem are generated and evaluated. One of them is chosen for further development. Also components and materials for this concept are chosen in the Define section.

In section **4 Brief,** initial assignment and the requirements to be met are formulated. In section **5 Development**, the design concept is developed further and first mock-up is created. In chapter **6**

Delivery, the first mock-up is tested and evaluated. And finally conclusions are drawn and advice for future steps is given.

1 SETTING THE GROUND

1.1 PROBLEM DEFINITION

The main problem is that a battery loses its performance when it is exposed to cold temperatures. It is caused because low temperature affects components activity inside the battery. Ions and electrons between the battery components are moving much slower in the cold. And as electrical current in batteries lies on movement of ions and electrons, that is the reason why batteries' functionality is limited in the cold.

1.2 DESIGN METHOD

The design process has quite important role in designing good product. There are many kinds of design methods described in various design books. "They range from short mnemonic devices, such as the 4Ds (define, design, develop, deploy), to elaborate schemes, such as Archer's 9-phase, 229-step "systematic method for designers." (Dubberly, 2004, p. 6)

Current paper follows method that is developed based on Double Diamond method. It also contains Evaluation Matrix, Positioning Map, Mind Map, Prototyping and Testing methods. Following image (Figure 1) illustrates Double Diamond method and shows in which parts other methods are used in it.

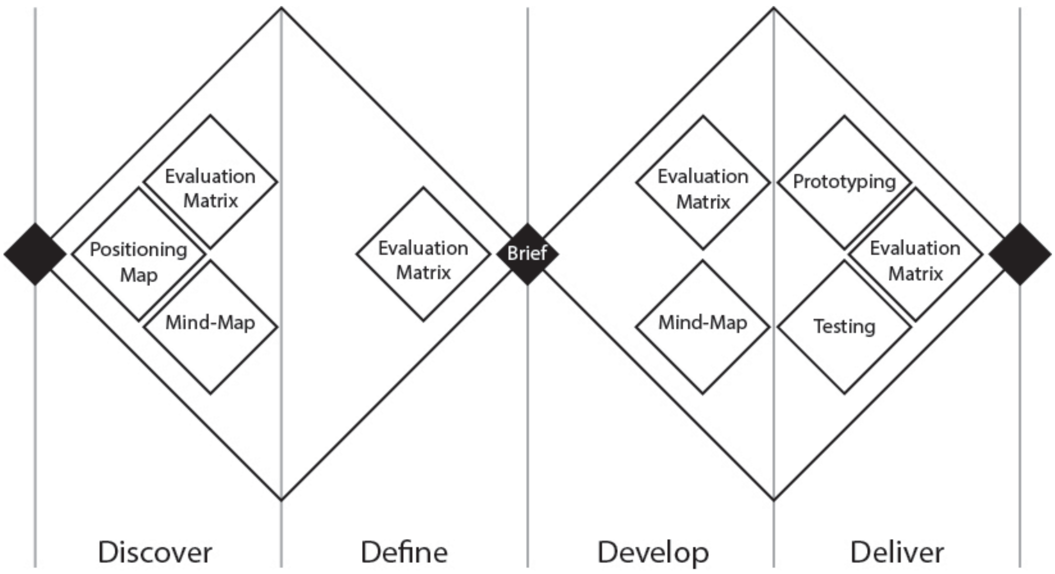


Figure 1 Double diamond method

1.2.1 Double Diamond Method

Double Diamond method was developed by British Design Council in 2005 as a simple graphical way of describing the design process. The following description of this method is based on Design Councils' research paper (Design Council, 2007).

This model divides design process into four distinct phases: discover, define, develop and deliver. These four stages are describing the different modes of thinking that designers are using, work that they are doing, work techniques and tools that they are using and goals that are set to each stage. Each phase describes a specific work in the process. Each following section starts from the outcome from the previous phase.

The first stage of the process is Discover phase. It marks the start of the project. In this phase as much information as possible about the field is gathered. In this paper battery history and technology is described. Also Market Research is conducted and user needs are identified in this phase.

The project is continued with the Define phase where user needs are interpreted and aligned into business objectives. In the end of the Define stage, alternative concepts to solve the design problem are presented and one or more concepts are chosen to be developed further. In this paper three design solutions were presented to the client and one concept was picked out for further development. This phase included constant communication with the client and potential manufacturers of component to be used in the final design.

In the end of Define phase, Design Brief is composed. Design brief identifies problems that need to be solved in the end of the design process. It will be the base for the Development stage.

In Development phase design solutions are developed and presented to the client. Also virtual and physical prototypes were created in this phase. In the early phase of design development virtual prototyping is used to reduce cost and development time. Later in the process physical models were created using traditional model-making methods.

Final stage of Double Diamond design model is Deliver phase. In this phase the developed design or service is finalised and launched in the market. In this paper (in the end of Delivery phase) resulting product is not yet launched in the market. In this paper design process ends with first testing of the prototype.

1.2.2 Evaluation Matrix Method

In multiple phases of this paper Evaluation Matrix method is used to evaluate different alternatives or to decide between many possible concepts. Evaluation Matrix is also named: weight criteria matrix, alternatives evaluation matrix, weighted decision matrix, decision grid, selection matrix, problem matrix, criteria rating matrix, solution matrix, criteria-based matrix, opportunity analysis (Tague, 2004).

It was invented by Stuart Pugh and for that reason it is also sometimes called Pugh Matrix or Pugh Concept Selection (Wikipedia, 2009). Evaluation Matrix is valuable decision-making tool that is used to evaluate alternatives based on specific evaluation criteria weighted by importance. Value of each alternative can be compared to create a rank order of their performance related to the criteria as a whole (Ouye, 2014). Primary objective of this method is to make subjective options between alternative options more objective.

For example criterias might be weight and price (Table 2). If most desirable option is low price and low weight, but one option is heavy and low price and other is light weight and expensive, then it is necessary to identify which criteria is more important. That kind of evaluation matrix is weighted evaluation matrix or weighted decision matrix (Salustri, 2013). Weight is given to each criteria and rating of each criteria of each option is multiplied by the value of each criteria's weight. That way the end result is weighted towards the option that has better ratings in more favourable/important criteria. In the example Evaluation Matrix table below (Table 2) the weight of the product is identified twice as important as price or the product, so in total the lighter product is resulting in bigger sore than score of cheaper product.

Weighted Evaluation Matrix is also the one that is used in current paper.

		Weight	**Price**	**Total**
Weights		4	2	
Product 1	Assigned	-1	1	
	Weighted	-4	2	-2
Product 2	Assigned	1	-1	
	Weighted	4	-2	2

Table 1 Example of Weighted Evaluation Matrix method

1.2.3 Positioning Map Method

In market research paragraph Positioning Map methodology is used to graphically analyse and study existing similar products on the market. Positioning map is a graphical device to study and analyse the position or perception of each of a group of competing products in respect of two specific product characteristic (Agrawala, 2010). It is a comparison of a competing products. It can help a company to classify existing products in different position categories. For example the characteristics on the axis can be Cost and Quality (Figure 2). All the competing products are positioned in this map according to these two product characteristics.

Here is one example of Positioning Map:

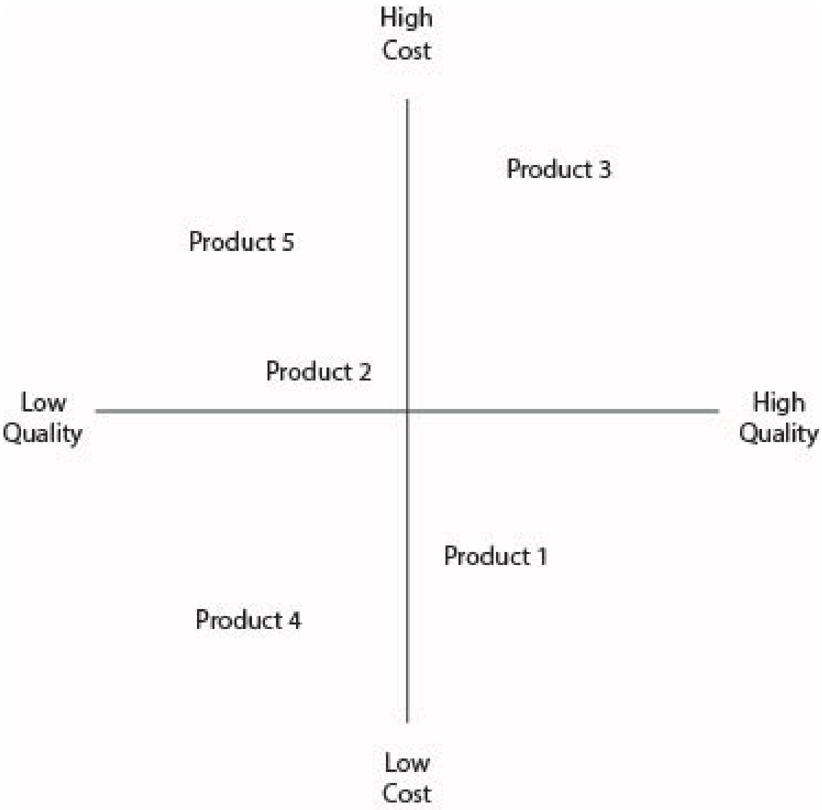


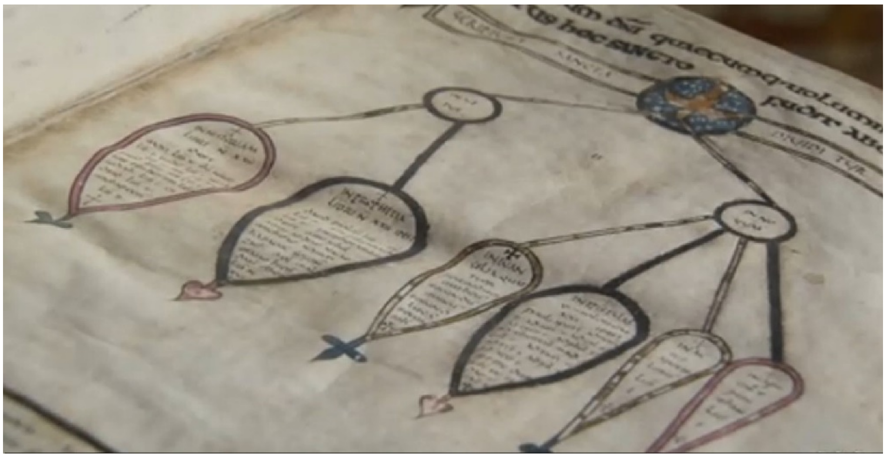
Figure 2 Example of Positioning Map

1.2.4 Mind Map Method

Mind map is a method to visually organise information. It has single starting point in the middle and it branches out and divides again and again. Components of the mind map can be words, images, lines and other visual illustrations. In current paper most simple version of mind map is used. It consists of just words, abbreviations and lines drawn between them to show relationships and connections.

This method was invented by Tony Buzan (Buzan, 2011). But what he did was just take quite well known technique, narrowed it down with his ten rules and 'invented' a name, which he then tried to trademark (Gee, www.mind-mapping.org, 2008). The first use of such visual layout of information is the Tree of Porphyry from 3rd century C.E. (Gee, 2014). It was made by Porphyry of Tyre, who was a Greek philosopher who lived from c.233 to c.309, C.E (Emilsson, 2011). But no examples of such diagrams by Porphyry have survived, but here is one example of a Bible (Picture 1) produced in the

Anglo-Saxon kingdom of Northumbria and was commissioned as a gift for the Pope in 692 C.E (Alex, 2010).



Picture 1 Codex Amiatinus, the earliest surviving example of a complete Bible (Alex, 2010)

1.2.5 Prototyping

Virtual and physical prototyping is also considered as one design method. In current paper it is done in delivery phase. The mock-up made in the final part of this paper is not functional. It is just imitating the shape and appearance of the design.

1.2.6 Testing

The prototype testing is executed in the end of design process to get feedback and proof to the concept.

1.3 DEFINITIONS

Battery Capacity – a measure (typically in Amp-hr) of the charge stored by the battery, and is determined by the mass of active material contained in the battery. The battery capacity represents the maximum amount of energy that can be extracted from the battery under certain specified conditions. (Honsberg & Bowden, 2013)

Battery memory effect – loss of capacity that occurs when a battery is recharged before it is fully depleted. (www.economist.com, 2002)

Energy density – the amount of energy stored in a given system or region of space per unit volume (www.dictionary.reference.com, 2014). In other words, relation between the size and capacity of the battery cell.

Specific Energy – amount of energy per unit mass (Wise Geek, 2014). In other words, relation between the mass and capacity of the battery cell.

Output Voltage – voltage released by a device. Output voltage produced by a battery is called electromotive force, or EMF. This term is a misnomer, as it's not actually a force: Instead, it's the energy made available by the mechanism that generates the electricity. (Robert, 2014)

Voltage cut off – Not all stored battery energy can or should be used on discharge, and some reserve is almost always left behind on purpose after the equipment cuts off. The cut-off voltage is the prescribed lower-limit voltage at which battery discharge is considered complete. For example most cell phones, laptops and other portable devices turn off when the lithium-ion battery reaches 3V/cell on discharge, and at this point the battery has about five percent capacity left. (Battery University, 2011)

Discharge rate – In describing batteries, discharge current is often expressed as a C-rate in order to normalize against battery capacity, which is often very different between batteries. A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity. (Team, 2008)

Flat Discharge Profile – The flat discharge is representative of a discharge where the effect of change in reactants and reaction products is minimal until the active materials are nearly exhausted. (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 3.3)

Power Density – The rate of energy flow (power) per unit volume, area or mass. Common metrics include: horsepower per cubic inch, watts per square meter and watts per kilogram. (OpenEI, 2010)

Load – Energy consumption of a piece of equipment (Business Dictionary, 2014). The power consumed by a circuit (Wikipedia, 2014).

DC – Dc is short for direct current. This is the current type used in electronic devices' batteries.

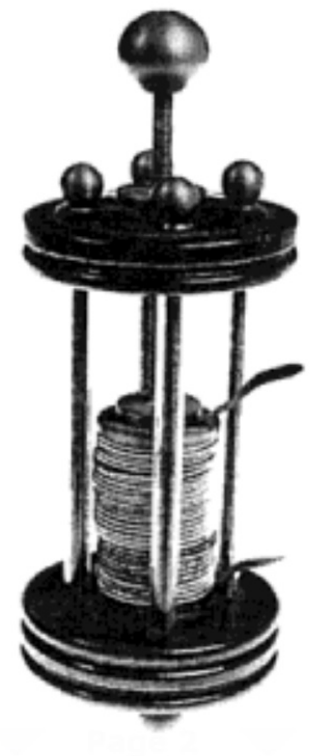
AC – AC is short for alternating current. This is the current type that is also in the domestic and industrial electric circulation.

2 DISCOVERY

Discovery phase of this project focuses on two main fields – cameras and batteries. Battery part consists of brief history of the battery, battery technology, market research and recent advances in battery technology. Also devices that have been designed to work in cold conditions have been considered. Camera and photography part of this chapter describes different types of outdoor photography and identifies cameras from five main manufacturers.

2.1 BATTERY HISTORY

Written evidence of battery history began 200 years ago. However, use of batteries go way back to ancient times. It is believed that Parthians who ruled Baghdad ca. 250 bc used batteries to electroplate silver, and also that the Egyptians were able to electroplate antimony onto copper over 4300 years ago (Buchmann, 2001).



Picture 2 Voltaic pile (Vincent, 1997, p. 2).

From the written evidence we know that the first experiment related to batteries was frog leg experiment conducted by Luigi Galvani in 1791. His experiments were continued by Alessandro Volta who discovered in 1793 that electricity could be produced by placing two dissimilar metals on opposite sides of a moistened paper (Lower, 2007). In a letter to Royal Society (London) in 1800 he wrote down the first authenticated description of an electrochemical battery (Vincent, 1997, p. 1). In this letter he described his invention of the first battery, voltaic pile (picture 2). In Encyclopedia of Electrochemistry voltaic pile is described as follows: “The original voltaic sell used two metal discs as electrodes, namely zinc and silver. Cardboards discs separated the electrodes and seawater was the electrolyte. A current was produced when the silver disc was connected to the zinc disk through an external wire. The voltaic pile established the foundation for the liquid battery type.” (Botte, 2007, p. 384)

After that first battery that used zinc and silver as electrodes and seawater as electrolyte, there have been many other experiments with many other metals and electrolytes. Figure 3 is an illustration of major events in the evolution of batteries in time.

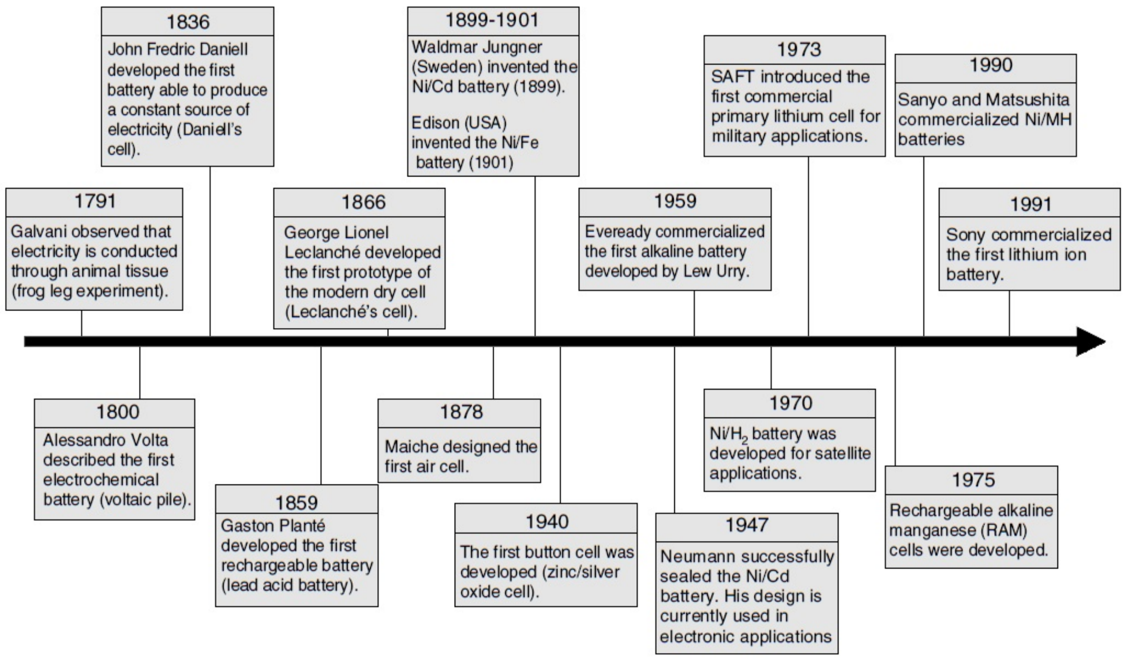


Figure 3 Timeline of the major events in the history of batteries (Botte, 2007, p. 385).

2.2 Battery Technology

This chapter is introduction to the world of batteries. It is important to navigate between different battery technologies to create most suitable design solution to solve current problem. This chapter explains the basic terminology of batteries, gives overview of history of batteries, explains how batteries are working and gives overview of different types of batteries that are used nowadays. Usually in books that write about batteries there are a lot of chemical equations to explain how batteries work. In this paper chemical equations are left out as the main focus of this paper is not in electrochemical processes and this part just tries to give general understanding of the field.

2.2.1 Basic Chemistry to Understand Batteries

To solve the current problem, it is necessary to remind some basic principles of chemistry. To understand how batteries work, we need to understand what electrons, atoms and ions are and how they react.

Atom is the smallest unit quantity of an element that is capable of existence (Housecroft & Constable, 2006). Inside Atom there are punch of positively charged particles called **Protons**. And outside of the Atom there is buzzing cloud of negatively charged particles called **Electrons**. Electrons are the key to electricity (Kurtus, 2013). The movement of electrons is what makes electrical device to turn on.

To create **electrical current** we need to get these electrons to move away from buzzing around the Atom. This is possible due to the characteristic of the electrons that they always want to be at the lower energy level (Physical Structure, 2014). If electrons are given opportunity to buzz around another atom where energy level is lower, then they leave buzzing around their current atom and move to buzz around the atom where the energy level is lower.

In normal atom there is balance between the protons and electrons. The number of protons equals the number of electrons. The **Ion** is an atom or molecule in which the total number of electrons is not equal to the total number of protons (The Free Dictionary, 2010). **A negatively charged ion** is an atom with excess electrons. Such ions are seeking out the opposite charge (positive ion). **A positive ion** is an atom which has a dearth of electrons. Such ion will seek out a negative charge whether that be another ion or electrons (Krebs, 2006). Desire of ions is to be neutral, so they seek their opposite charge and stick together. So, the heart of the battery lies is electrons trying to achieve lower energy levels and ions trying to get neutral.

In current paper it is important to understand that transportation of ions and electrons is suppressed by low temperatures. One example is brought out in Figure 4 which shows how specific energy of different secondary battery systems is effected by temperature.

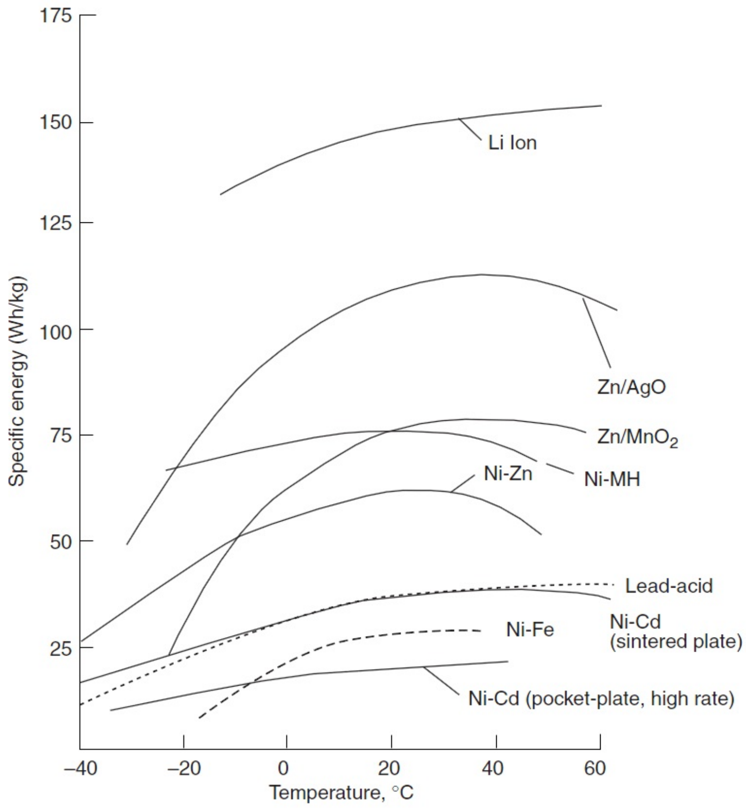


Figure 4 Effect of temperature on specific energy of secondary battery systems at approximately C/5 discharge rate (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002)

When a battery discharges in conditions of lower temperature, it will result in a reduction of capacity as well as an increase in the slope of the discharge curve (Figure 5). Both the specific characteristics and the discharge profile vary for each battery system, design, and discharge rate, but generally best performance is obtained between 20 and 40°C. (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 3.10)

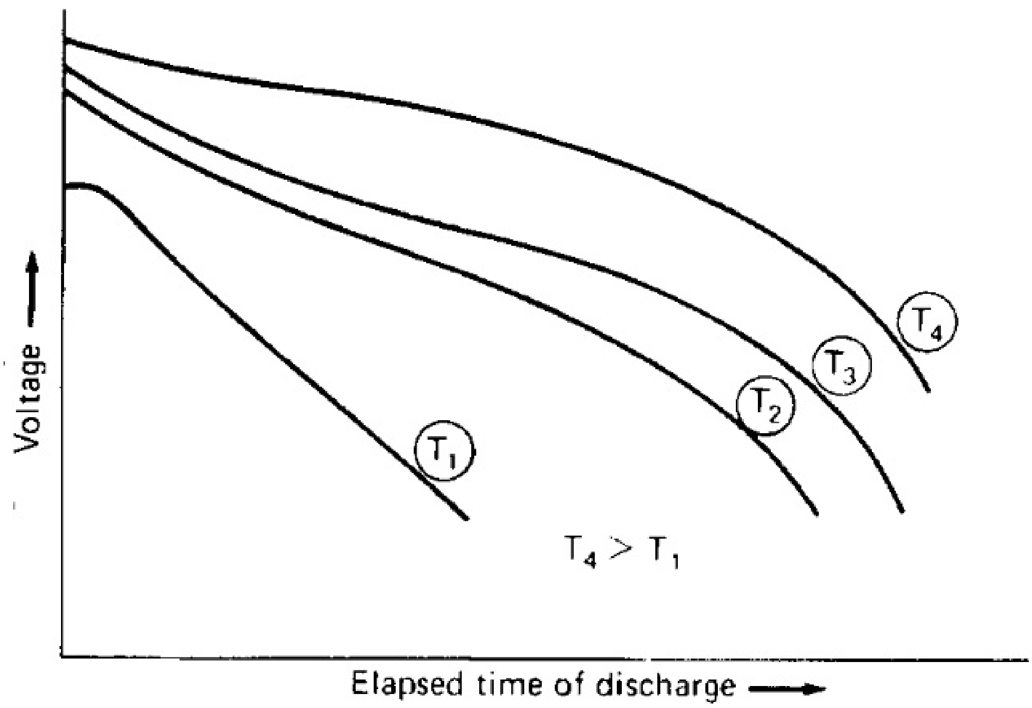


Figure 5 Effect of temperature on battery capacity. T1 to T4—increasing temperatures (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002)

2.2.2 Basic Battery Terminology

What is battery? **Handbook of Batteries** answers this question with following definition:

"A battery is a device that converts the chemical energy contained in its active materials directly into electric energy by means of an electrochemical oxidation-reduction (redox) reaction"

(Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 1.3).

Batteries can be rechargeable or not rechargeable. Not rechargeable batteries are identified as **primary batteries** and rechargeable batteries are identified as **secondary batteries**. Battery can consist of one or many electrochemical **cells**. "A cell is the basic electrochemical unit providing a source of electrical energy by direct conversion of chemical energy" (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 1.3). Cell consists of three main components: 1) **anode** – negative electrode, 2) **cathode** – positive electrode and 3) **electrolyte** – the ionic conductor. Cells are connected to each other in series or parallel depending on the desired voltage and capacity. Cells are connected in series to provide higher voltage than the voltage of single cell and if the higher capacity is required then cells are connected in parallel (Botte, 2007, p. 380).

Conventional aqueous secondary batteries are characterized, in addition to their ability to be recharged, by high power density, flat discharge profiles, and good low-temperature performance (Linden & Reddy, Handbook of Batteries, 2002, p. 22.3).

In current paper the primary batteries are out of the interests range. Focus lies on secondary batteries, as these are the ones that can be recharged.

2.2.3 How Batteries Work?

Batteries have two metallic or carbon electrodes, separated by an electrolyte. Current is created by ion exchange between the electrolyte and the anode and between electrolyte and the cathode. That would be the most simplified explanation of how batteries work. It is called Oxidation-reduction reaction.

Electrochemical oxidation-reduction (redox) reaction is activated when some electrical device (external load) is connected with battery's positive and negative electrodes. It creates path for electrons in the cathode (positive electrode) with high energy level to travel towards the anode (negative electrode) with lower energy level which is preferable environment for electrons. If these two electrode materials would be put together then all electrons would just go from cathode to anode – from high energy level material to lower energy level material. From stopping electrons taking the shortcut, barrier (electrolyte material) is added inside the battery between these two materials. That forces electrodes to create the electric circuit when battery is connected to electrical device (external load). When electrons start to move through circuit from cathode to anode, atoms in cathode start to lose electrons and they start turning into positively charged ions – cations. And atoms in anode start to turn into negatively charged ions - anions, as electrons from cathode arrive to anode. But as ions always want to be neutral, positive ions (cations) from cathode will move also to anode and negative ions (anions) will move from anode to cathode (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 1.7). But ions are not moving through the circuit like electrons. Ions are not leaving the battery. Moving is made possible thanks to special electrolyte material. So electrolyte in the battery always needs to be such kind of material that lets ions through but blocks electrons from taking the shortcut. So, as battery discharges electrons and cations are traveling from cathode to anode and anions from anode to cathode. When there is no free electrons to move from the cathode to the anode, the battery is fully discharged. To recharge the battery, we need to do these things in reverse. To get electrons back to the cathode, we need to connect battery to the energy (power supply) that forces electrons to travel back to the cathode. Cations also leave from anode through the electrolyte material and join with their lost electrons and anions move back to anode. And battery is ready to discharge again (All this process is described on Figure 6).

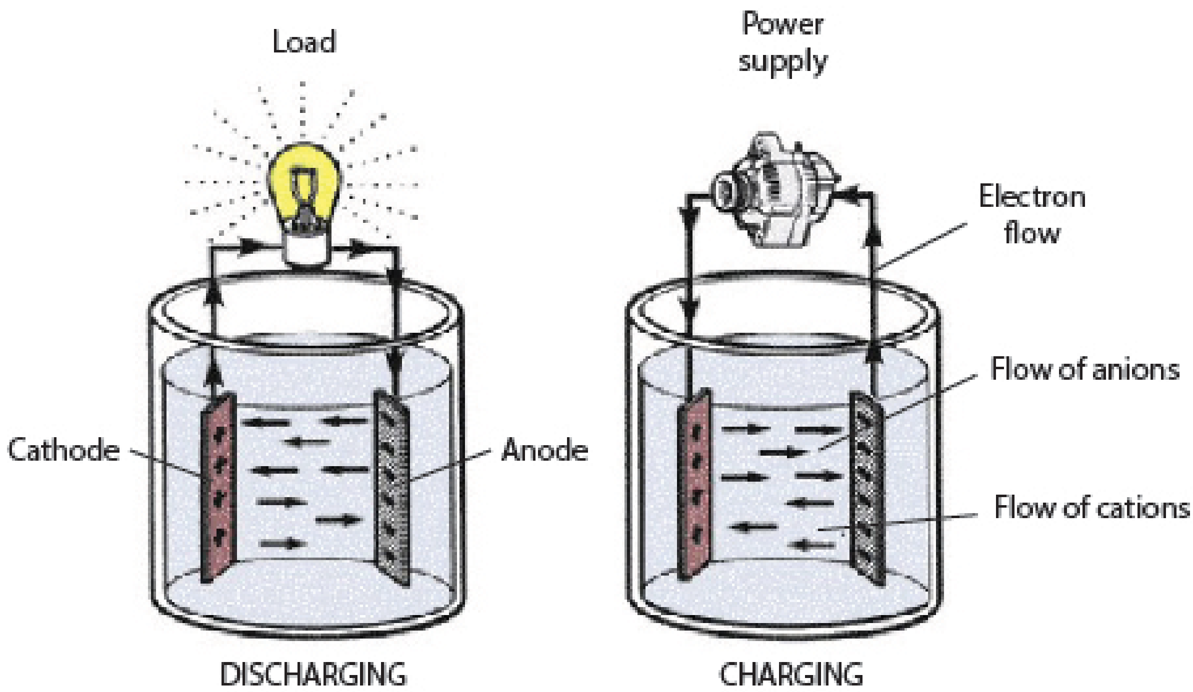


Figure 6 Movement of electrons and ions while discharging and charging battery (carbattery.com, 2010)

This part intended to give better understanding of batteries and how they work. Takeshi Akamatsu writes in the beginning of book *Energy Storage Systems for Electronics* that battery experts have this 'golden saying': "You will never understand the battery unless you make it. You will never understand it even though you make it" (Akamatsu, 2000, p. 3). So, it is good if this brief explanation managed to give at least basic understanding and knowledge about battery technology to the readers.

2.2.4 Types of Batteries

All batteries consist of three basic elements as also described in previous sections. These components are: cathode material, anode material and electrolyte material. But the specific materials used for all of them depend on the battery type and application (Botte, 2007, p. 380).

Figure below illustrates different type of batteries in graphical mind map (Figure 7).

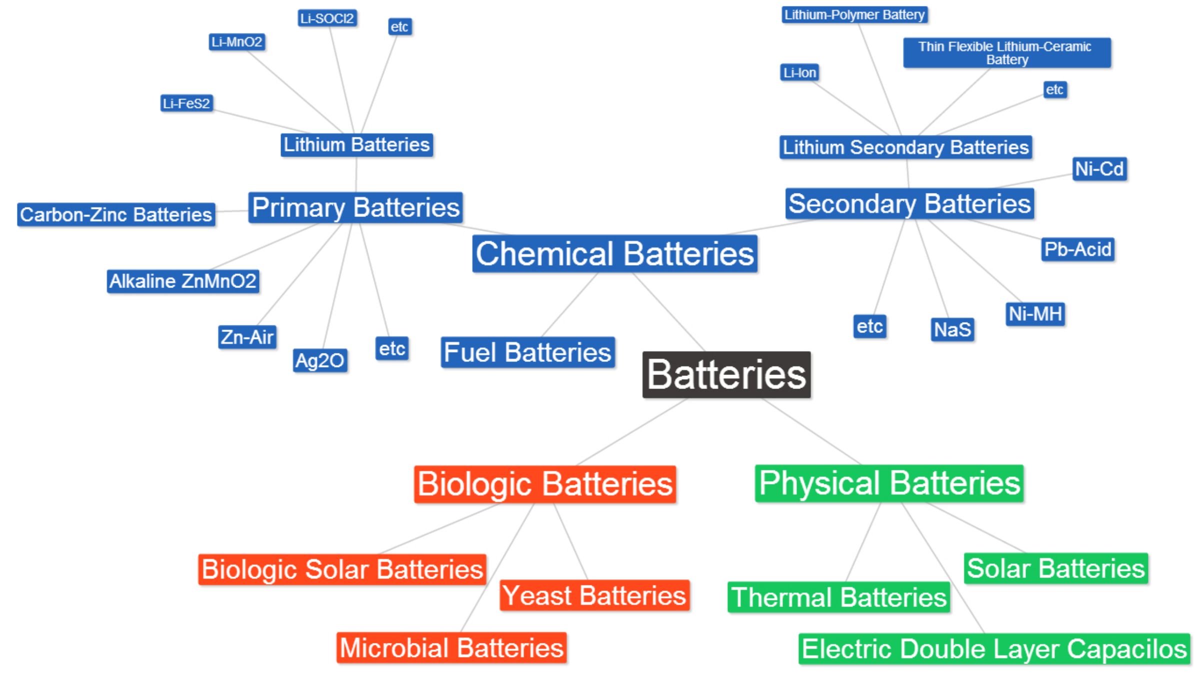


Figure 7 Battery types drawn out using mind mapping method

Batteries are different also in shapes and sizes. But the most common batteries are prismatic or cylindrical. For example typical prismatic batteries are valve-regulated lead-acid (VRLA) batteries that are typically used in cars for starting, lighting, and ignition (Rahn & Wang, 2013, p. 8). Cylindrical batteries are the ones that are used in TV remotes, flashlights, etc. Besides prismatic and cylindrical batteries, there are also button shaped batteries that are used in smaller devices like wrist-watches and cardiac pacemakers (Figure 8).

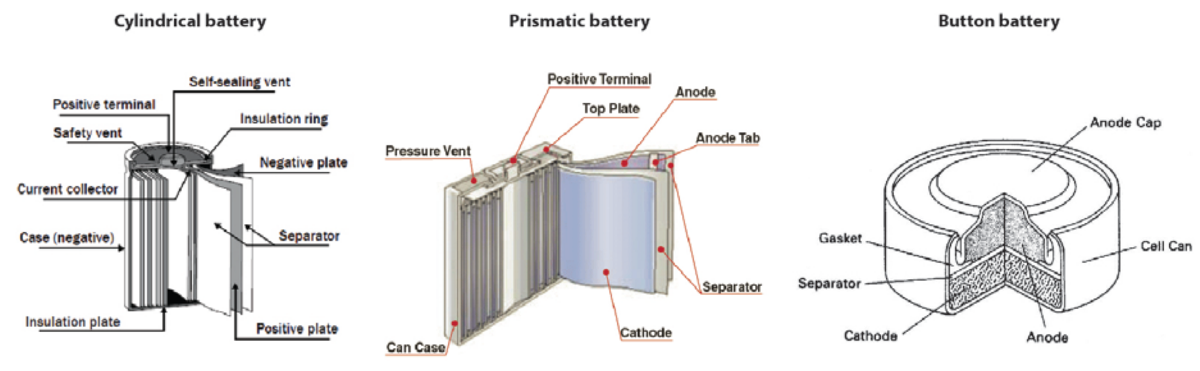


Figure 8 Shapes of batteries (www.progenyintl.com, 2011), (www.sustainablemfr.com/, 2010), (www.support.radioshack.com, 2004)

Lead-Acid Batteries

Electrolyte material in the batteries can be either liquid or solid material. Lead-acid batteries are ones with liquid electrolyte. The lead-acid battery system is by far the least costly of the secondary batteries (Linden & Reddy, Handbook of Batteries, 2002, p. 22.23). Its sales represent approximately 40 to 45% of the sales value of all batteries in the world (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 23.1). Batteries with liquid electrolyte material are also called wet cell or flooded cell batteries.

Portable electronic devices are not using batteries with liquid electrolyte materials because they might leak and damage the equipment. Instead electronic devices are always using batteries with solid electrolyte material – dry cell batteries. That kind of batteries are for example alkaline batteries.

Alkaline Batteries

Most popular alkaline secondary battery is the **Nickel-Cadmium** (Ni-Cd) battery. This kind of battery is used in heavy-duty industrial applications, such as materials-handling trucks, mining vehicles, railway signalling, emergency or standby power, and diesel engine starting. (Linden & Reddy, Handbook of Batteries, 2002, p. 22.9)

Nickel-Iron battery was also used in heavy-duty industrial applications such as materials-handling trucks, mining and underground vehicles, railroad and rapid-transit cars, and in stationary applications. It lost its market share to the industrial lead-acid battery in 1970s, as it had limitations, namely, low specific energy, poor charge retention, and poor low-temperature performance, and its high cost of manufacture. (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 22.10)

Silver Oxide batteries are very costly and have never reached commercial market. It is used in special applications, such as nonmagnetic batteries, electronic news gathering equipment, submarine and training target propulsion, and other military and space uses. (Linden & Reddy, Handbook of Batteries, 2002, p. 22.10)

Nickel-Zink batteries have characteristics midway between those of the nickel-cadmium and the silver-zink battery systems. It is used in electric bicycles, scooters and trolling motors. (Linden & Reddy, Handbook of Batteries, 2002, p. 22.10)

Hydrogen Electrode batteries are using hydrogen as the active negative material. These batteries are being used exclusively for the aerospace programs which require long cycle life at low depth of discharge. A further extension, sealed nickel-metal hydride battery, manufactured in small prismatic and cylindrical cells, are being used for portable electronics, hybrid and non-hybrid electric vehicles and. (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 22.10)

Many of the conventional primary battery systems have been manufactured as rechargeable batteries. The only one that was still in production of them in 2002 is **Zinc/alkaline-Manganese Dioxide** battery, which have a higher capacity than the conventional secondary battery and a lower initial cost, but its cycle life and rate capability are limited. (Linden & Reddy, Handbook of Batteries, 3rd edition, 2002, p. 22.11)

Lithium Ion batteries have emerged in the last few decades to capture over half of the sales value of the secondary consumer market, with applications such as laptop computers, cell phones and camcorders. Lithium ion cells provide high energy density and specific energy (see Figure 3) and long life cycle, typically greater than 1000 cycles with only 80% depth of discharge. Battery management circuitry is required to prevent over charge and over discharge, both of which are harmful to performance. The circuits may also provide an indication of state-of-charge and safety features in the case of an over-current or an over-heating condition. (Linden & Reddy, Handbook of Batteries, 2002, p. 22.11)

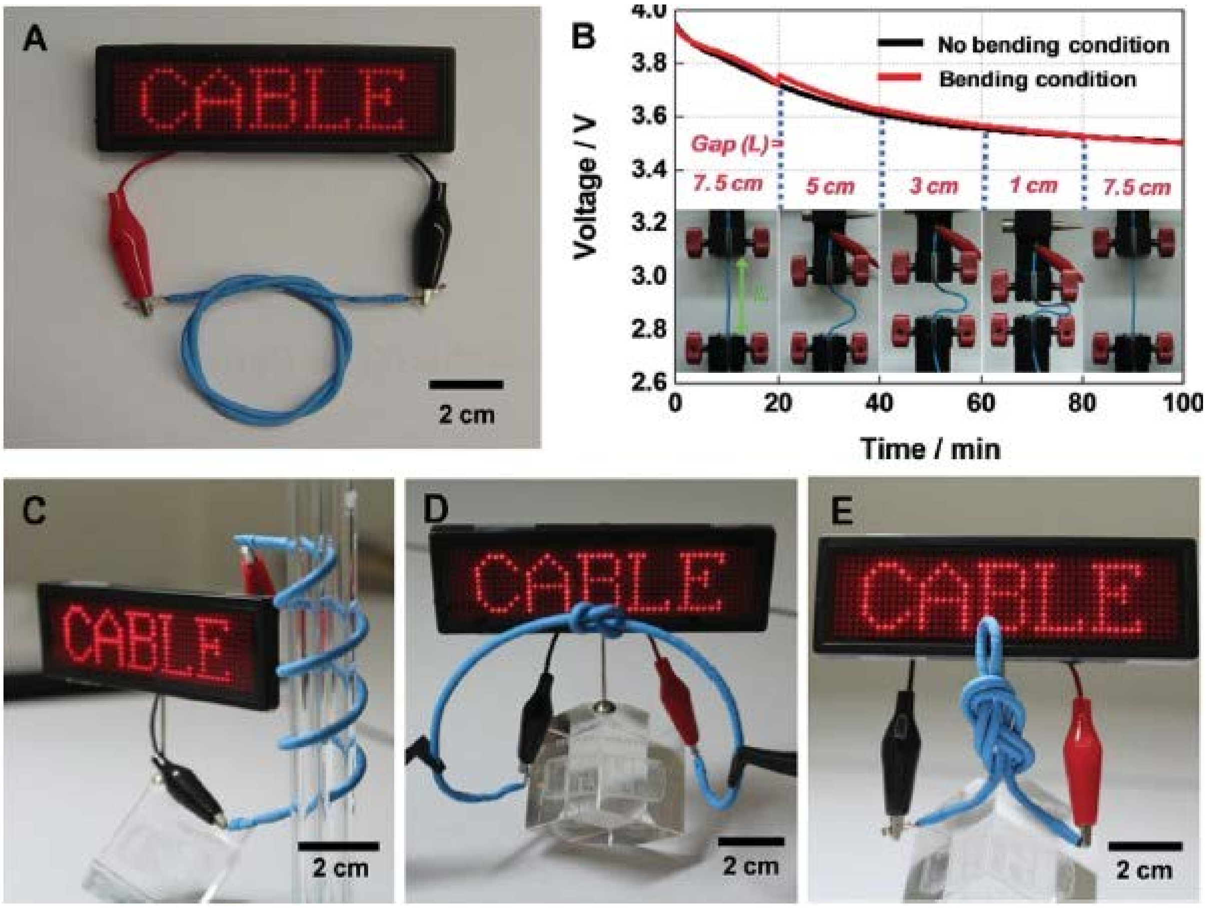
2.2.5 Recent Advances in Battery Technology

Different smartphone producers have worked on developing flexible displays for many years. The idea is to produce phones or other devices with displays that could fold up. But to make it, they also need flexible batteries. So they have worked on that also.

Honour of developing a **flexible battery** goes to New Jersey Institute of Technology professor Som Mitra and his assistant – doctoral student in chemistry, Zhiqian Wang. Their flexible battery is made with carbon nanotubes and micro-particles that serve as active components. (www.phys.org, 2013)

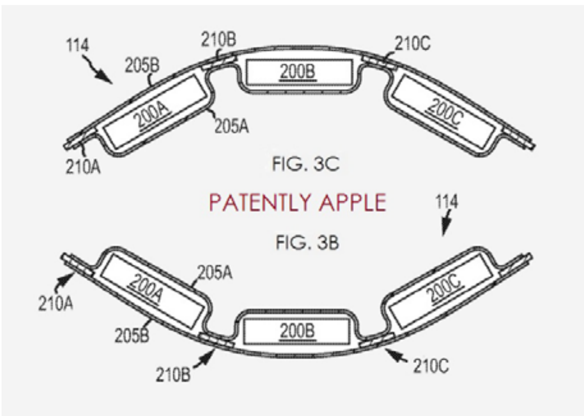
Around the same time Korean company LG unveiled three new types of batteries – curved-, stepped- and cable batteries (Hide, 2013). Curved battery is made to fit inside smartphones, smartwatches and smart glasses. Stepped battery is said to be able to fit into different small spaces and compartments that normal rectangular batteries can't (Hide, 2013). And finally the one that was found to be the most high-tech of these three – cable battery (Picture 3). It is said to be able to bend any way and can even be tied into a knot (Hide, 2013).

They say the lithium-ion cable batteries could be ready for mass production in about five years (Bourzac, 2012).



Picture 3 Cable battery from LG (Owano, 2013)

Also Apple has registered a patent for flexible battery. But in their patent they still use solid non-flexible battery cells. What they have registered is just solid battery cells connected in a strap that makes the whole package flexible (Picture 4)



Picture 4 Apple flexible battery detail drawing (Kahn, 2013)

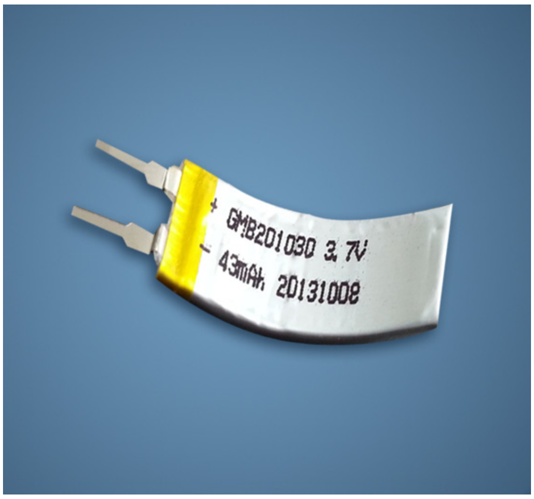
2.2.6 Prologium Flexible Lithium-Ceramic Battery Cells

Another Flexible battery is: Lithium-Ceramic Battery by Taiwanese company Prologium (Picture 5). They write on their website and also show in videos uploaded to the YouTube that heir thin battery cells are ultra-safe. In one video they demonstrate how one cell is cut with scissors and nothing happens, even led light that is connected to it remains lit up (www.youtube.com, 2014). Normally batteries light up by themselves or even explode when their damaged.

Picture 5 Prologium thin flexible Lithium-Ceramic battery cells connected in parallel (www.prologium.com, 2014)

2.2.7 Lithium-Polymer Battery Cells

LiPo cells are new kind of Lithium Ion battery cells. Same way as Li Ion battery cells, energy is produced by transferring Lithium ions, but electrolyte material is polymer composite that allows battery to be curved (Picture 6).



Picture 6 Lithium-Polymer curved battery from GM Battery (www.gmbattery.com, 2014)

LiPo cells are pouch cells. Inside the pouch, electrode sheets and separator sheets are laminated together onto each other. These cells don't need no strong metal casing, which makes these cells over 20% lighter. But to achieve the rated performance, a battery composed of pouch cells must include a strong external casing (Wikipedia, 2010).

Today there are several manufacturers who are focussing on producing flexible battery cells. For example:

1. http://ultralifecorporation.com/be-commercial/products/thin-cell/cp064243/
2. http://www.gmbattery.com/product/Curved_LiPo_batteries.htm
3. http://www.solicore.com/flexion-batteries.asp
4. http://www.bluesparktechnologies.com/index.php/products-and-services/battery-products/standard-series
5. http://www.prologium.com.tw/product_en.htm

2.3 Market Research

The aim of the market research was to find if there are similar products currently in the market and what the price range of similar battery products on the market is.

During the market research no such products were found that would have been designed specially to solve this problem of batteries not working in the cold. But if photographers want to solve this problem there are some products they can do it with. So in this part these products are analysed and compared. These product are classified by using Positioning Map method and evaluated by using Evaluation Matrix method.

2.3.1 Battery Grip

Picture 7 Nikon MB-D80 battery grip (www.marketplace.tapprs.com, 2014)

One option would be buying battery grip (Picture 7), which allows to insert two batteries into the camera. This would make battery capacity of the camera twice as big. It is attached to the base of the camera. It makes camera heavier and bigger, but extra weight can't be seen as only positive or negative aspect. It depends of the user. For some users more lighter and compact camera is preferable, for others bigger and heavier body of the camera gives more stability in taking pictures. Also Battery Grip adds vertical grip with extra shutter release which facilitates shooting photos in portrait format. But battery grips can only double the capacity of the battery as instead of one battery you can insert two batteries. Batteries are still exposed to the cold weather and effected by it. That means that with –20°C these batteries will stop working despite of bigger battery capacity. And also the price is quite high. For example battery grip Canon BG-E11 for Canon EOS D5 Mark III costs $272. This is discount price in Amazon.com (www.amazon.com, 2014). Discount price on Canon USA e-shop is $416.5 (www.shop.usa.canon.com, 2014). Also you have to buy one more battery to go in there. Canon EOS D5 Mark III uses Canon LP-E6 battery with original capacity of 1100 mAh. In Canon e-shop it costs $85 dollars (www.shop.usa.canon.com, 2014). It is possible to buy aftermarket LP-E6 batteries from other producers that produce them with bigger capacity and lower price. For example you can find 2600 mAh LP-E6 battery produced by some unknown Chinese brand Wasabi Power from $14.99 dollars (www.amazon.com, 2014). Another unknown producer offers pack of two 2600 mAh LP-E6 batteries for $22.99 dollars (www.amazon.com, 2014). So, from Canon e-shop you can get battery grip and extra battery which (together with one that you already got with the camera) provide capacity of 2200 mAh from $501.5 dollars or you can buy the same Canon battery grip from Amazon and pack of two aftermarket batteries which together provide capacity of 5200 mAh from $295 dollars. In this following analyse here these both options are taken to compare with other solutions.

Also one cheaper battery grip Canon BG-E2N is taken into the comparison. It is compatible with Canon EOS cameras 20D, 30D, 40D and 50D. They all use Canon battery: BP-511.

Also Nikon battery grip MB-D80 with EN-EL3e batteries is taken into the comparison.

2.3.2 External Battery Pack

Another option is external battery. There are different options, but all are relatively big and heavy and with big capacity – 4 to 6 times more than normal internal batteries. Some come with a pocket and you can attach it either to the tripod or your clothing (picture 8).

Picture 8 LanParte external battery (www.lanparte.com, n.d.)

Those big external batteries are also not meant to be used in cold temperatures, but as they are connecting to the camera with a wire, user can place them to their winter jackets' inside pocket and that way protect battery from exposure to the cold weather. Negative side is heavy weight and bulky design. Also wire that connects battery and camera can create some restrictions in user behaviour.

LanParte is not providing EN-EL14 dummy battery with their PB-600 external battery. They are more concentrated on dummy batteries for Canon cameras. They have lots of Canon dummy batteries available, some for Sony and for Nikon only EN-EL15 battery type, but not the EN-EL 14.

2.3.3 Evaluating Current Products

In following table are the product that were analysed in the market research (Table 2).

	Picture	Price	Voltage	Capacity	Weight	Dimensions	Compatibility
LanParte PB-600 external battery		$ 124 ($ 91)	7.4 V	6000 mAh	708.7 g	14.7 x 7.5 x 2.4 cm	Canon EOS 5D III/ 5D II/ 60D/ 7D
Takkeon MP 3450 R3 external battery		$ 199.95	5-19 V	7700 mAh (7.5 V) 4800 mAh (12 V)	462 g	17.3 x 8.3 x 2.3 cm	
Switronix PB70-24 Battery Pack		$ 299	14.8 V (for 12V devices)	4800 mAh	635 g	16 x 8.4 x 4.5 cm	Canon EOS 5D II/ 5D III/ 7D/ 60D/ 70D
Canon BG-E2N Battery Grip + 2x BP-511		$ 55	7.4 V	4400 mAh	425.2 g	150 x 123 x 84 cm	Canon EOS 20D/30D/40D/50D
Canon BG-E11 Battery Grip + 2x aftermarket LP-E6 batteries		$ 295 (discount, Amazon)	7.4 V	5200 mAh (2x aftermarket 2600 mAh batteries)	731 g	14.5 x 11.3 x 7.5 mm	Canon EOS 5D III
Canon BG-E11 Battery Grip + 2x LP-E6 batteries		$ 501.5 (Canon USA)	7.4 V	2200 mAh	701 g	14.5 x 11.3 x 7.5 mm	Canon EOS 5D III
Nikon MB-D80 Battery Grip + 2x EN-EL3e		$ 315	7.4 V	3000 mAh	536 g	7.6 x 5.7 x 3.8 cm	Nikon D80/D90

Table 2 Data of products that are evaluated

In following Positioning Maps these products are positioned to visually show their weaknesses and strengths. Two product characteristics that are important to the customers are depicted on x and y-axis. In the first positioning map the characteristics are Price and Capacity (Figure 9) and on the second Capacity and Weight (Figure 10).

Figure 9 Comparison of Capacity and Price

Figure 10 Comparison of Capacity and Weight

According to Fil Salustri, design researchers have found that a five-point scale provides sufficiently fine measurements without being overly precise (Salustri, Design Wiki, 2013). So, rating scale in following evaluation matrix is from -2 to +2.

Value	**Meaning**
-2	Performs terribly
-1	Slightly inferior
0	Neutral
+1	Slightly better
+2	Performs significantly

Following evaluation matrix is weighted evaluation matrix. Weights scale is from 1 to 5 points.

Value	**Meaning**
1	Irrelevant
2	Slightly important
3	Important
4	More important
5	Most important

Criterias for analysing and evaluating in evaluation matrix (Table 3) are following:

Working in cold: A product that is likely to perform better in cold conditions gets higher points. Battery grips are not given high rating, because batteries are still exposed to the cold. External battery packs are given slightly higher rating because they can be positioned so that they are not exposed to the cold. Weight of this criteria is 5 because this is the most important criteria for current project.

Price: Price is also one essential criteria for potential customers in decision making phase before buying the product. Cheaper products receive higher points and more expensive ones lower.

Value	**Meaning**
-2	400 – 500 €
-1	300 – 400 €
0	200 – 300 €
+1	100 – 200 €
+2	0 – 100 €

In this evaluation matrix weight for price is valued 1 because photographers are generally not very price sensitive and for that it is seen as less important criteria.

Capacity: As higher capacity means longer work time and more pictures that can be taken with one charging, then it has also huge effect in customers' decision making. Higher capacity gets higher points.

Value	Meaning
-2	0 – 2000 mAh
-1	2000 – 4000 mAh
0	4000 – 6000 mAh
+1	6000 – 8000 mAh
+2	8000 – 10000 mAh

Weight value of the Capacity is 4 as it is seen as second most important criteria for users.

Weight: As nature photographs have high levels of mobility and always have to carry all their equipment with them, weight is another important criteria for them. Lighter product gets more points.

Value	Meaning
-2	400 – 500 g
-1	300 – 400 g
0	200 – 300 g
+1	100 – 200 g
+2	0 – 100 g

Weight value for this criteria is 2 as it is not that important.

Usability: Different aspects have effected this rating. For example: ease of charging, carrying, disruptive factors in usage, etc. Product that is better to use gets higher points. Weight value is valued 3 as important.

Connectivity: A product that is easier to connect gets higher points. Products that are connected to the camera by the wire are not getting high points in this category, as wiring can limit some freedom and ease of handling of camera. Weight value for this criteria is 2 as slightly important.

		Working in cold	Price	Capacity	Weight	Usability	Connectivity	
	Weight	5	1	4	2	3	2	Totals
LanParte PB-600 external battery	Assigned	1	1	1	-2	0	0	
	Weighted	5	1	4	-4	0	0	6
Takkeon MP 3450 R3 external battery	Assigned	1	1	1	0	-1	-1	
	Weighted	5	1	4	0	-3	-2	5
Switronix PB70-24 Battery Pack	Assigned	1	0	0	-1	0	0	
	Weighted	5	0	0	-2	0	0	3
Canon BG-E2N Battery Grip	Assigned	-1	2	0	0	1	1	
+ 2x BP-511	Weighted	-5	2	0	0	3	2	2
Canon BG-E11 Battery Grip (Amazon)	Assigned	-1	0	0	1	1	1	
+ 2x aftermarket LP-E6 batteries	Weighted	-5	0	0	2	3	2	2
Canon BG-E11 Battery Grip (Canon USA)	Assigned	-1	-2	-1	1	1	1	
+ 2x LP-E6 batteries	Weighted	-5	-2	-4	2	3	2	-4
Nikon MB-D80 Battery Grip	Assigned	-1	-1	-1	2	1	1	
+ 2x EN-EL3e	Weighted	-5	-1	-4	4	3	2	-1

Table 3 Evaluation Matrix

Summary of the evaluation matrix.

Ranking for the products evaluated in the matrix is:

Product	**Rank**
LanParte PB-600 external battery	1
Takkeon MP 3450 R3 external battery	2
Switronix PB70-24 Battery Pack	3
Canon BG-E2N Battery Grip + 2x BP-511	4/5
Canon BG-E11 Battery Grip + 2x aftermarket LP-E6 batteries	4/5
Nikon MB-D80 Battery Grip + 2x EN-EL3e	6
Canon BG-E11 Battery Grip + 2x LP-E6 batteries	7

Table 4 Evaluation Matrix rank table

At the first end of the ranking table there are only external battery packs. This is because of their big capacity which was second most important criteria in the matrix and because their fairly good performance in the cold which was the most important criteria in the matrix.

The very best option according to this matrix is Lanparte PB-600. The third criteria in favour of Lanparte Pb-600 is price as it is fairly cheap product. Lanparte earned minus points in weight as it is heaviest product in the list.

Second best product according to this matrix is Takkeon MP 3450 R3. It earned same points for working in cold, price and capacity as Lanparte. But it earned minus points in usability and connectivity. This is caused because it doesn’t come with dummy battery options as it is general universal external battery pack.

Canon BG-E11 and Nikon MB-D80 battery grips earned least points from this evaluation matrix. It is because their low capacity, low rate in working in the cold and high price. They earned positive marks in weight, usability and connectivity, but as these criterias were least important, it didn’t affect their final score significantly.

2.4 OTHER APPLICATIONS WHERE BATTERIES ARE USED IN COLD TTMPERATURES

This part is taking into focus how battery thermal problem have been solved in some existing applications.

2.4.1 Satellites

Satellites are working in extremely cold temperature. So, how have satellites' engineers solved energy provision on satellites?

They have solved it by using either passive or active thermal control systems. "Passive techniques include having multilayer insulation surfaces, which either reflect or absorb radiation that is produced internally or generated by an external source. These techniques include a good layout plan for the equipment, careful selection of materials for structure, thermal blankets, coatings, reflectors, insulators, heat sinks and so on" (Maini & Agrawal, 2007, p. 132). In space, cold is not the only problem. Another factor that satellites need to be protected from is sun radiation. Golden thermal blanketing is used to retain internal satellite heat to prevent too much cooling and also to shade the satellites from excessive heating due to sunlight (Maini & Agrawal, 2007, p. 140).

Active temperature control techniques are remote heat pipes, controlled heaters and mechanical refrigerators (Maini & Agrawal, 2007, p. 141). This is unlikely that this kind of approach could be applied to solve camera battery problem. But solving camera battery problem with taking lead from passive thermal control techniques is more likely. This approach would probably be some sort of cover made from special multi-layered reflecting insulation materials that could be installed around the camera.

Another thing to study from satellites is battery technology that is used in space applications. Since the 1960's Nickel-Cadmium batteries have been used (Hill, 1998, p. 155). Also nickel-hydrogen batteries are used, but one of its disadvantages is its high cost (Maini & Agrawal, 2007, p. 142). And Lithium Ion batteries are used as they produce the same energy as nickel metal batteries but weight approximately 30% less (Maini & Agrawal, 2007, p. 142).

2.4.2 Head Lamps for Hiking

Another application where designers and engineers have had to solve this problem of battery being exposed to cold environment is hiking and camping headlamps (Picture 9).

Petzl company that specializes to producing professional hiking equipment writes on their website about one of their headlamps: "The high-capacity ACCU 4 ULTRA remote rechargeable battery allows the user to reduce the weight worn on the head while keeping the battery warm, for example under clothing, in order to optimize battery life in cold conditions" (Petzl.com, 2014).

Picture 9 Ultra Vario Belt headlamp with remote rechargeable battery by Petzl (Petzl.com, 2014)

2.4.3 Solar-Powered Camera Strap

Design student Weng Jie has created concept of Solar-Powered camera neck-strap (Picture 10). It is neck-strap that is covered with flexible solar elements to collect solar energy while photographer is outside. Energy is transmitted to the camera by wire that is connected to it. Of course camera still needs to have battery in it.

Picture 10 Solar-Powered Camera Strap concept by Weng Jie (www.boredpanda.com, 2014)

2.4.4 Battery Bracelet

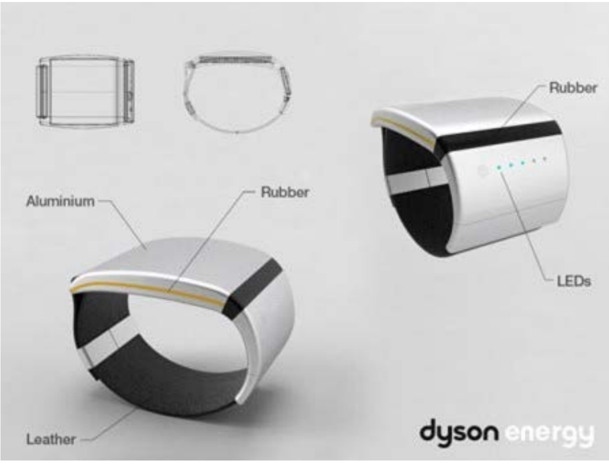
Rechargeable Lithium ion battery bracelet (1500mAh, 5.5V) is device that is meant mainly as back up for telephones' batteries (Pictures 11 and 12). It is a wrist strap with battery cells and it can be connected to the desirable device and boost its' battery with extra energy. It is similar to the initial idea of the client, but this particular product can't be used for boosting up DSLR cameras' batteries, as the voltage is not high enough. But this product can be seen as another source of ideas in current project. For example the spring cable is element that should be used for connecting the external battery to the camera.

Picture 11 Universal battery bracelet from TsirTech (Park, 2009)

Picture 12 Universal battery bracelet from TsirTech (www.thinkgeek.com, n.d.)

2.4.5 Energy Bracelet Concept that Creates Energy from Air

Dyson Energy Bracelet is just a concept (Picture 13). It was designed by student Mathieu Servais of the Nantes Atlantic Design School in 2009. It produces electricity from the ambient air and stores it in its internal LI-PO battery, which can then be used to charge some gadget on the go (ketyung, 2009). Electricity is produced from the ambient air in the Seebeck effect, which allows to turn the conversion of temperature differences directly into electricity. This concept uses difference of the temperature of human body on the one side and ambient air temperature on the other side (Denié, 2009). Reason why it is still just a concept is probably low efficiency, high cost, high output resistance and adverse thermal characteristics of this technology (Wikipedia, 2014). Also these are the reasons why this technology is not further considered as potential solution for the cameras battery problem.



Picture 13 Dyson Energy Bracelet (ketyung, 2009)

2.5 Outdoor Photography

In general there are three types of nature photography. First is wildlife photography that also consists of photographs going to the hideout and spending many hours waiting for the animals? Second type is still-life photography that includes long hikes and lots of moving. And third is time-lapse and long exposure photography that requires sometimes multiple hours of photo shooting without even touching the camera.

2.5.1 Wildlife Photography

Wildlife photography usually requires waiting for long hours in hideout. When it is cold outside, all photo equipment is exposed to the low temperature. One technique that is used by photographs to keep their equipment functional, is wearing one or many spear batteries always in the glove or somewhere underneath the clothing to keep them warm and then exchanging the batteries when one in the camera is getting too cold. In the hideout it is also important to stay as quiet as possible. Even slightest noise might ruin the opportunity to get the picture that photographer came after. Changing batteries is potential source of unnecessary noise.

2.5.2 Nature Still-Life Photography

Nature still-life photography usually means just going to the nature, hiking and taking photographs. It might be that photographer will just drive to the nature with a car and not hike very much, just take the photos and drive back to the civilisation. But it might also be that photographer will go to the wilderness for longer hike, carrying all the photography equipment with him. This is the situation where battery malfunctioning caused by the low temperature happens.

2.5.3 Time-Lapse and Long Exposure Photography

Time-Lapse photographers need to stay in the nature for many hours. Photographer David Kingham writes on his website that when he was shooting the Perseids meteor shower he went through 5 batteries (1500mAh) in 8 hours (Kingham, 2012). They need many batteries or one big external one.

2.5.4 Conclusions

Taking these three types of nature photography into the consideration, it becomes more and more evident that the initial idea that came from the client is the one to be developed into the final design proposal. If photographer is waiting in the hideout during cold winter, the only source of heat is photographers' body. And during the hiking body produces even mode heat. So, it seems to be the most logical solution, to take battery out from the camera where it is exposed to the effects of the external low temperature and locate it somewhere where it can absorb the heat of photographers' body.

2.6 CAMERA STRAPS

Most photographers are using neck strap to carry their camera (Picture 14). But there are also other options. For example there is wrist strap (Picture 15) that some photographers prefer.

Picture 14 Regular camera neck strap (Amazon.com, 2013)

Picture 15 Wrist strap (unknown, 2009)

In addition, there are few more variations of neck straps. One of them is shoulder strap that allows to wear the camera like a shoulder bag (Picture 16). And other one is double neck strap (Picture 17) that allows to carry two cameras around your neck.

Picture 16 Shoulder neck strap (www.amazon.com, 2012)

Picture 17 Double neck strap (digitalcamfan.com, 2012)

Whatever way of carrying their cameras photographer prefers, it must be possible to use Battery Sleeve. All users must be able to comfortably use Battery Sleeve. This means that user must be able to draw out the wire of the Battery Sleeve either from the sleeve of the winter jacket or from the neck opening of the winter jacket.

2.7 CAMERAS

Digital single-lens reflex (DSLR) cameras are categorized into three categories: consumer, semi-professional and professional cameras. There are five main producers – Canon, Nikon, Pentax, Olympus and Sony. Each producer have various cameras in each three category and different cameras are using different batteries with different capacity, voltage and shape. Not all but many of these cameras have specially designed little feature that allows usage of different external batteries. External batteries are usually connected to the camera through dummy battery with a wire. This special feature is little hole next to the battery door that allows to shut the battery door when the dummy battery with the wire is placed to the camera (picture 18).

Picture 18 DSLR camera battery door with special hole for cable (www.linkdelight.com, n.d.)

Some cameras have DC IN socket. This input allows usage of external batteries without dummy battery. Photographer David Kingham writes about building your own external battery on his website (Kingham, 2012). Most external batteries are connected to the camera through dummy battery, but he uses DC input (Picture 19).

Picture 19 External battery connected to Nikon D700 through DC IN socket (Kingham, 2012)

When using dummy battery to connect external power source to the camera it is important to know that each manufacture has multiple different battery types that different cameras are using. Five main DSLR camera producers are using 31 different types of batteries (Figure 11).

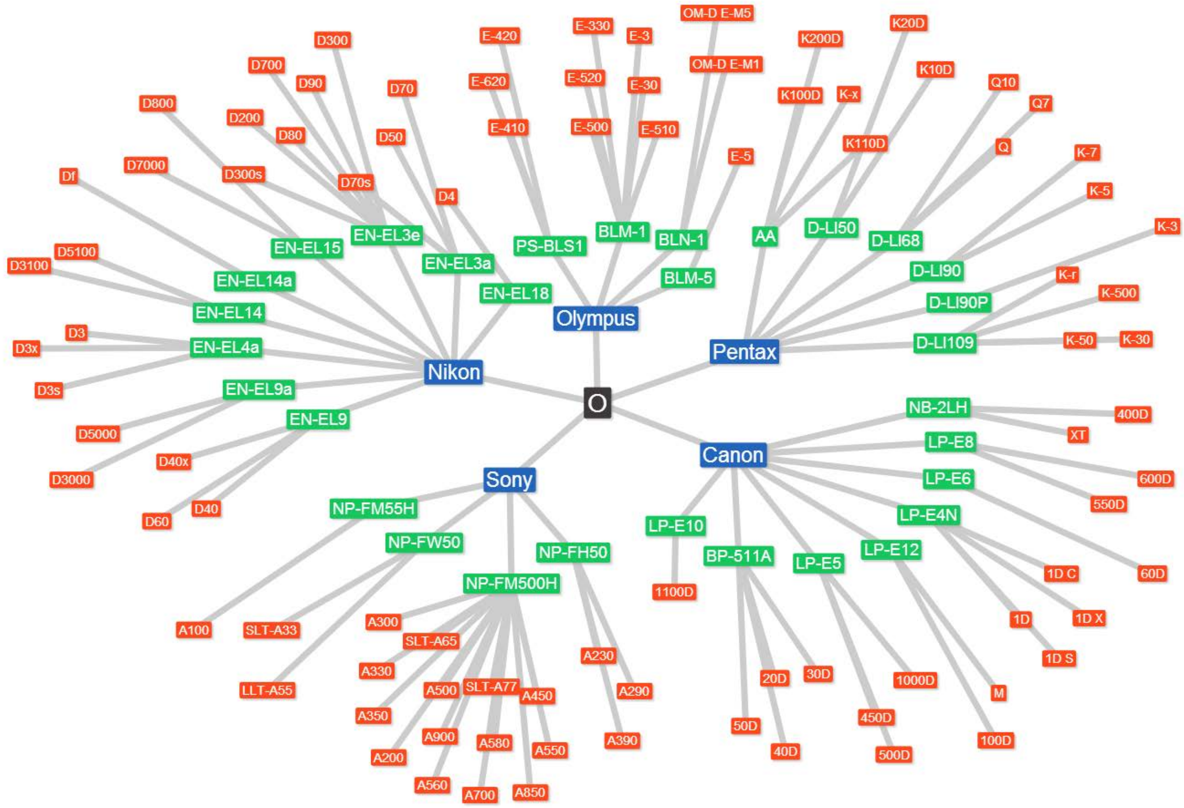


Figure 11 DSLR cameras categorized by producer and battery type

DSLR cameras are also categorized by level of professionalism – consumer, semipro and pro (Figure 12). Cameras made for regular consumers are cheaper and technically not so advanced. These cameras belong to consumer category. Then there are more expensive and more professional cameras categorized as semi-professional cameras. Finally there are very expensive and technically advanced cameras that are categorized as professional cameras.

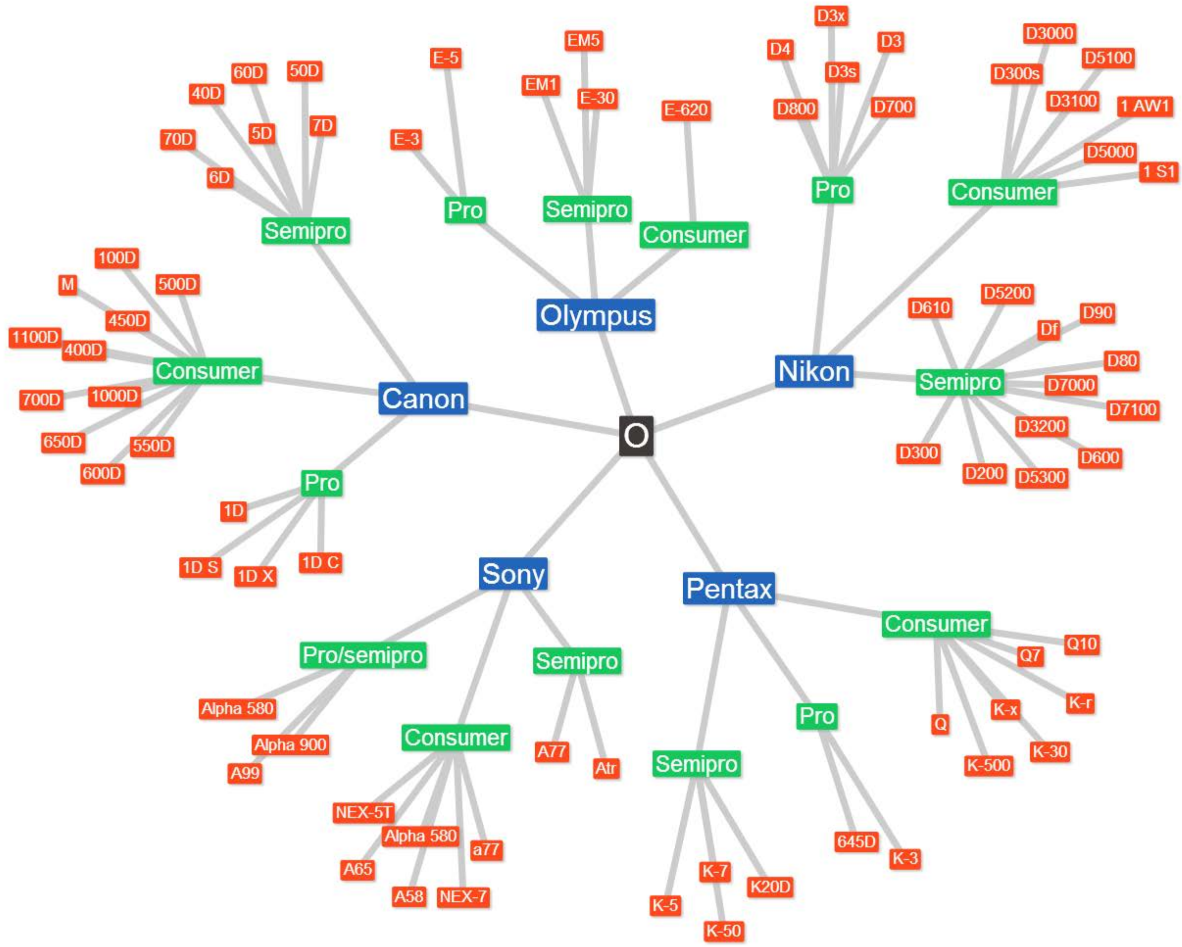


Figure 12 DSLR cameras categorized by producer and user type

3 Define

3.1 First Concepts for the Solution

According to the discoveries and analyse of the research data, 3 concepts were developed.

In this part three concepts is suggested to address the problem. One of these three concepts is the one that Start-up Company had when they approached to the author of this paper. Other two are alternatives that would also solve the problem. These three solutions are analysed and evaluate in the evaluation matrix.

Battery sleeve

Battery sleeve is the concept that Start-up Company came up with and needed designer for. The idea of battery sleeve is similar to external battery concept. Difference from existing external batteries would be the shape and usability factor. With current external batteries in the market it is possible to solve this cold problem by just putting the huge battery pack to the inside pocket of photographer’s winter jacket. Battery sleeve would be around photographer’s hand and that eliminates the big bulky extra weight in the pocket. Also it would be against the body where the temperature is even higher than in the pocket of the winter jacket (Figure 13).

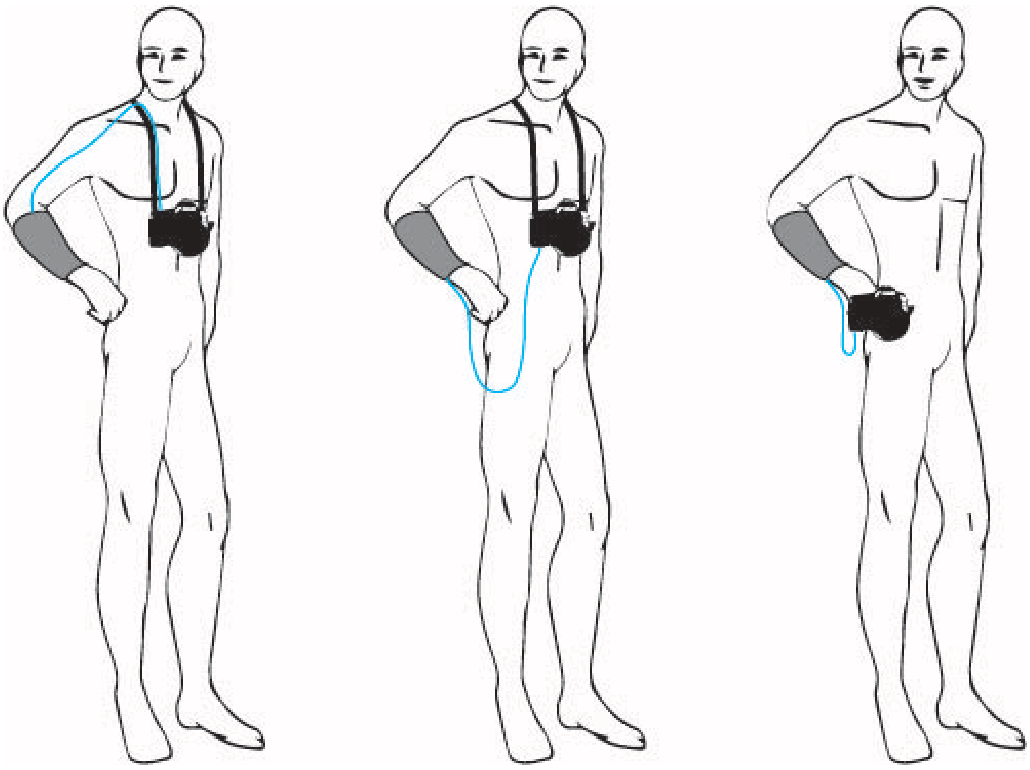


Figure 13 Battery Sleeve concept

Camera heater

Alternative concept would be designing solution that would heat the battery inside the camera or even keep the whole camera warm. Here it would be possible to fallow either passive or active thermal control methods. Passive would mean that battery or whole camera is covered in multiple layers of different advanced insulation materials. Active method would mean that this cover needs to have heaters and that in turn needs to be supplied with energy. It needs to have battery of its own or it needs access to cameras' battery.

Battery adaptor

Third concept is battery adaptor. The idea of this concept would be using the existing battery but placing it out of the camera where it is exposed to the cold and placing it to somewhere warm – for example inside pocket of the winter jacket. Battery adaptor would consist of dummy battery (Picture 20), wire and container similar to battery charger (Picture 21) where battery would be places. Existing battery would be placed to the container and dummy battery in the other end of the wire would connect it to the camera.

Picture 20 Lanparte LP-E8 dummy battery for Canon cameras (www.ebay.com, 2014)

Picture 21 Canon LC-E8 Battery Charger (www.hddv.net, 2014)

Evaluation of these three solutions

These three concepts are evaluated in following evaluation matrix.

Rating scale in following evaluation matrix is from -2 to +2.

Value	Meaning
-2	Performs terribly
-1	Slightly inferior
0	Neutral
+1	Slightly better
+2	Performs significantly

Following evaluation matrix is weighted evaluation matrix. Weights scale is from 1 to 5 points.

Value	Meaning
1	Irrelevant
2	Slightly important
3	Important
4	More important
5	Most important

Criterias for analysing and evaluating in following evaluation matrix are:

- First criteria evaluated in following matrix is provision of extra capacity. Only concept that scores in this criteria is Battery Sleeve as other two won't add any battery capacity.
- Second criteria is price. From this criteria only concept scoring points is Battery Adaptor for obviously being cheapest solution in any means.
- Third criteria is complexity and Battery Adaptor earns points here for being technically very simple solution.
- Next criteria is weight. Again Battery Adaptor earns the most points.
- In final criteria Connectivity the Camera Heater earns points for being only solution where no external wiring is needed.

According to this evaluation matrix (Table 5) the best solution would be the one that was initially suggested by the client – Battery Sleeve.

		Extra capacity	Price	Complexity	Weight	Connectivity	
	Weight	5	1	4	2	3	Totals
Battery Sleeve	Assigned	2	0	0	-1	-1	
	Weighted	10	0	0	-2	-3	5
Camera Heater	Assigned	-2	0	-1	0	1	
	Weighted	-10	0	-4	0	3	-11
Battery Adaptor	Assigned	-2	2	2	2	-1	
	Weighted	-10	2	8	4	-3	1

Table 5 Concept evaluation table

Battery Sleeve concept earned the best score primarily because this concept offers extra capacity and it is the most important criteria in this evaluation matrix. Other two alternative concepts earned minus points in this category as they would not give any extra energy to the camera. Battery sleeve earned minus points for weight and connectivity.

Second best concept according to this evaluation matrix is Battery Adaptor. It earned highest points in three category – price, complexity and weight. That's because it would be the cheapest, simplest and lightest of these three concepts.

Camera Heater would be the worst concept to solve this problem according to this evaluation matrix. It earned minus points in capacity category for not offering any extra energy and in complexity category because materials and manufacturing of this product would require skills and knowledge that are not part of this companies capabilities.

These alternative concepts were also introduced to the client and they also agreed to move on with the initial Battery Sleeve concept.

3.2 Choosing The Components

One of the most determining part of this design process was choosing the battery cells. There was many aspects that made this decision making quite complex.

The most preferable option in the beginning was ProLogiums thin flexible battery cells. Main advantage of these cells is their flexibility. When LiPo batteries can be curved in the manufacturing phase, but can't stand much bending or flexing in usage, then ProLogium's battery cells are flexible also in the usage. But these flexible battery cells were not chosen for the current project for various reasons. One reason was that it was quite complicated to communicate with the Prologium Company. They were not very eager to give information about their battery cells and it seemed that they wanted to choose to whom they sell their cells. So, as timeframe of our project was limited, we couldn't depend on Prologium. But communication between the start-up company and Prologium continues and when their cells will become available, then it is reason for starting development of battery sleeve second generation/version.

Finally the decision was made in favour of LiPo cells provided by GM Battery. We chose to use cells with dimensions of 3x50x50mm. One important aspect is its thickness of only 3mm. This cell's capacity is 750mAh and voltage is 3.7V. So in order to get 7.4V out of these cells two of these cells is needed to be connected in series. All together 6 of these cells are used in the battery sleeve, which makes the capacity of the battery sleeve 2250mAh.

3.3 Neoprene Fabric

Neoprene or polychloroprene is a family of synthetic rubbers that are produced by polymerization of chloroprene (Rubber, 4. Emulsion Rubbers, 2012). Neoprene has very good chemical stability. It maintains flexibility over a wide temperature range. It is very resilient material. Neoprene has high tolerance for extreme conditions. It resists degradation more than natural or synthetic rubber (Rubber, 4. Emulsion Rubbers, 2012). For these material characteristics, neoprene was chosen for building Battery Sleeve.

Neoprene can be produced in either closed-cell or open-cell form. The closed-cell form is waterproof, less compressible and more expensive. The open-cell form can be breathable (www.intecfoams.co.uk, 2014). For Battery Sleeve it is not essential that it would be waterproof, as it is underneath the clothes and that way already protected from the weather. So, it can be produced using the cheaper open-cell form neoprene, and final price of the product can be kept also lower that way.

Neoprene rubber sheets are manufactured in different thicknesses from 0.5mm to 10+mm. For Battery Sleeve 1 mm thickness neoprene is used.

Depending of the use, neoprene sheet is laminated on one or both sides with textile. Then it is called neoprene textile or neoprene fabric. It has really wide range of use: waders, insulated can holders, wet suits (Picture 22), sports gloves, mouse pads, elbow and knee pads, orthopaedic braces, horse-riding gear, etc.

Picture 22 Detail picture of O'Neill neoprene wetsuit (www.kalipso.ee, 2014)

There is also neoprene fabric for all kind of different purposes offered by neoprene manufacturers. For example: super stretch neoprene, fire retardant neoprene, warmth retention neoprene, abrasion and chemical resistant neoprene etc. (www.macrointlco.com, 2013)

For Battery Sleeve two types of neoprene is used. Both of them laminated on one side only. One is neoprene that is against the arm, and that needs to be laminated with the sports fabric that is meant to be worn against the body. And other neoprene is the one that will form the outside layer of the Battery Sleeve, and that needs to be laminated with the Velcro hook compatible fabric. For example there is that kind of neoprene fabrics available from Macro International Company (www.macrointlco.com, 2013).

Today there are several manufacturers who are focussing on producing neopreene. For example:

1. Macro International Company, Macro Products, Inc.: http://www.macrointlco.com/
2. Foamorder.com: http://www.foamorder.com/neoprene.html
3. Seattle Fabrics, inc. http://www.seattlefabrics.com/neoprene.html
4. Du Pont: http://www.dupont.com/products-and-services/plastics-polymers-resins/elastomers/brands/neoprene-polychloroprene.html

3.4 WHICH DC CONNECTOR TO USE

There are lots of dummy batteries in the market and all dummy batteries in the market are following similar design. There is the dummy part that goes inside the camera and that part varies depending of the camera model and battery shape that it uses. Then there is cable that comes out of the dummy. Length of the cable can be different. And in the other end of the wire all different dummy battery manufacturers are using 5.5mm female DC connector (Picture 23), which is standard and most commonly used DC connector measure. Exception is LanParte dummy batteries that come along with their PB-600 external battery. LanParte is using 3 pin xlr connector (picture 24).

Picture 23 Dummy battery for Canon cameras that are using LP-E6 type batteries (www.globalmediapro.com, 2014)

Picture 24 LanParte is using 3-pin xlr connector in their PB-600 external battery (www.hdvideoshop.com, 2014)

Reason why most of the dummy batteries have 5,5 mm DC socket is that they would be usable with AC adaptors and universal external batteries witch all have male plug to go inside the device.

For Battery Sleeve there was option of developing some new comfortable connecting solution like Lanparte have done or to go with universal 5.5 mm DC socket-plug version. It was found most reasonable to go with universal approach. One reason was that this way it is possible to buy existing dummy batteries from the market and add them into the product package. This is the current preferred direction, considering the profile of the start-up company.

The start-up Company decided to offer 15 different dummy batteries in the beginning. It will cover 59 different cameras (Figure 14).

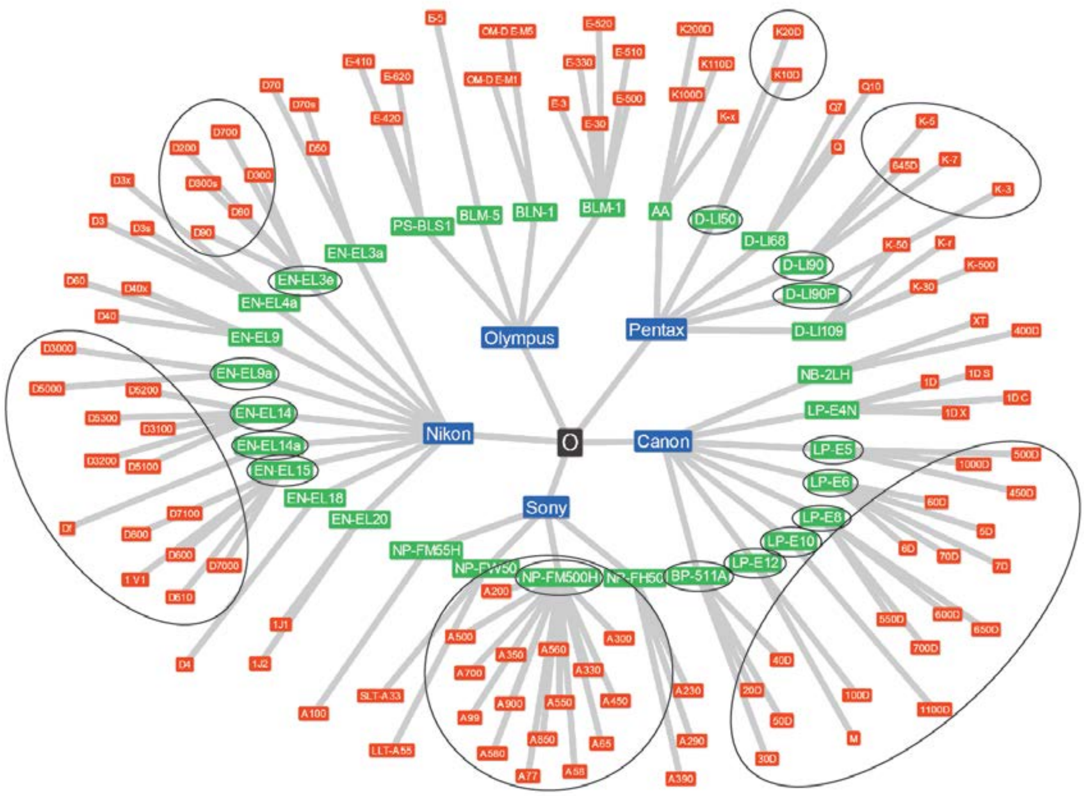


Figure 14 Dummy batteries that were decided to add into the selection for clients to choose from

4 Brief

Client

As this company is not even registered yet, there is no previous visual materials or products to take into account in designing this product. The initiators of the company have decided to start small and then grow bigger as project evolves. In the beginning they have planned to manufacture their product themselves. Ardi who has background in electronics engineering will be responsible of the production side and Sander will be responsible for the marketing and selling. So, as the scope is not big and they are planning to be able to produce their product themselves, the design must follow these restrictions. For example such manufacturing techniques that require massive orders can't be involved. The product must consist of the components that can be ordered in small or average quantities and then be assembled by themselves.

Market background

Target is to launch new product to the external battery packs' market. It is niche market where there are not so many competitors. Compared to the big bulky external battery packs, Battery Sleeve should be located somewhere in-between 100-200 € in price range. And as objective is to create external battery that would be less bulky, then it is wise to not set the goal of battery capacity as high as capacity of these heavier external batteries (Figure 15).

Target audience

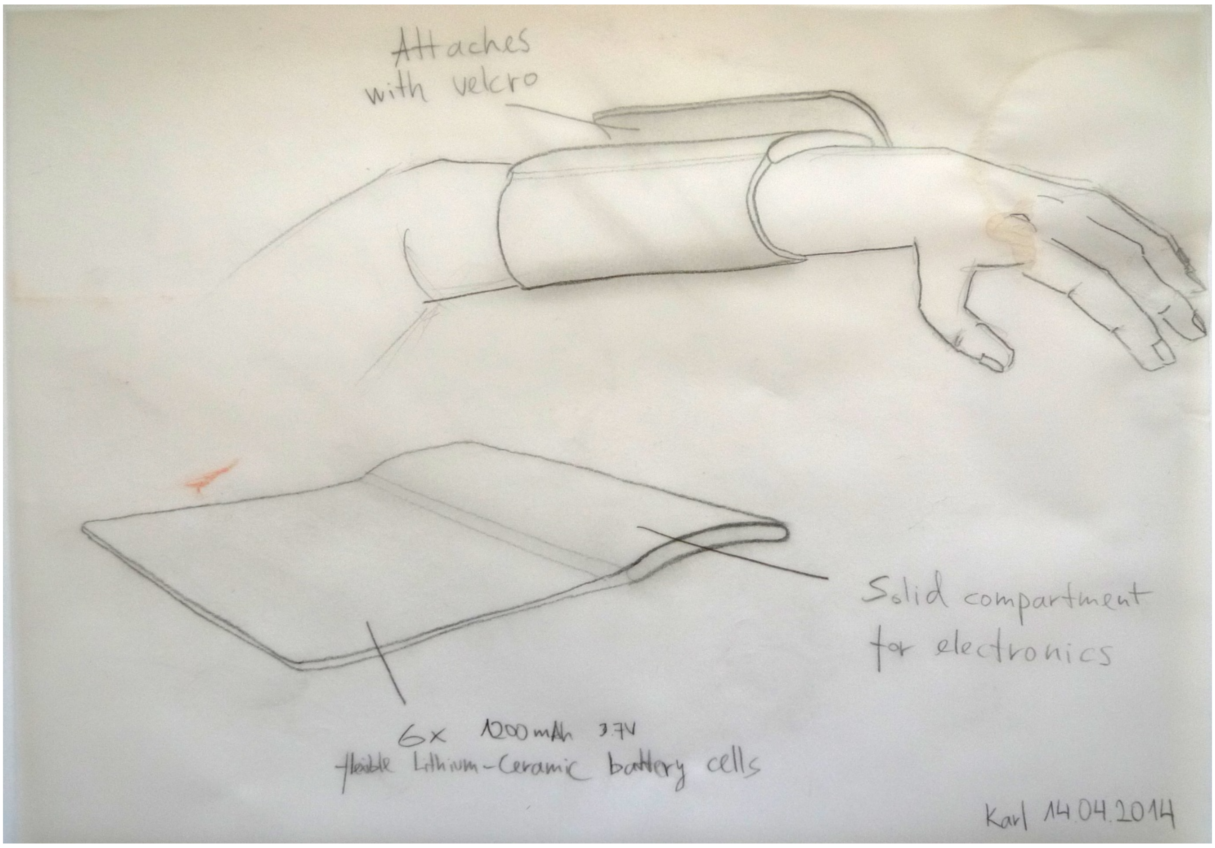
Target audience of this product is professional- and hobby nature photographers, who are shooting photos in cold conditions. So, photographers of northern countries.

Figure 15 Locating Battery Sleeve

5 DEVELOPMENT

5.1 EARLY SKETCHES

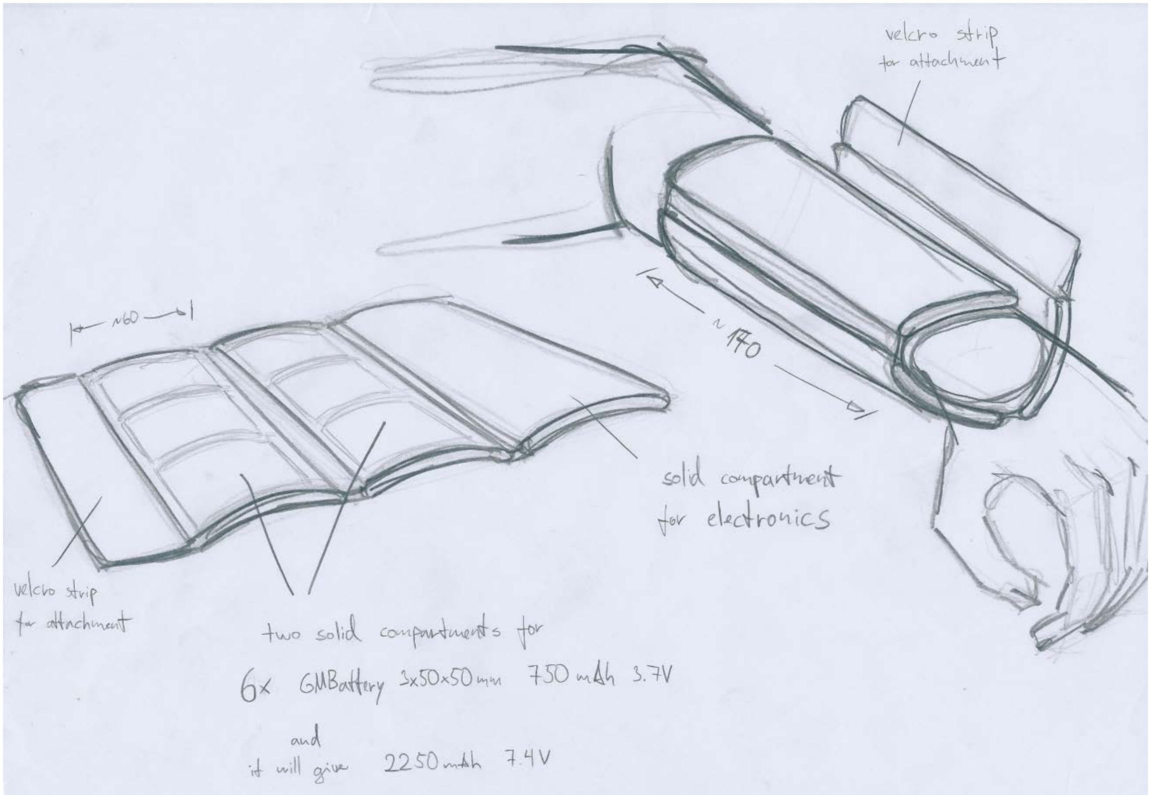
Final concept evolved out from the concept that was created using Prologium's thin flexible lithium-ceramic battery cells (Picture 25 and 26). Concept had one solid part for electronic components and the part that was flexible and around the arm, held 6 thin flexible cells on top of each other and everything was meant to be surrounded with neoprene textile. Neoprene textile was chosen because of its elasticity and high durability properties. These 6 cells would have been giving out 7.4 V and capacity would have been 3600 mAh.



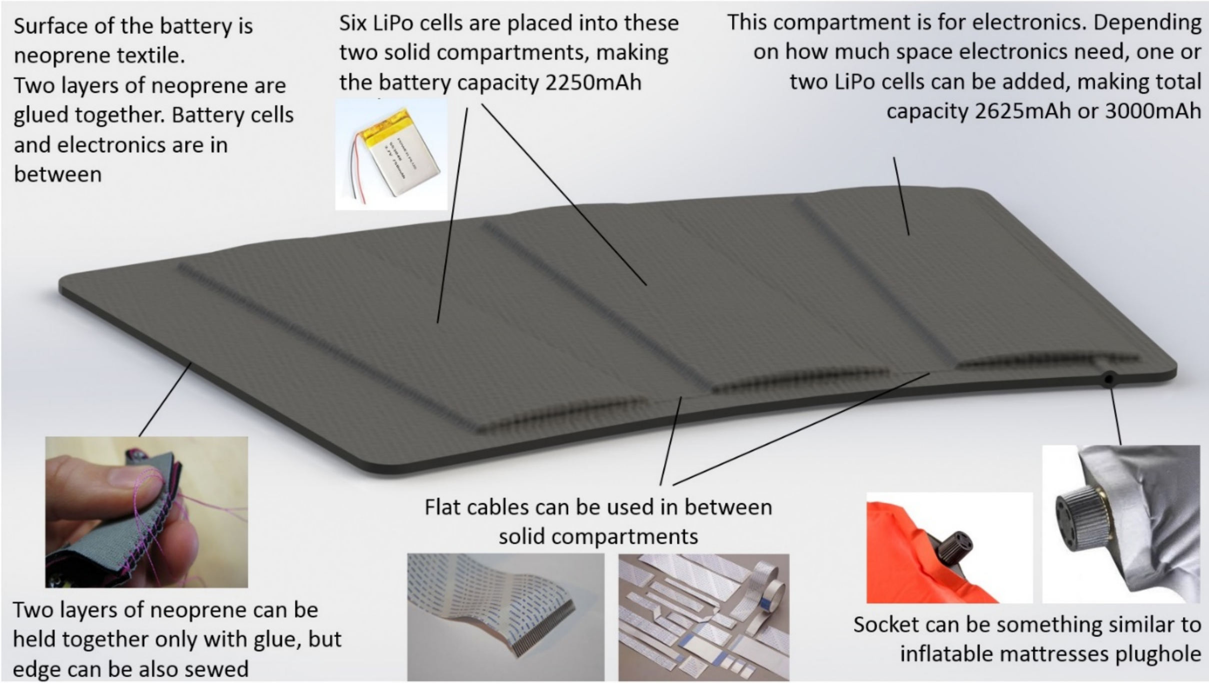
Picture 25 First concept was using thin flexible lithium-ceramic battery cells from Prologium

Picture 26 First mock-up made of wood, textile and velcro

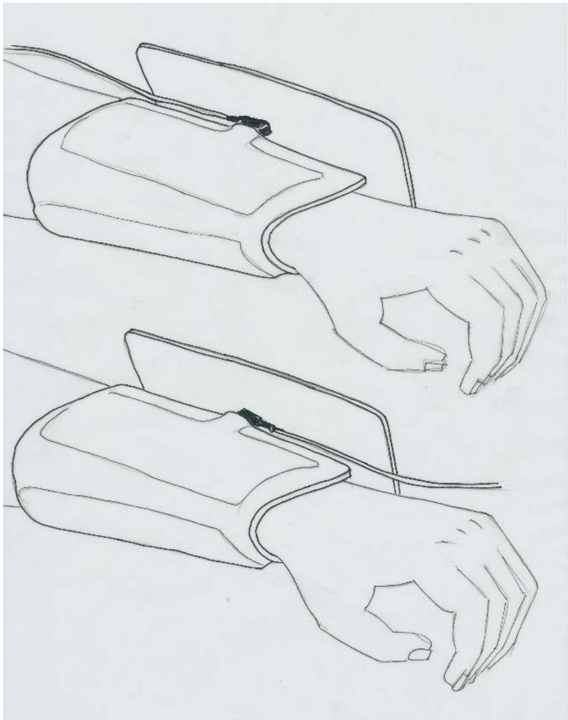
But as it was not possible to get these Prologium's thin flexible lithium-ceramic battery cells (described previously in Define part), this concept evolved into next concept using the battery technology that was already available. This technology is Lithium Polymer battery technology that allows cells to be curved into desirable radius but is not flexible. Instead of one solid compartment, now it needed three solid compartments. Two of these compartments holding 6 LiPo battery cells in them and third one holding electronics (Picture 27). These 6 calls are together giving out 7.4V and their capacity is 2250 mAh. Material of the Sleeve itself is still neoprene. Two layers of neoprene glued together with thermo-adhesive and solid compartments put in-between these two layers. For connecting solid compartments with each other, flat cables are used (Picture 28). And output socket would be 5.5 DC socket coming out from the third solid compartment, where all the electronics is located. The output socket is located to the place where it would be comfortable to connect the camera either with the cable going up from the sleeve and out from the collar or straight out from the sleeve (Picture 29).



Picture 27 Battery Sleeve concept using GM Battery Lithium-Polymer battery cells



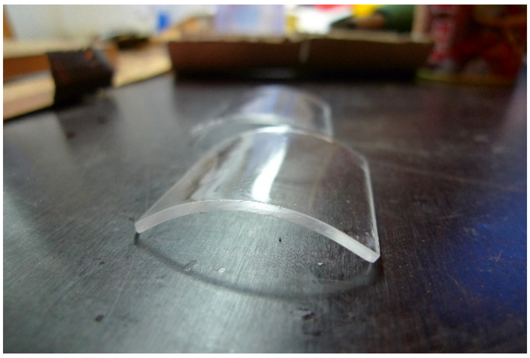
Picture 28 First 3D model and ideas for components



Picture 29 Output socket located so that it would be comfortable to drag the cable either way

5.2 Figuring Out the Right Shape And Positioning for the Elements

Next step was to find out the most optimal shape and position of the battery elements. As perimeter of the hands of different users is varying, it was important to find the optimal radius for the battery cells to fit to wider range of users. Three different radiuses for battery cells were tested – 40, 45 and 50cm radiuses. Test elements were made of Plexiglas. Shape was given by warming up the Plexiglas with industrial heat gun and then bended into required radius (Picture 30). These tests were carried out on 4 different test user's hands. Two extremes were presented in this test - one of them with very thin hand and one with very large arm perimeter. Measures of these test users' hands are shown in Table 6.



Picture 30 Test elements with different radiuses

	Perimeter from the wider end of the arm	Perimeter from the thinner end of the arm
Arm 1	20 cm	14 cm
Arm 2	22 cm	15 cm
Arm 3	29 cm	19 cm
Arm 4	32 cm	23 cm

Table 6 Measurements of test users' hands

Test cells of Plexiglas were connected with paper tape (Picture 31).

Picture 31 Mock-up for testing out different radiuses for Li-Po cells

The result from testing different radius elements on different arm parameters was that optimal radius to fit all different arms was 45cm.

5.3 Mock-up

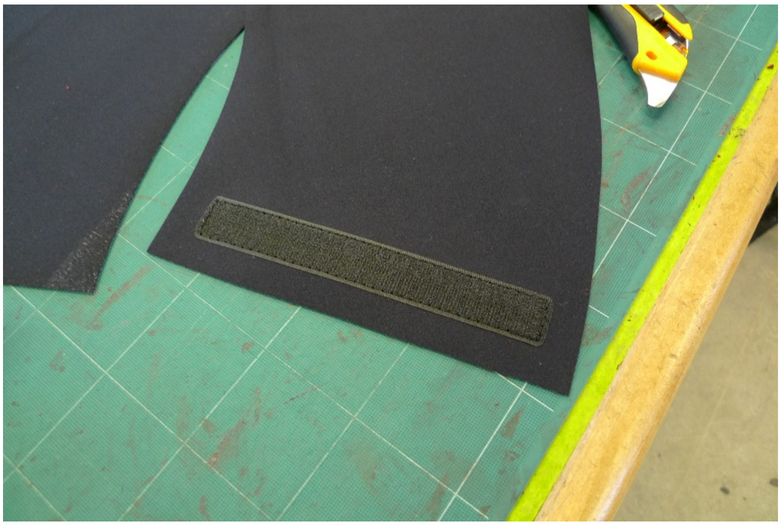
First mock-ups were made not using the real battery cells or neoprene material.

To imitate the solid compartments of the Battery Sleeve, Plexiglas was bended into 45cm radius and two 2mm layers were glued together to achieve the 4mm thickness which will be the approximate thickness of the solid compartments (Picture 32).

Picture 32 Gluing together two layers of Plexiglas to achieve right thickness

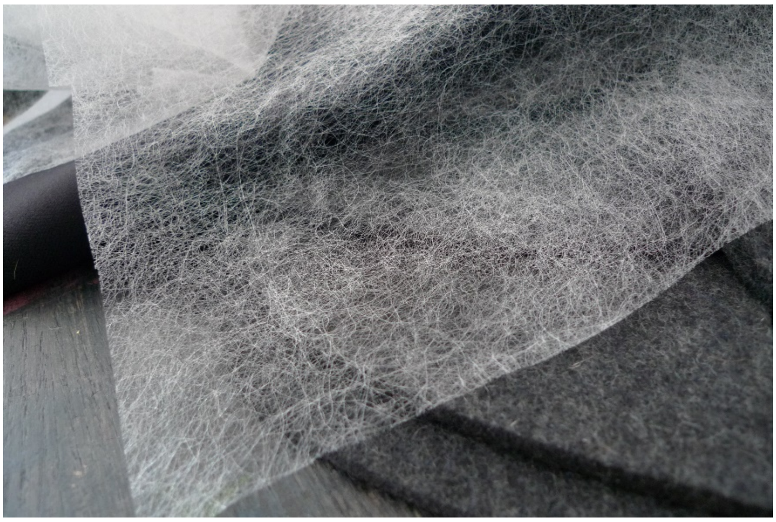
Before gluing two layers of neoprene together, Velcro strap needs to be sewed to the bottom layer neoprene. For sewing Velcro and neoprene, it needs industrial sewing machine. For the mock-up leather sewing machine was used (picture 33 and 34).

Picture 33 Sewing Velcro on the neoprene, using leather sewing machine

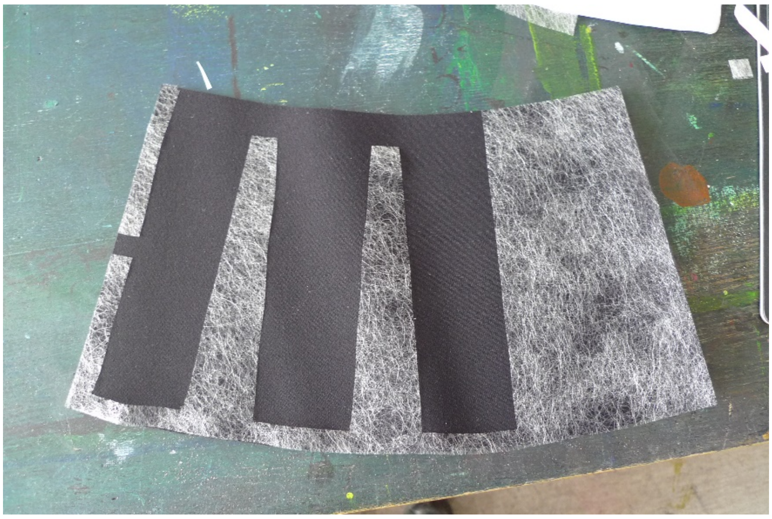


Picture 34 Velcro sewed to the neoprene

For gluing together the two layers of neoprene, Thermo-adhesive material is used (Picture 35). It is applied with thermo-transfer press. Right size and shape of the thermo-adhesive material is cut out and placed in-between the two neoprene layers. These two neoprene layers are not glued together entirely, but gaps for installing solid compartments with battery cells and DC socket are cut into the thermo-adhesive material to leave right size pockets for them (Picture 36).



Picture 35 Thermo-adhesive material

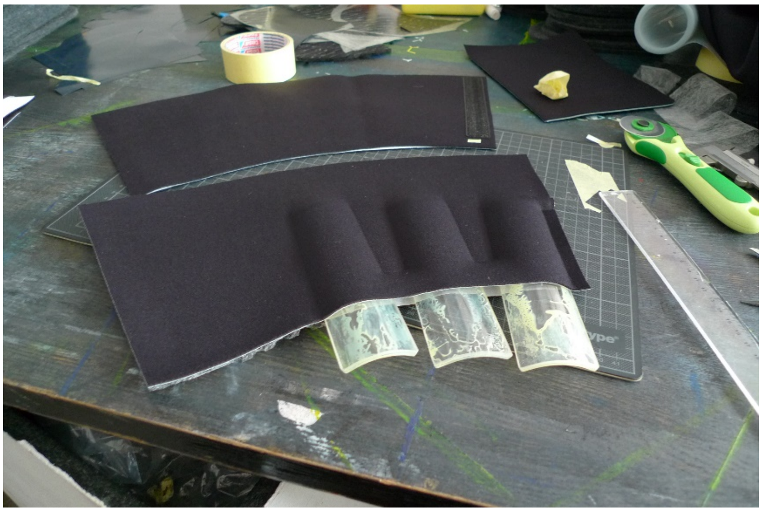


Picture 36 Thermo-adhesive material between neoprene textiles

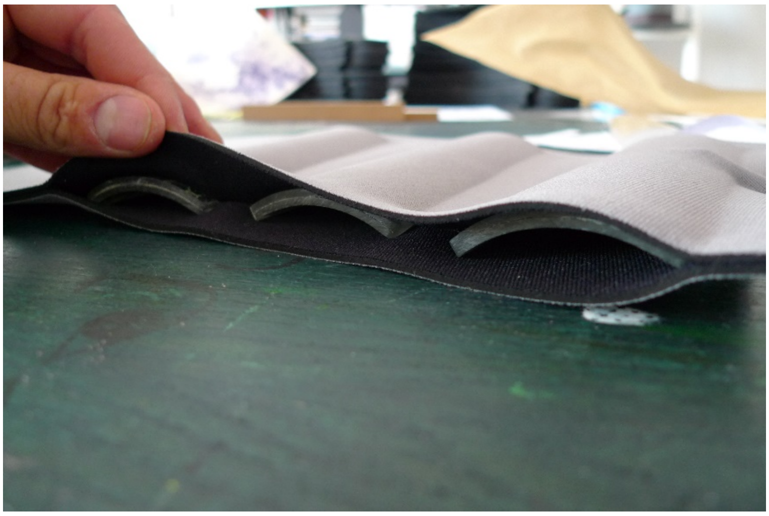
Picture 37 Manual thermo-transfer press with bottom layer of neoprene and thermo-adhesive material on it

Two layers of neoprene and thermo-adhesive material in-between them is inserted to the manual thermo-transfer press (Picture 37). Press is set to 150°C and pressing time is 30 seconds. That was determined with tests, and applies only for this material that was used for this first mock-up. Right temperature and time is to be determine for each different types of material.

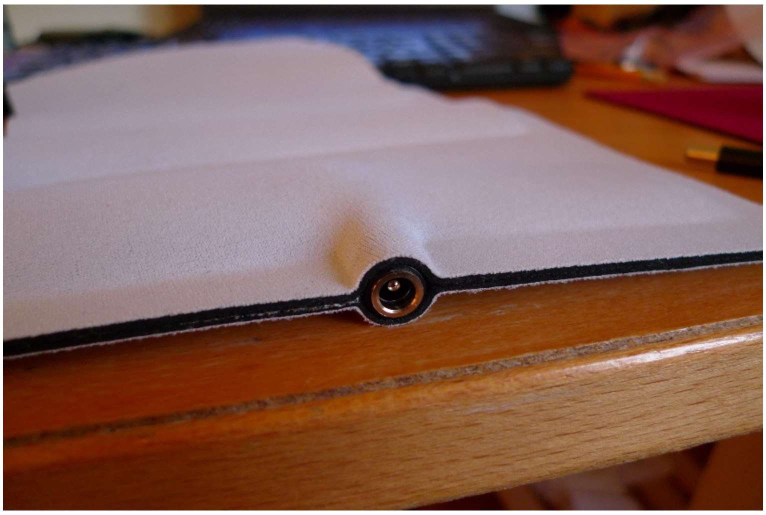
With right temperature and time for pressing, the thermo-adhesive in-between the neoprene layers activates and glues these two layers together. After taking out from the press, it needs some time for cooling down. When it has cooled down, two layers of neoprene are strongly bond together and parts that were left without thermo-adhesive material are not. These are the gaps where solid compartment can be placed (Picture 38). Also there is room left for wiring (Picture 39) and small gap for the socket (Picture 40).



Picture 38 Inserting Plexiglas elements into the sockets



Picture 39 One end is left open to insert the elements. There is also room specially left for wiring

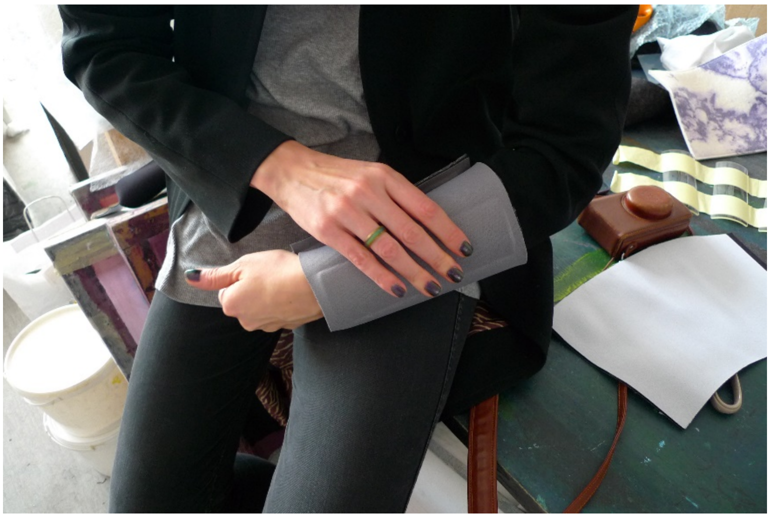


Picture 40 DC socket on first test piece

After installing solid compartments in their places, the open edge needs also to be glued together. It is again done with thermo-adhesive material (Picture41). But this time thermo-transfer press can't be used, as it would damage the battery cells and electronics that are in their places in-between the two neoprene layers. Instead, iron and cooking paper is used for that (Picture 42).

Picture 41 Thermo-adhesive material installed in-between the final opened edge to glue it together

Picture 42 Applying heat with iron to glue together the final open edge



Picture 43 Testing the first mock-up on the hand

First mock-up was also tested on the hand with very small wrist perimeter and it was fitting well (Picture 44).

Picture 44 First mock-up around the hand with very small perimeter

6 DELIVERY

6.1 FIRST TESTING

So as the first mock-up doesn't contain real battery cells, but just Plexiglas imitating the battery cells, then it is not yet possible at this point to fully test the product. Also there is 30°C weather outside, so it would not have been possible also to test it functioning in the conditions for what it is designed for. So the testing in this point was done just to find out if the ergonomics of the product is functional.

Purpose of following testing was to find out:

- If the Velcro fastening system is good
- How comfortably Sleeve sits on the arm
- How the wiring works

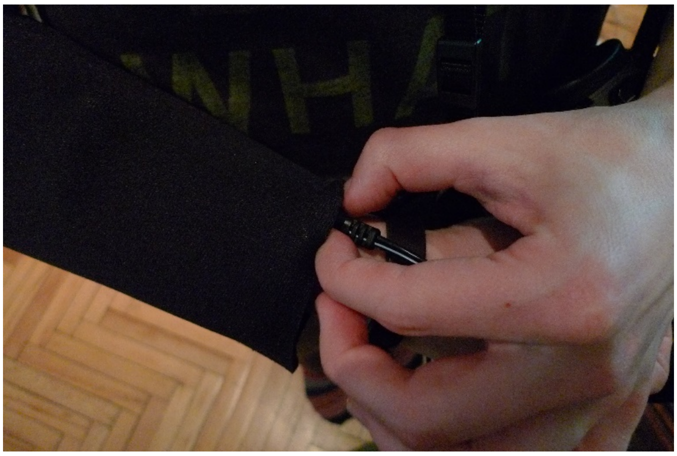
The Velcro fastening was tested by just letting test user to put the sleeve on the arm by himself without any assistance. It turned out that if nobody else is assisting, then it can be a little bit complicated. Test user managed to put it around the hand, but it was a little bit loose. So, it needed some tightening and current system turned out to not being the best solution for that.

Comfortability was evaluated by the feedback from the test user. He wore the Battery Sleeve on his hand while he was out taking pictures. Testing time was about one hour. In general the feedback was good and Battery Sleeve around the hand was comfortable.

Different wires were tested during this one hour test photo-shoot.

First test was done using the short wire to connect the camera and Battery Sleeve. Wire was connected to the Sleeve. Then Sleeve was attached around the hand. And then jersey and jacket was put on to imitate the situation during the winter (Picture 45). Feedback from the test user was good. Short wire in-between camera and Sleeve didn't disturb the workflow at all. When he wanted to put the camera away, then he had to disconnect the camera from the battery. First version of the short wire turned out not to be the best for that. The wire was little bit too short, so the connection between the dummy socket and plug of the short wire was hiding under the sleeve (picture 46). So, the short wire was extended by 45mm. Now the connection was out from underneath the sleeve (picture 47). With extended length added to the short wire now it was very comfortable to disconnect them without removing sleeve from around the hand or taking dummy battery out from the camera.

Picture 45 Battery Sleeve under the jersey



Picture 46 First version of the short wire was little bit too short for disconnecting comfortably

Picture 47 Second and little bit longer version of the short wire

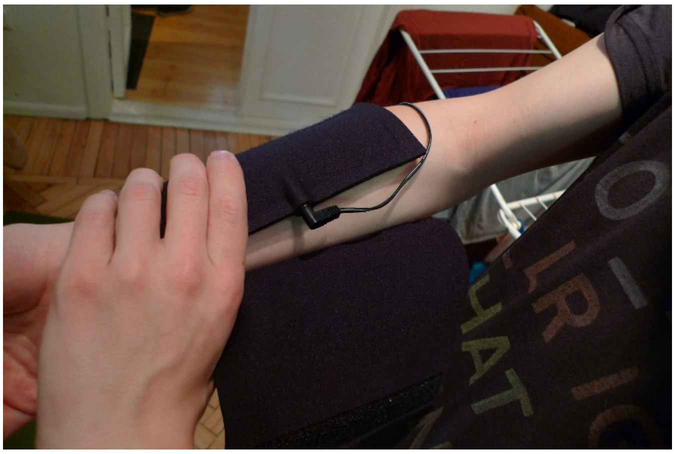
Testing of the short wire showed that it was even possible to hold the camera around the neck with the neck-strap while connected to the Battery Sleeve with the short cable (Picture 48). It was comfortable to take photos and wire did not disturb the usability at all (Picture 49). Also it was convenient to unplug, if it was needed (Picture 50)

Picture 48 Battery Sleeve connected to the camera using short wire

Picture 49 Testing the short wire

Picture 50 Unplugging the short wire

Second version of the wiring test was performed using the long wire to connect the camera while it rested around the photographers' neck using neck strap. First the Battery Sleeve was connected to the long wire and placed around the photographers' hand (picture 51). Then photographer put on the jersey and winter jacket, like he would do if working out in the field during winter. The other end of the long wire was taken out from the collar, camera was placed around the neck and then the wire was connected to the socket hanging out from the dummy battery inside the camera (picture 52). That version of connection turned out to be comfortable. The wire coming out from the collar didn't disturb the test photographer at all (Picture 53). When the photographer wanted to put the camera away it was also easy to unplug the camera and take the camera off from around the neck



Picture 51 Battery Sleeve with long wire

Picture 52 Long wire coming out from the collar and connecting to the socket of the dummy

Picture 53 Battery sleeve connected to the camera with a long wire coming up from the sleeve and out from the collar

Third version of the wiring test was done using the spring-cable. First it was connected like the short wire version – out from the sleeve. Advantages of spring cable was that it offer more freedom of movement (Picture 54). Then it was connected like long wire – up from the sleeve and out from the collar (Picture 55). This version also didn't disturb taking photos at all (Picture 56). Although it was noted that spring didn't even have to be that long as it was.

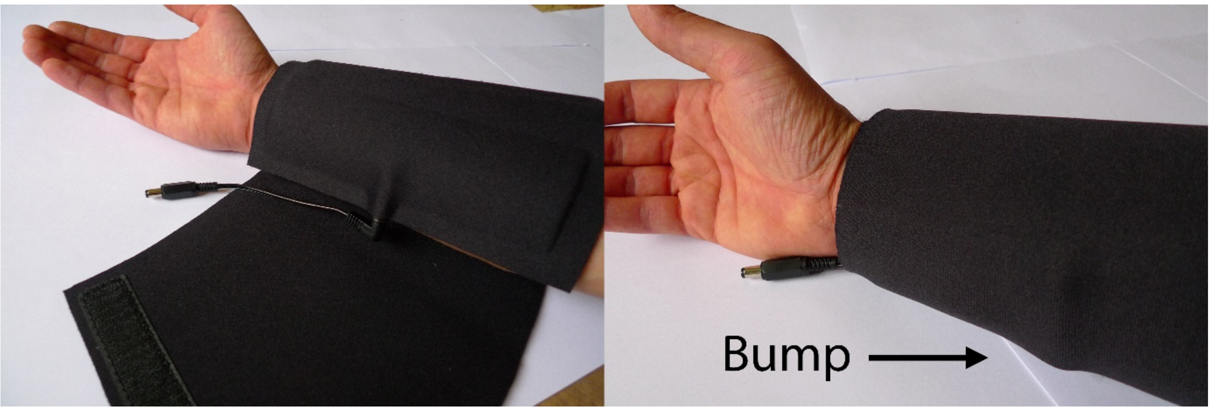
Picture 54 Spring-cable coming out from the sleeve

Picture 55 Spring-cable coming out from the collar

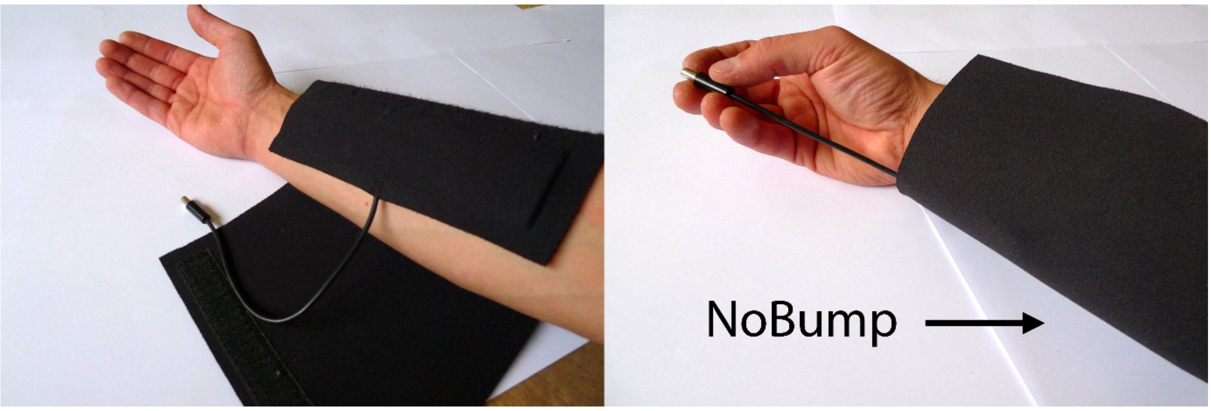
Picture 56 Taking photos with spring cable hanging out from the collar

After testing it was clear that spring-cable and short wire were effective, but long wire not so necessary, as spring-cable did the same job but performed better.

Encouraged by the results of the test, also another adjustment was done concerning the wiring, plugs and sockets. It was decided to make the short wire permanently attached to the Battery Sleeve. Having DC socket coming out from the middle of the Sleeve had some drawbacks. When it was attached with a Velcro around the arm, there was a bump that caused some discomfort (Picture 57). By attaching the short wire permanently to the Sleeve, this bump and discomfort caused by it have been eliminated (Picture 58). Also it reduces the cost, as one socket and plug are eliminated.

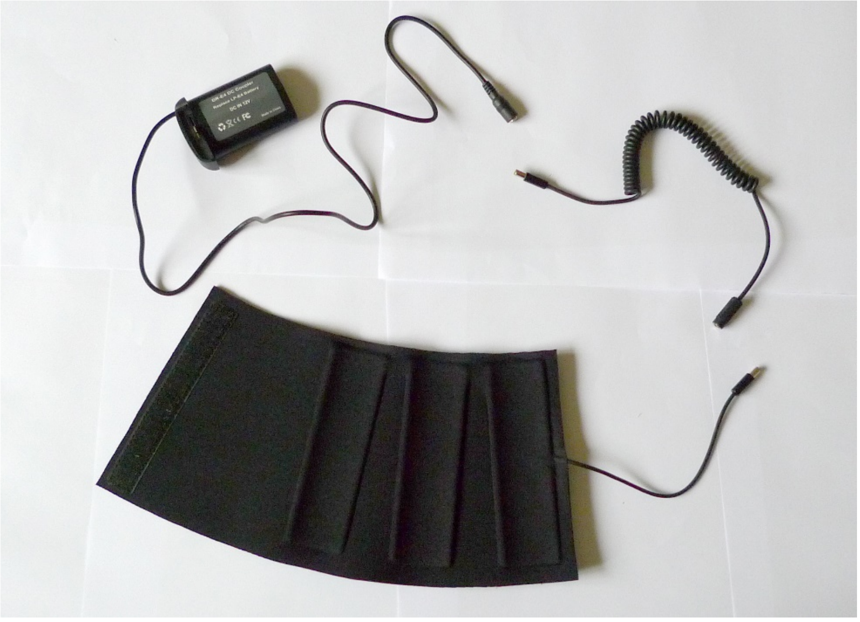


Picture 57 First Mock-up with disconnectable short wire



Picture 58 First Mock-up with short wire attached to the Sleeve permanently

So, after testing and some adjustments, if was decided that this product will include Battery Sleeve itself with short wire attached to it, one dummy battery that is chosen by the client and spring-cable extension wire (Picture 59).



Picture 59 Battery Sleeve with LP-E4 dummy and spring cable

6.2 Evaluation

"Because design is inherently an iterative and incremental activity, the evaluation phase provides essential feedback to the design process and the design product under development. A design artefact is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve" (Hevner, March, Park, & Ram, 2004).

To identify if Battery Sleeve solves the problem it was designed to solve, an evaluation matrix is used. Battery Sleeve is put into the same evaluation matrix that was used in the beginning of the design process to identify and evaluate other battery products that could be seen as competition. In general, market consists of bulky external battery packs that are not designed especially to stand cold.

Follows the evaluation matrix (Table 7):

		Working in cold	Price	Capacity	Weight	Usability	Connectivity	
	Weight	5	1	4	2	3	2	Totals
LanParte PB-600 external battery	Assigned	1	1	1	-2	0	0	
	Weighted	5	1	4	-4	0	0	6
Takkeon MP 3450 R3 external battery	Assigned	1	1	1	0	-1	-1	
	Weighted	5	1	4	0	-3	-2	5
Switronix PB70-24 Battery Pack	Assigned	1	0	0	-1	0	0	
	Weighted	5	0	0	-2	0	0	3
Canon BG-E2N Battery Grip	Assigned	-1	2	0	0	1	1	
+ 2x BP-511	Weighted	-5	2	0	0	3	2	2
Canon BG-E11 Battery Grip (Amazon)	Assigned	-1	0	0	1	1	1	
+ 2x aftermarket LP-E6 batteries	Weighted	-5	0	0	2	3	2	2
Canon BG-E11 Battery Grip (Canon USA)	Assigned	-1	-2	-1	1	1	1	
+ 2x LP-E6 batteries	Weighted	-5	-2	-4	2	3	2	-4
Nikon MB-D80 Battery Grip	Assigned	-1	-1	-1	2	1	1	
+ 2x EN-EL3e	Weighted	-5	-1	-4	4	3	2	-1
Battery Sleeve	Assigned	2	0	-1	0	1	0	
	Weighted	10	0	-4	0	3	0	9

Table 7 Battery Sleeve compared with other products in the market with the Evaluation Matrix

From the matrix we can see that Battery Sleeve proves to solve the problem and get the higher points than existing external batteries. It earns its first place for satisfying the most important criteria of the matrix – working in the cold. For connectivity, weight and price it earns neutral marks. In connectivity criteria it earns same points as existing external batteries, because it connects in the same manner – with a dummy battery and cable. But in usability criteria it gets better points for being lighter, less bulky and comfortably wearable. In capacity criteria it earns minus points, as 2250 mAh is not so good. But it satisfies the goal that was set in the positioning map (Figure 16).

Figure 16 Positioning that was determined in the Brief

6.3 Conclusions and Future Work

This study intended to find solution for photographers' problem of their cameras' batteries not working in the cold. The problem was approached by looking into what causes it and how other applications that have to work in the cold environments have solved it. It was decided to solve it by designing Battery Sleeve – external battery designed to be worn around the photographers arm. In this point the design process has reached to the point where the first mock-up and tests with that have been executed.

But as the first mock-up was not made fully functional, the design process will continue. First test battery cells have been manufactured and are on their way to Estonia. When they will arrive, then the functional mock-up can be made and tests with fully functional mock-up can be carried out. Estonia's most famous and awarded nature photographer Reimo Savisaar has already agreed to take the Battery Sleeve with him to the North Pole on his next photo expedition to test it and give feedback.

Another thing that has to be worked out before fully functional battery sleeve can be produced, is electronic part of the Battery Sleeve. This is to be carried out by one of the founders of the company – Ardi Mäesalu. From this process might emerge need to change some properties of the solid compartments.

Another aspect to work with is Battery Sleeves' capacity. As was revealed from the comparison with the existing external batteries, the current solution for Battery Sleeve is falling behind in this criteria. It must be considered to increase the capacity of the cells inside the Battery Sleeve. This might also highlight the need to change the shape and size of the solid compartments.

As it turned out from the first test, the current Velcro solution can be also re-considered. Other Velcro fastening solutions should be tested.

Also one important next step for the start-up company is the registration of the company, as it hasn't been registered yet. Also after that it is necessary to create visual identity for the company. This includes logo for the company, name for the Battery Sleeve (as Battery Sleeve is just work name), packaging for the product, website, business cards for the employees etc.

7 SUMMARY

Current paper is dealing with the problem that outdoor photographers are facing with when they go to shoot photos during winter. Performance of the battery inside the camera is dropping significantly as it is affected by the low temperature. This project is trying to solve this problem for photographers.

This project was initiated by Start-up Company of two young men. This company is so fresh that it hasn't even been registered jet.

The main target of this project is to design a product that would solve this problem.

Current paper follows method that is developed based on Double Diamond model. This model divides design process into four distinct phases: discover, define, develop and deliver. Also Evaluation Matrix, Positioning Map, Mind Map, Prototyping and Testing methods are used in different phases of this paper.

The initial starting point is the idea from the start-up company – a concept of external battery that would be located around the photographers' hand. Author of this paper does not take their idea blindly, but takes one step back and starts with wider background research.

From the findings of the Market Research it became evident that there are no such products in the market that would specialise on that problem. All external batteries on the market are big, heavy and bulky.

In the Define phase of this paper, also two other solutions are presented that would solve the problem. All three concepts are evaluated and Battery Sleeve concept is picked out for further design development process.

Neoprene textile is chosen for the Battery Sleeve because for its elasticity and high durability properties. In-between two layers of neoprene there are Lithium-Polymer battery cells. Lithium-Polymer cells are chosen because this technology allows elements to be curved into desirable radius. Special test is conducted to find out the right radius for bending the Lithium-Polymer battery cells.

Developed Battery Sleeve is external battery that allows nature photographers to work outside during cold winter. The product consists of the Battery Sleeve itself, one dummy battery that is chosen by the client and spring-cable extension wire.

In the end of current project, first mock-up is produced. If is not fully functional prototype, as it consists of Plexiglas elements imitating the size and the shape of the real battery cells. This first mock-up is also tested and the results show, that there is reason to carry on with developing this product.

As the first mock-up was not made fully functional, the design process will continue. First test battery cells have been already manufactured and are on their way to Estonia. When they will arrive, then the functional prototype can be made and tests with it can be carried out.

8 KOKKUVÕTE

Käesolev magistritöö on rakenduslik-loomingulise disainiprotsessi kirjeldus. Tegemist on reaalse tellimustööga. Tellijaks on kaks noort ettevõtjat, kes soovivad antud töö tulemusena sündivat toodet tootma hakata.

Disainiprotsess lähtub ‘Double Diamond’ meetodist, mida on kirjeldatud töö esimeses peatükis. See koosneb neljast peamisest etapist – otsingud (Discover), defineerimine (Define), arendamine (Development) ja vormistamine (Delivery). Lisaks sellele on erinevates ’Double Diamond’i etappides rakendatud muid disainimeetodeid. Nendeks on hindamismaatriksi meetod (Evaluation Matrix), positsioneerimiskaardistamise meetod (Positioning Map), ämbliku meetod (Mind Mapping), prototüüpimise meetod (Prototyping) ja testimise meetod (Testing).

Disainiprotsess tegeleb külmades tingimustes akude (mitte-)töötamisega. Konkreetsemalt on fookuses loodusfotograafide seisukohast fotokaamerate akude lühike tööaeg talvises pakases. Praktilise töö eesmärgiks on välja töötada aku, mis võimaldaks fotograafidel pildistada ka külmades tingimustes.

Antud töö lähtepunktiks on kliendi poolt välja pakutud aku-varruka idee. Tegemist on põhimõtteliselt välise akuga, mis käib ümber fotograafi randme. Sedasi ei ole aku külma poolt ohustatud vaid fotograafi kehasoojuse poolt soojendatud ja tema talveriietuse all ilmastikutingimuste eest kaitstud.

Enne antud kontseptsiooniga tööle asumist on käsitletud akutehnoloogiat ja –ajalugu üldisemalt, et luua paremat arusaama antud valdkonnast. Otsingute faasis on teostatud ka turuanalüüs, mis annab ülevaate ja hinnangu käesoleval hetkel turul olevatele toodetele, mis võiksid ka põhimõtteliselt külmaprobleemi lahendada. Tehtud on ka fotoaparaatide analüüs ja loodusfotograafia peamiste tüüpide ülevaade.

Defineerimise etapis on ka välja pakutud kaks alternatiivset kontseptsiooni aku-varruka kontseptsioonile. Neid kontseptsioone on hinnatud hindamismaatriksi abil. Selle tulemuseks on ikkagi see, et aku-varruka kontseptsioon on nendest parim ja selle arendamisega tegelebki edasine töö. Defineerimise etapi lõpus on välja valitud ka komponendid ja materjalid, millest toode koosneb.

Varruka materjaliks on valitud neopreen kangas. Neopreen on kummi laadne materjal, mis on kas ühelt- või mõlemalt poolt kaetud kangaga. Sellest materjalist tehakse näiteks kalipsosid. Antud materjal on valitut tänu tema headele omadustele. See materjal on väga hea keemilise stabiilsusega, säilitades oma elastsuse väga laias temperatuurivahemikus.

Arendamise etapis on välja toodud kavandeid kontseptsiooni arenduse erinevatest faasidest ja kirjeldatud maketeerimise protsessi ja tehnoloogiaid. Loodud makett ei sisalda akuelemente vaid neid imiteerivad pleksiklaasist painutatud detailid.

Aku-varrukas koosneb kahest 1 mm paksusest neopreeni kihist. Kumbki nendest on vaid ühelt poolt kangaga kaetud. Alumisel kihil on spetsiaalse spordi-kangaga kaetud see pool, mis jääb kasutaja naha vastu. Pealmine neopreeni kiht on kaetud spetsiaalse kangaga, mis võimaldab velcroga kinnitamist. Need kaks neopreeni kihti on omavahel kokku liimitud ja nende kihtide vahel paiknevad kolmes kõvakestaga osas akuelemendid ja elektroonikakomponendid.

Aku-varrukas kasutatavaks akutehnoloogiaks on Liitium-Polümeer tehnoloogia, mis võimaldab akuelementide painutamist soovitud raadiusega. Antud töös on läbi viidud test, mille tulemusena selgus, et kõige optimaalsemaks elementide raadiuseks antud rakenduses on 45 cm.

Vormistamise etapis on teostatud esimene testimine loodud maketiga. Testi tulemused tõestavad, et ergonoomilise külje pealt vaadatuna antud kontseptsioon töötab. Akut on mugav fotoaparaadiga ühendada ja käe peal kanda. Peale testimist sai tehtud ka mõningaid muudatusi, mis on tööjoonistel rakendatud.

Töö viimane peatükk võtab tehtud töö kokku ja kirjeldab edasisi tegevusi. Edasiste tegevuste hulka kuulub:

Täielikult funktsionaalse prototüübi loomine ja testimine

Aku-varruka energiamahtuvuse e. akuelementide suurendamise kaalumine

Aku-varruka velcro-kinnituse arendamine ja testimine

9 BIBLIOGRAPHY

(2007). Retrieved from Design Council: https://www.designcouncil.org.uk/sites/default/files/asset/document/ElevenLessons_Design_Council%20(2).pdf (10.05.2014)

(2009). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Decision-matrix_method (22.05.2014)

(2010). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Lithium_polymer_battery (22.05.2014)

(2010). Retrieved from OpenEI: http://en.openei.org/wiki/Definition:Power_density#cite_note-1 (26.05.2014)

(2010). Retrieved from The Free Dictionary: http://encyclopedia2.thefreedictionary.com/ion (21.05.2014)

(2011). Retrieved from Battery University: http://batteryuniversity.com/learn/article/premature_voltage_cut_off (26.05.2014)

(2012). Retrieved from digitalcamfan.com: http://digitalcamfan.com/2012/11/29/nice-deal-on-a-quick-release-dual-shoulder-camera-neck-strap/ (27.05.2014)

(2012). Retrieved from www.amazon.com: http://www.amazon.com/dp/B002VEDQMC/ref=as_li_ss_til?tag=expertphotog-20&camp=0&creative=0&linkCode=as4&creativeASIN=B002VEDQMC&adid=0H7TX71ZSXN8QM2QJTEV

(2013). Retrieved from www.macrointlco.com: http://www.macrointlco.com/category/10/Neoprene_Fabrics-_Fabrics_Laminated_on_Neoprene.html (25.05.2014)

(2013). Retrieved from Amazon.com: http://www.amazon.com/Crumpler-Industry-Disgrace-Camera-IDE001-B00000/dp/B004TTL9S0 (27.05.2014)

(2014). Retrieved from www.youtube.com: https://www.youtube.com/watch?v=uz9fjwF6CHM (17.05.2014)

(2014). Retrieved from www.prologium.com: http://www.prologium.com.tw/product_en.htm (17.05.2014)

(2014). Retrieved from www.gmbattery.com: http://gmbattery.com/product/Cuved_lipo_201030.htm (17.05.2014)

(2014). Retrieved from Physical Structure: http://www.brooklyn.cuny.edu/bc/ahp/SDPS/SD.PS.electrons.html (21.05.2014)

(2014). Retrieved from www.dictionary.reference.com: http://dictionary.reference.com/browse/energy+density (26.05.2014)

(2014). Retrieved from Wise Geek: http://www.wisegeek.com/what-is-specific-energy.htm (26.05.2014)

(2014). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Electrical_load (26.05.2014)

(2014). Retrieved from Business Dictionary: http://www.businessdictionary.com/definition/load.html (26.05.2014)

(2014). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Thermoelectric_generator (26.05.2014)

(2014). Retrieved from www.kalipso.ee: http://www.kalipso.ee/est/kataloog/detail/ice-breaker-team-jacket/43/ (27.05.2014)

Agrawala, K. (2010). Retrieved from E-Notes: http://www.enotes.com/homework-help/what-positioning-map-marketing-how-can-we-create-137049 (22.05.2014)

Akamatsu, T. (2000). What Does The User Expect From Secondary Batteries Mounted in Portable Electronics? In T. Osaka, & M. Datta, *Energy Storage Systems for Electronics.* Gordon and Breach Science Publishers.

Alex. (2010). Retrieved from www.sociamind.wordpress.com: http://sociamind.wordpress.com/2010/09/08/is-this-the-worlds-oldest-mind-map/ (24.05.2014)

Botte, G. G. (2007). Volume 5: Electrochemical Engineering. In *Encyclopedia of Electrochemistry.* Wiley-VCH.

Bourzac, K. (2012). *www.technologyreview.com*. Retrieved from http://www.technologyreview.com/news/428968/cable-shaped-batteries-with-a-twist/ (19.03.2014)

Buchmann, I. (2001). *www.buchmann.ca*. Retrieved from http://buchmann.ca/chap1-page3.asp (05.03.2014)

Buzan, T. (2011). Retrieved from http://www.tonybuzan.com/: http://www.tonybuzan.com/ (24.05.2014)

Denié, M. (2009). Retrieved from YouTube: https://www.youtube.com/watch?v=IjPi5qkWgTs (26.05.2014)

Dubberly, H. (2004). *How do you design?* Dubberly Design Office.

Emilsson, E. (2011). Retrieved from Stanford Encyclopedia of Philosophy: http://plato.stanford.edu/entries/porphyry/ (24.05.2014)

Gee, V. (2008). Retrieved from www.mind-mapping.org: http://www.mind-mapping.org/mindmapping-learning-study-memory/who-invented-mind-mapping.html (24.05.2014)

Gee, V. (2014). Retrieved from http://www.mind-mapping.org/: http://www.mind-mapping.org/blog/mapping-history/roots-of-visual-mapping/ (24.05.2014)

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information System Research. *MIS Qurterly*, 75-105.

Hide, N. (2013). Retrieved from www.cnet.com: http://www.cnet.com/news/lg-to-launch-flexible-batteries-is-bend-the-new-black/ (17.05.2014)

Hill, C. A. (1998). Satellite Battery Technology - A Tutorial And Overview. The Aerospace Corporation.

Honsberg, C., & Bowden, S. (2013). *pvcdrom.pveducation.org*. Retrieved from http://pvcdrom.pveducation.org/BATTERY/capacity.htm (25.04.2014)

Housecroft, C. E., & Constable, E. C. (2006). Chemistry: An Introduction to Organic, Inorganic and Physical Chemistry. Pearson Education.

Jana, K. (2013). *Understanding Batteries for Your RE System*. Retrieved from http://www.homepower.com/: http://www.homepower.com/articles/solar-electricity/equipment-products/understanding-batteries-your-re-system (12.03.2014)

jmeyer. (2012). *www.nphotomag.com*. Retrieved from http://www.nphotomag.com/2012/11/05/nikon-camera-batteries-the-complete-list-for-every-current-dslr/ (19.03.2014)

Kahn, J. (2013). *9to5mac.com*. Retrieved from http://9to5mac.com/2013/07/05/apple-details-flexible-battery-packs-suitable-for-rumored-iwatch-product/ (09.04.2014)

ketyung. (2009). *www.techchee.com*. Retrieved from http://www.techchee.com/2009/07/06/dyson-energy-bracelet-produces-electricity-in-ambient-air-for-charging-gadgets/ (19.03.2014)

Kingham, D. (2012). *www.davidkinghamphotography.com*. Retrieved from http://www.davidkinghamphotography.com/blog/2012/10/external-power-for-a-nikon-d700 (19.03.2014)

Krebs, R. E. (2006). The History and Use of Our Earth's Chemical Elements. Greenwood Publishing Group.

Kurtus, R. (2013). Retrieved from School for Champions: http://www.school-for-champions.com/science/electricity.htm#.U3w7pPl_vVU (21.05.2014)

Linden, D., & Reddy, T. B. (2002). *Handbook of Batteries.* McGraw-Hill.

Linden, D., & Reddy, T. B. (2002). *Handbook of Batteries, 3rd edition.* New York: McGraw-Hill.

Lower, S. (2007). Retrieved from http://www.chem1.com/acad/webtext/elchem/ec1.html#CHEMEL (26.02.2014)

Maini, A. K., & Agrawal, V. (2007). *Satellite Technology: Principles and Applications.* West Sussex: John Wiley & Sons.

Ouye, J. (2014). Retrieved from Cornell University: http://iwsp.human.cornell.edu/file_uploads/reinvent_ex3_1238263608.pdf (22.05.2014)

Owano, N. (2013). Retrieved from www.phys.org: http://phys.org/news/2013-10-lg-chem-cable-batteries.html#inlRlv (17.05.2014)

Park, W. (2009). *www.intomobile.com*. Retrieved from http://www.intomobile.com/2009/01/21/forget-the-slap-bracelet-meet-the-battery-bracelet/ (19.03.2014)

Petzl.com. (2014). *www.petzl.com*. Retrieved from http://www.petzl.com/en/outdoor/headlamps/specialized/ultra-vario-belt (12.03.2014)

Rahn, C. D., & Wang, C.-Y. (2013). *Battery Systems Engineering.* John Wiley & Sons.

Robert, C. (2014). Retrieved from eHow: http://www.ehow.com/info_10010476_output-voltage.html (26.05.2014)

Rubber, 4. Emulsion Rubbers. (2012). In W. Obrecht, J.-P. Lambert, M. Happ, C. Oppenheimer-Stix, & J. D. Krüger, *Ullmann's Encyclopedia of Industrial Chemistry.* Wiley-VCH, Weinheim.

Salustri, F. (2013). Retrieved from Design Wiki: http://deseng.ryerson.ca/dokuwiki/design:weighted_decision_matrix (22.05.2014)

Salustri, F. (2013). Retrieved from Design Wiki: http://deseng.ryerson.ca/dokuwiki/design:concept_evaluation (22.05.2014)

Simon, H. A. (1996). *The Science of the Artificial.* London: MIT Press.

Tague, N. R. (2004). Retrieved from American Society for Quality: http://asq.org/learn-about-quality/decision-making-tools/overview/decision-matrix.html (22.05.2014)

Team, M. E. (2008). Retrieved from Massachusetts Institute of Technology: http://web.mit.edu/evt/summary_battery_specifications.pdf

unknown. (2009). *www.ephotozine.com*. Retrieved from http://www.ephotozine.com/article/jacobs-leather-camera-grip-strap-review-12492 (02.04.2014)

Vincent, C. A. (1997). *Modern Batteries: An Introduction to Electrochemical Power Sources.* Butteworth Heinemann.

www.amazon.com. (2014). Retrieved from http://www.amazon.com/Canon-BG-E11-Battery-Cameras-Black/dp/B007FH1FZ0 (03.04.2014)

www.amazon.com. (2014). Retrieved from http://www.amazon.com/Wasabi-Power-Battery-Canon-LP-E6/dp/B0041MY32Y/ref=sr_1_4?s=electronics&ie=UTF8&qid=1396539872&sr=1-4&keywords=LP-E6 (03.04.2014)

www.amazon.com. (2014). Retrieved from http://www.amazon.com/LP-E6-Replacement-Batteries-Digital-Camera/dp/B005AYT6R4/ref=sr_1_6?s=electronics&ie=UTF8&qid=1396539872&sr=1-6&keywords=LP-E6 (03.04.2014)

www.boredpanda.com. (2014). Retrieved from http://www.boredpanda.com/cool-and-creative-gadgets-for-photographers/ (18.03.2014)

www.digital-slr-guide.com. (n.d.). Retrieved from http://www.digital-slr-guide.com/digital-slr-batteries.html (19.03.2014)

www.ebay.com. (2014). Retrieved from http://www.ebay.com/itm/New-Lanparte-LP-E8-Camera-Power-Coupler-DC-Dummy-Battery-Pack-For-550D-600D-650D-/370731885945 (12.05.2014)

www.economist.com. (2002). Retrieved from http://www.economist.com/node/1176209 (25.04.2014)

www.globalmediapro.com. (2014). Retrieved from http://www.globalmediapro.com/dp/A2HNG9/Globalmediapro-ZD-E6-Dummy-Battery-Adapter-for-Canon-DSLR-Cameras/# (04.05.2014)

www.hddv.net. (2014). Retrieved from http://hddv.net/showthread.php?41641-T3i-T2i-Grips-amp-Battery-Options-After-market-vs-Genuine (12.05.2014) *www.hdvideoshop.com*. (2014). Retrieved from http://www.hdvideoshop.com/en/accessories/2308-lanparte-portable-battery.html (04.05.2014)

www.intecfoams.co.uk. (2014). Retrieved from http://www.intecfoams.co.uk/foams/closed_cell_foam.html (08.05.2014)

www.lanparte.com. (n.d.). Retrieved from http://www.lanparte.com/html/169.html (02.04.2014)

www.linkdelight.com. (n.d.). Retrieved from http://www.linkdelight.com/330801049W-LanParte-PK-01-DSLR-Camera-Follow-Focus-Rig-Kit.html (02.04.2014)

www.phys.org. (2013). Retrieved from http://phys.org/news/2013-11-njit-flexible-battery-carbon-nanotubes.html (17.05.2014)

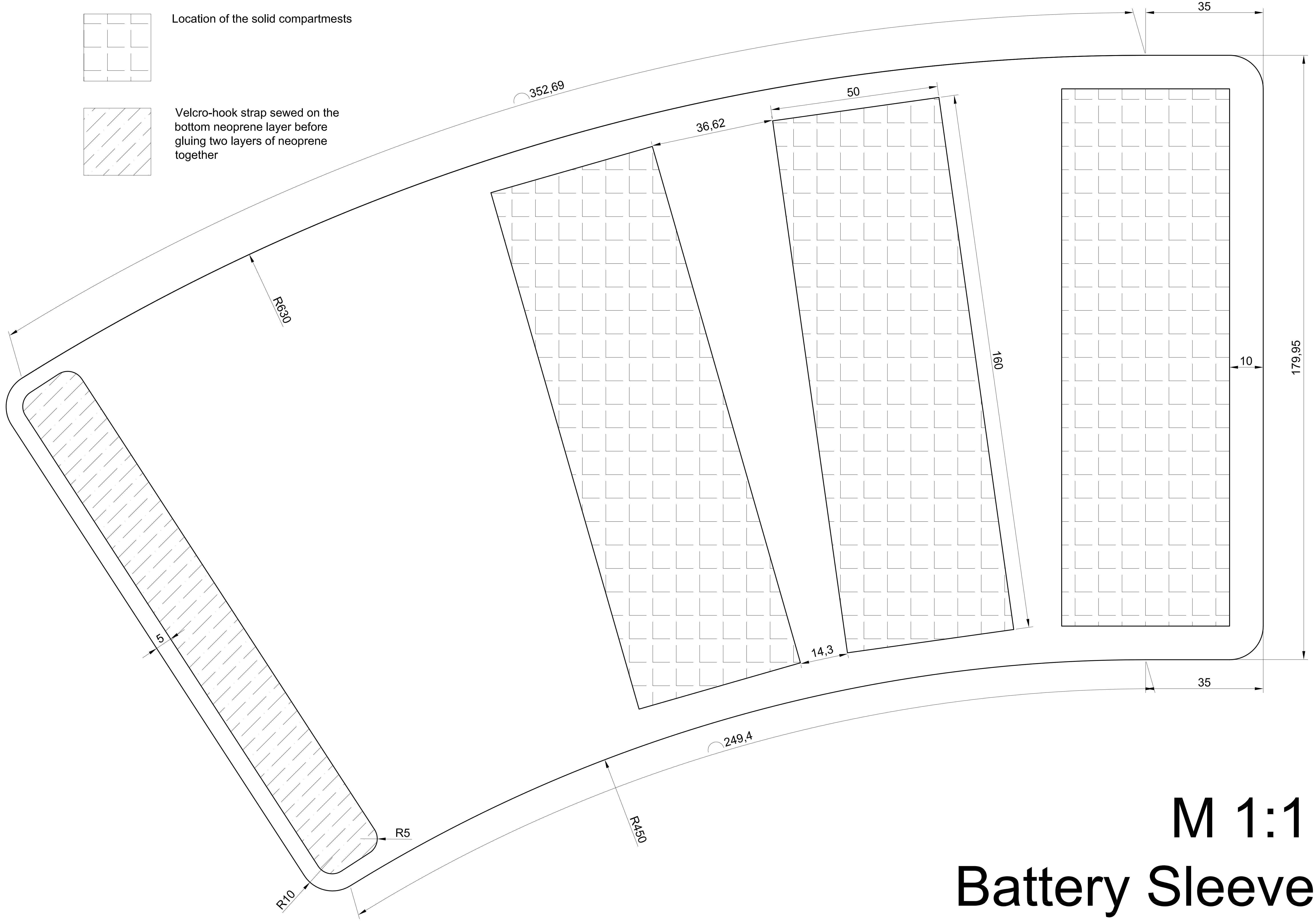
www.shop.usa.canon.com. (2014). Retrieved from http://shop.usa.canon.com/shop/en/catalog/batteries-and-chargers/eos-batteries-chargers-grips/battery-grip-bg-e11 (03.04.2014)

www.shop.usa.canon.com. (2014). Retrieved from http://shop.usa.canon.com/shop/en/catalog/batteries-and-chargers/eos-batteries-chargers-grips/battery-pack-lp-e6 (03.04.2013)

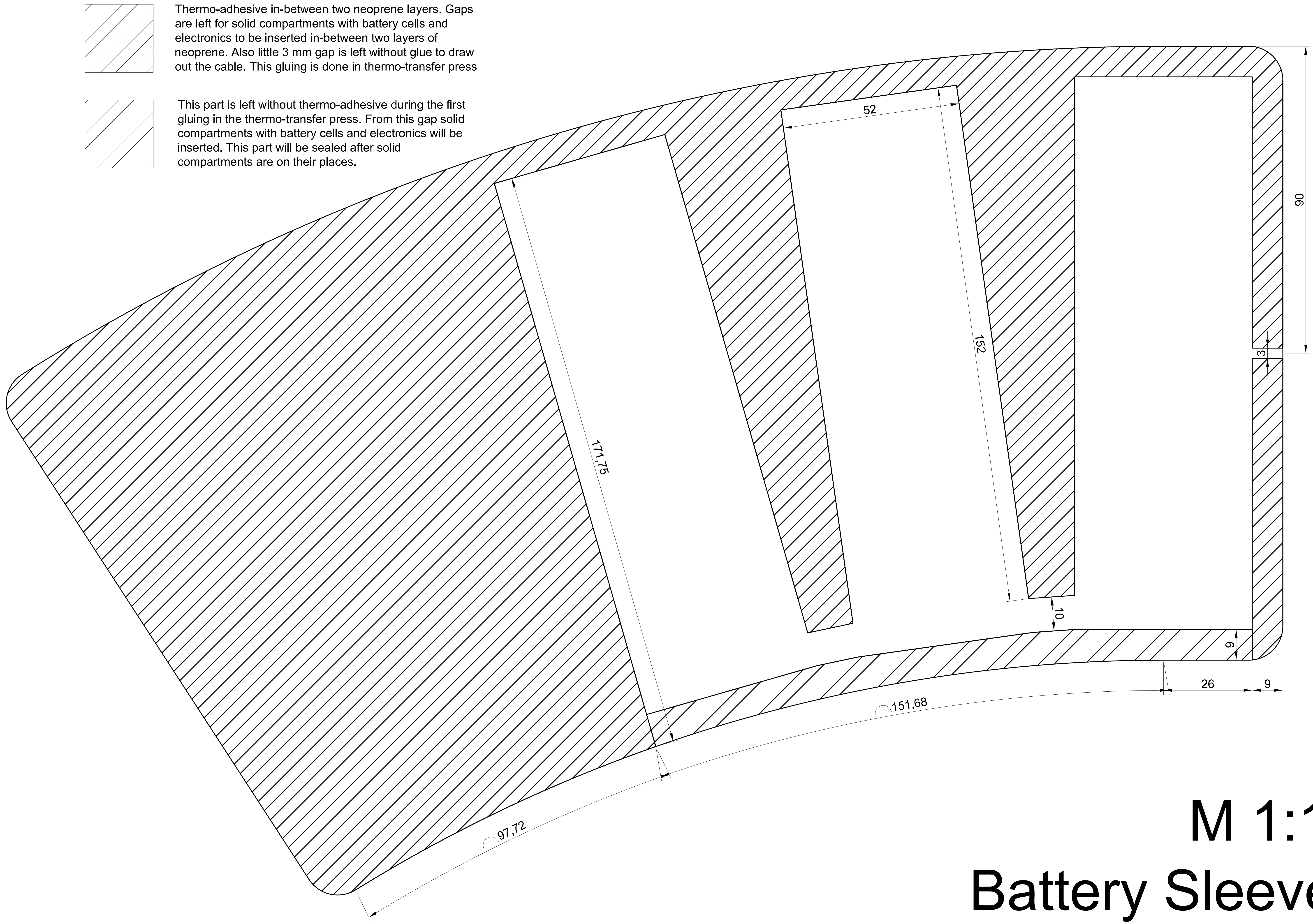
www.thinkgeek.com. (n.d.). Retrieved from http://www.thinkgeek.com/product/ceca/#tabs (19.03.2014)

10 LIST OF FIGURES

11 APPENDIX



M 1:1
Battery Sleeve



M 1:1

Battery Sleeve