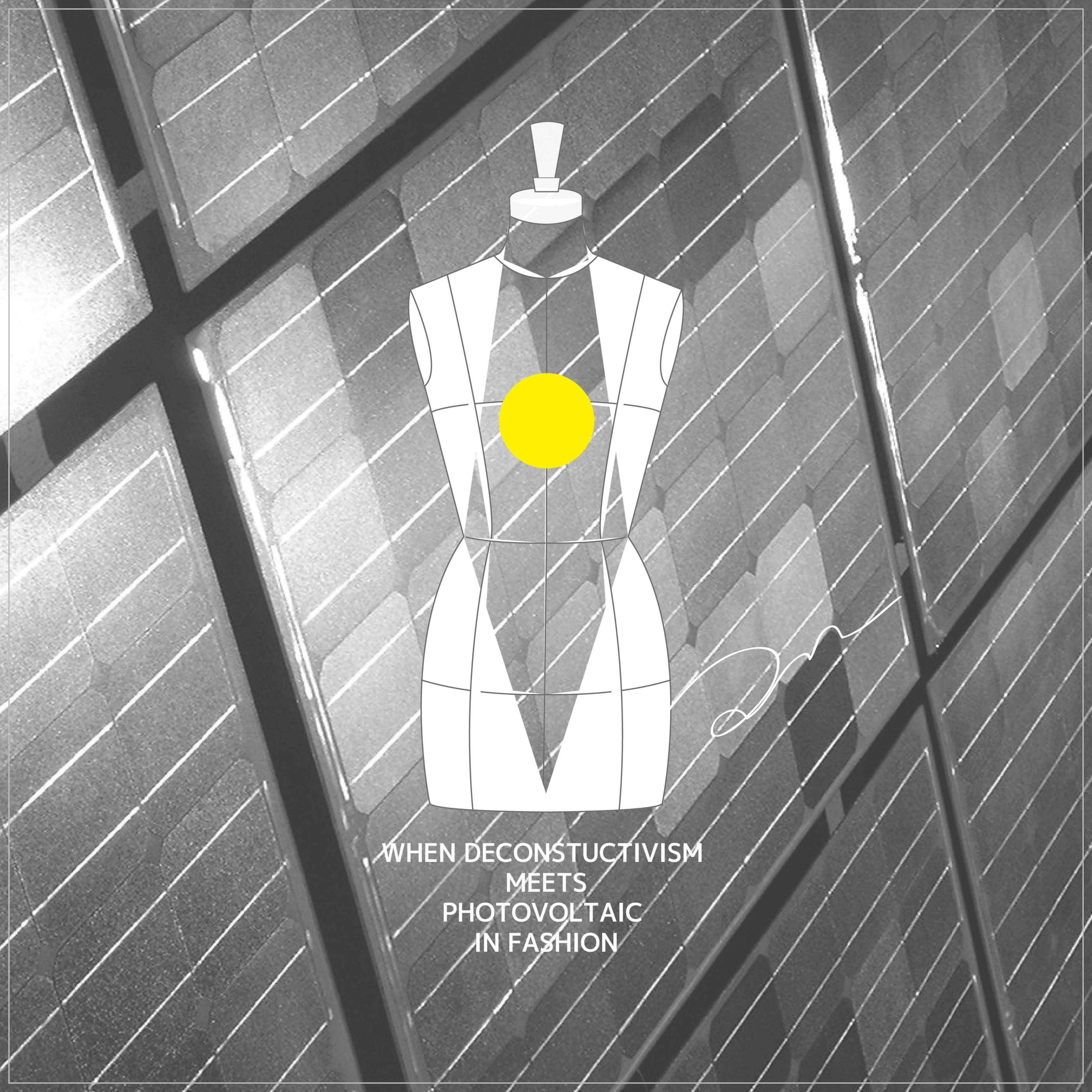
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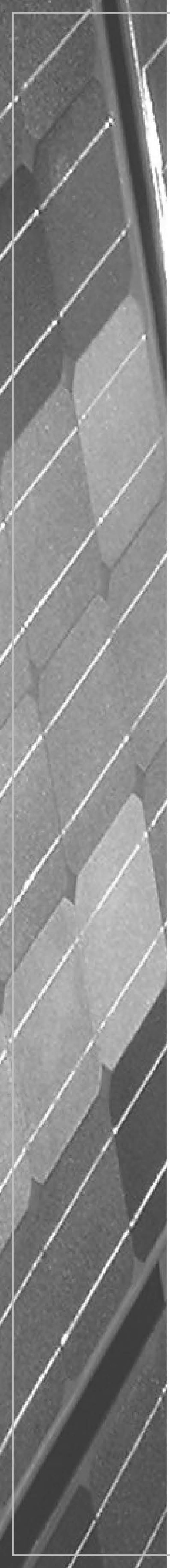


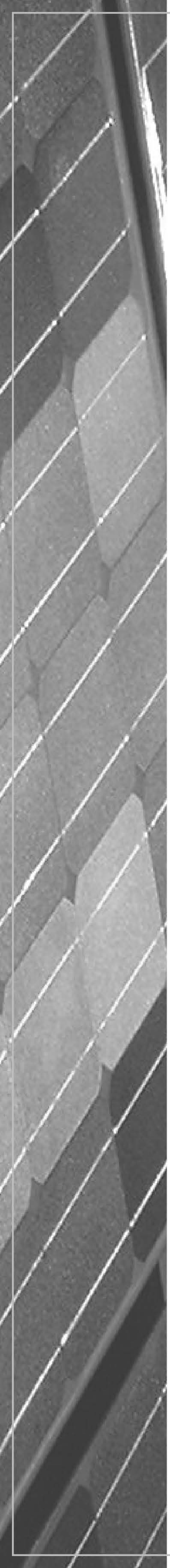
WHEN DECONSTRUCTIVISM MEETS PHOTOVOLTAIC IN FASHION
The development of photovoltaic system integrated
illuminating deconstructive garments

By

Yuxi Wang

A thesis exhibition presented to OCAD University
in partial fulfillment of the requirements for the degree of
Master of Design in the Digital Futures Program

49 McCaul Street, Toronto, Ontario, Canada, 2014
Exhibit: April 11, 2014



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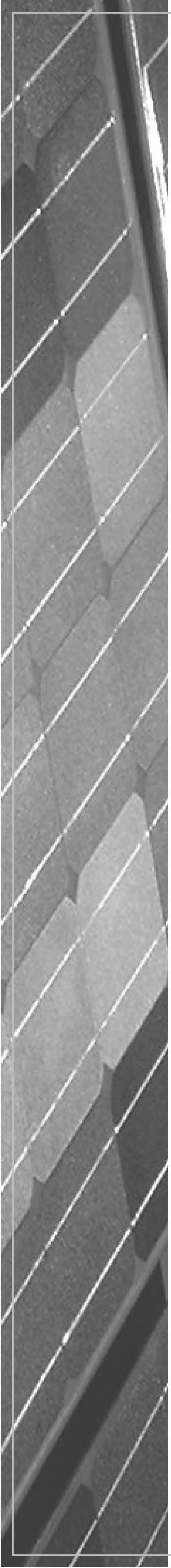


ABSTRACT

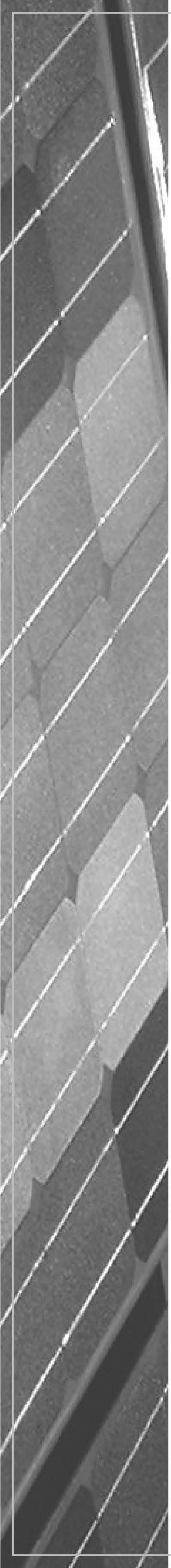
When Deconstruction Meets Photovoltaic In Fashion:
The Development Of Photovoltaic System Integrated Illuminating Deconstructive Garments

Master of Design
2014
Yuxi Wang
Digital Futures
Ontario College of Art and Design University

In this paper I show 'how deconstructivism in fashion can enhance the aesthetics and functional design of the photovoltaic integrated garment' (PV garment). I also demonstrate how integrated lighting can be powered by solar technology.

Photovoltaic (PV) technology generates electricity by converting solar radiation into direct current electricity. Power supply is a vitally important question to be addressed in the development and acceptance of wearable technology. The value of PV technology is as a green power source that can be embedded in the garment.

My intention is to provide a new design approach for a PV garment that can combine function with aesthetics. These are garments designed to be worn by trendsetters. I will provide solutions for embedding a photovoltaic powered system into different positions on the body through the use of deconstruction fashion techniques. I will also demonstrate how this design approach optimizes the performance of a PV system.



ACKNOWLEDGMENTS

I would like to express my deepest gratitude to the people who have helped and supported me throughout my project.

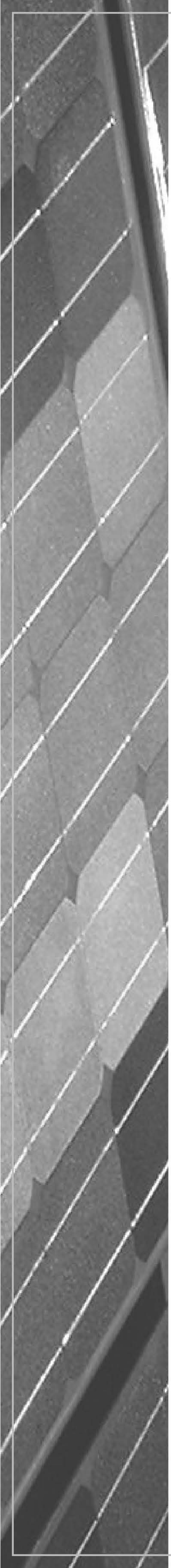
I am grateful to my supervisor Marie O'Mahony for her continuous support for the project and this paper, from her initial advice and contacts in the early stages of conceptualization to her ongoing advice and encouragement to this day.

Thanks to my secondary supervisor Kate Hartman who has provided me with great support and guidance throughout my project.

Special thanks goes to my sponsor Zhen Fang who helped me in completing the project and who exchanged his interesting ideas and thoughts and who made this project easy and accurate.

I wish to thank my parents Junling Zhu and Yongjie Wang for their unwavering support and interest. They inspired me and encouraged me to go my own way. Without them I would have been unable to complete my project.

Last but not least I want to thank my friends who participated in my user testing sessions. I could not have accomplished this work without their help and kind support.



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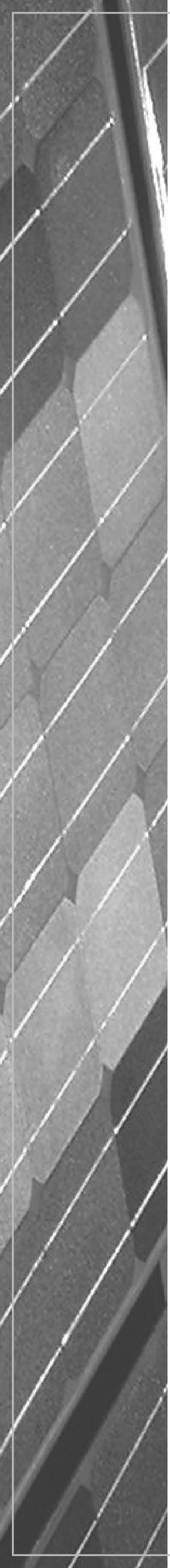

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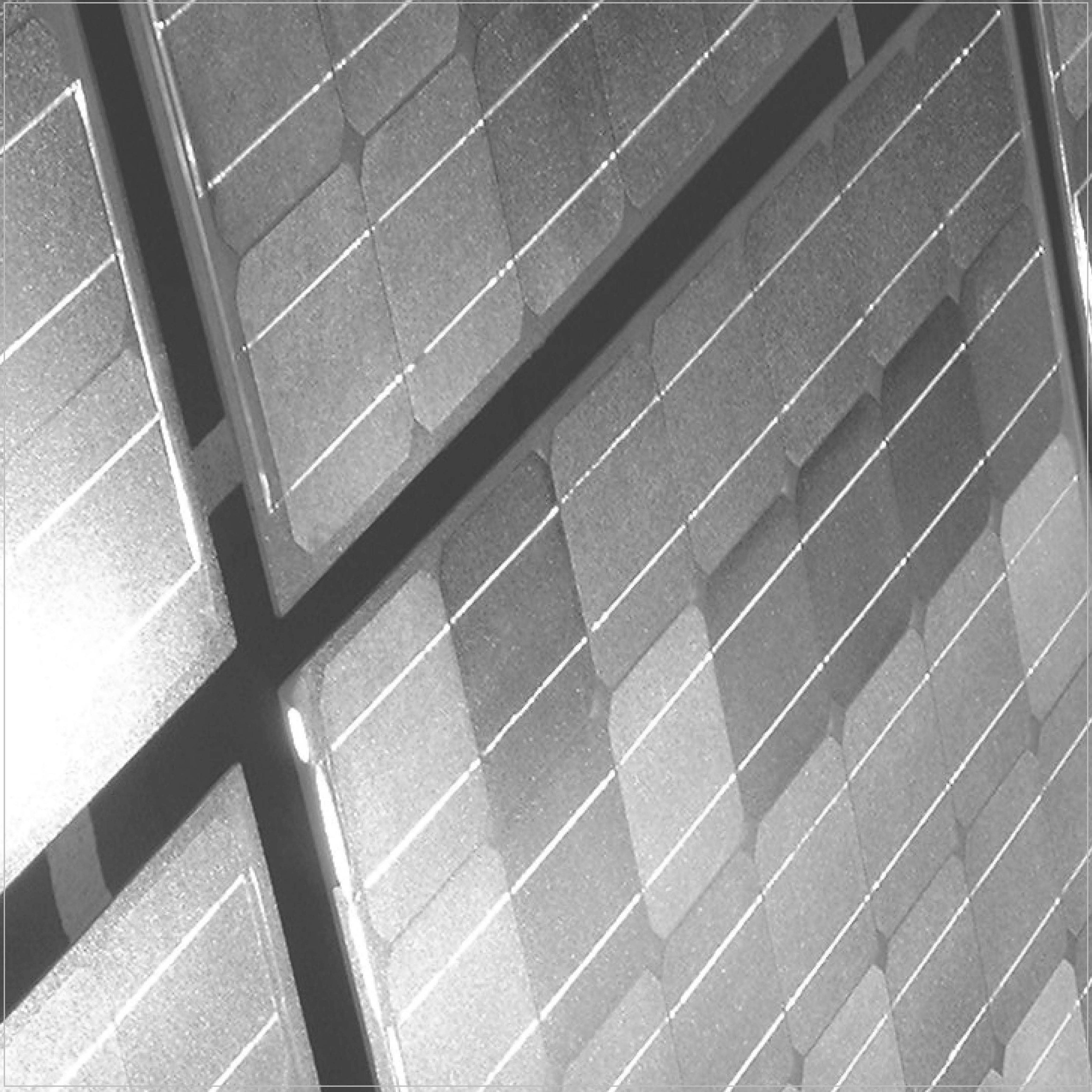
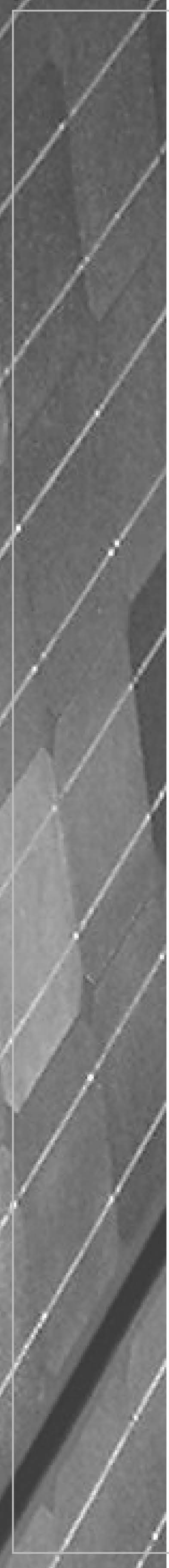




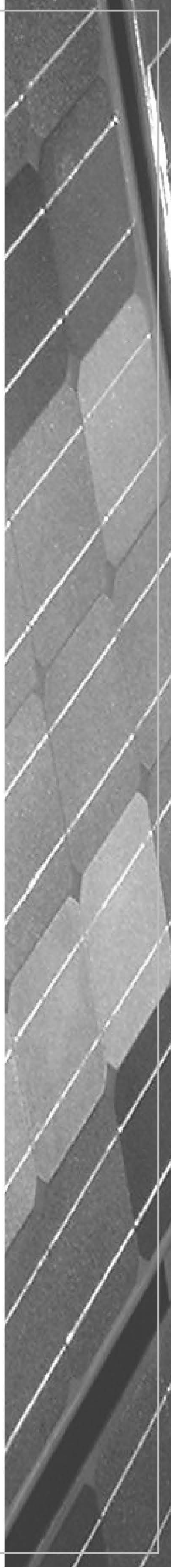
I propose that deconstructivism is a design approach to combining function and aesthetics when incorporating photovoltaic technology into high fashion.

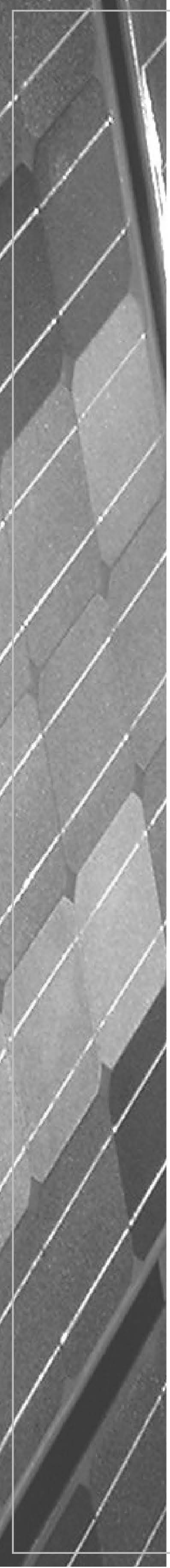
INTRODUCTION

INTRODUCTION

Wearable technology refers to different forms of body-mounted technology, including wearable computers, smart clothing, and functional clothing (Dunne, 2004). Smart clothing are clothes that sense and respond to changes within their environment, which have already been integrated through technologies built into them. The technologies used range from performance fabrics to electronic or 'e-textile'. A wearable computer is a device that turns humans into part of the feedback loop of a computational process (Steve Mann, 2001). It can be mounted onto or embedded in the garment with full functionality and can be self-powered (Dunne, 2004). The immaturity of function and the aesthetic design of a wearable computer embedded garment is one of the biggest challenges in the field of wearable technology. While we are starting to see the use of photovoltaic systems in fashion, these tend to be photovoltaic cells attached to the garment without deep consideration of functionality and the aesthetics of design. In my opinion, there are three main reasons leading to this.

The first issue is one of energy supply. This has been one of the chief impediments to the realization of the embodiment of wearable technology. Users have to charge the computer battery (most commonly lithium) manually, showing that the accessibility of the charging system is very important. That is why designers have always kept the computer revealed in order to make the task easier. Because of this the wearable computer cannot be fully integrated into the garment. This has restricted the development of an aesthetic design for the wearable technology garment because of the revealed electronic components. A further problem occurs once the power system has to be connected to an external power resource, making power charging one of the biggest obstacles for embedding a wearable computer in a garment. Harvesting energy through photovoltaic materials allows the wearable device to recharge itself without external power input and offers what is believed to be one of the best ways to eliminate the power-charging problem.



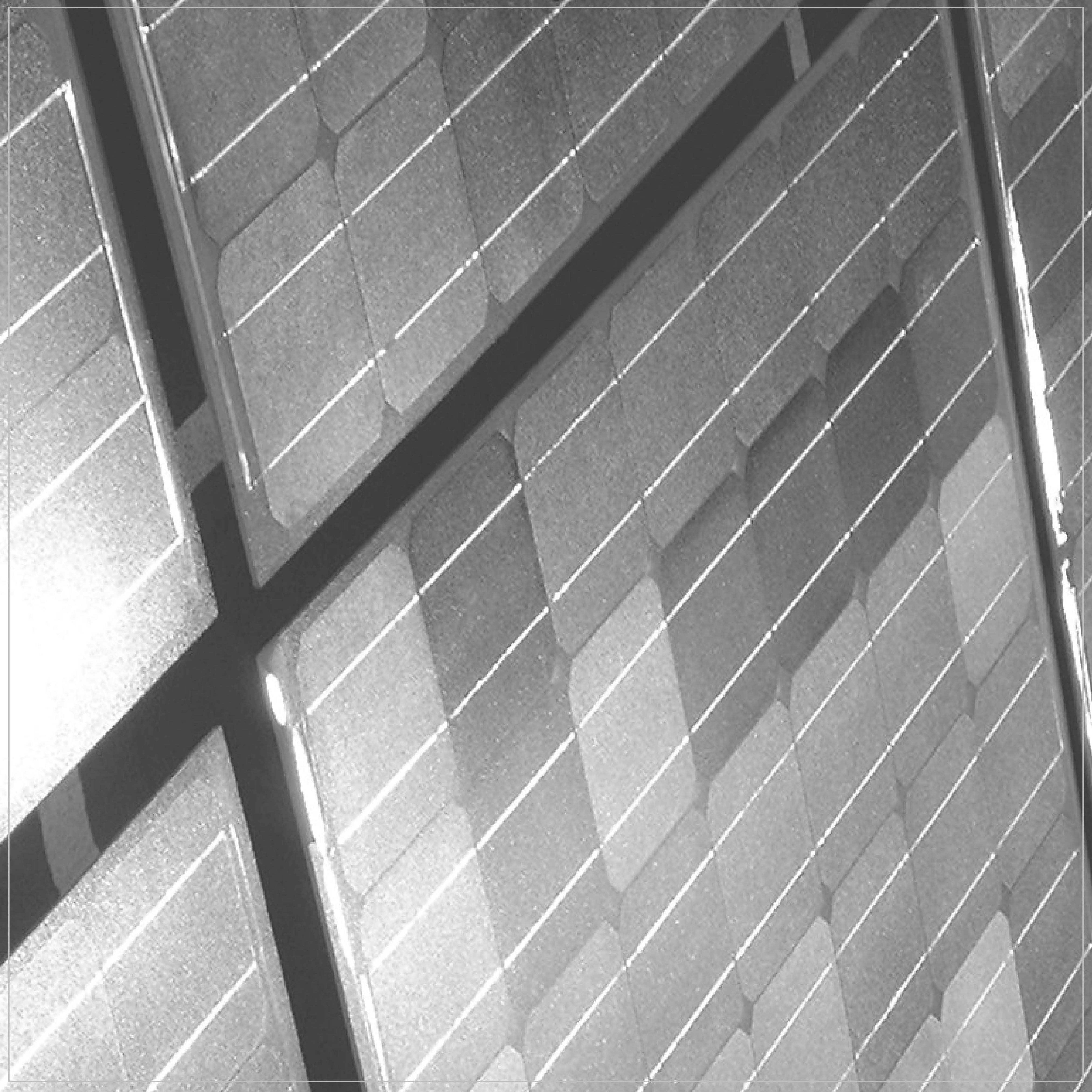


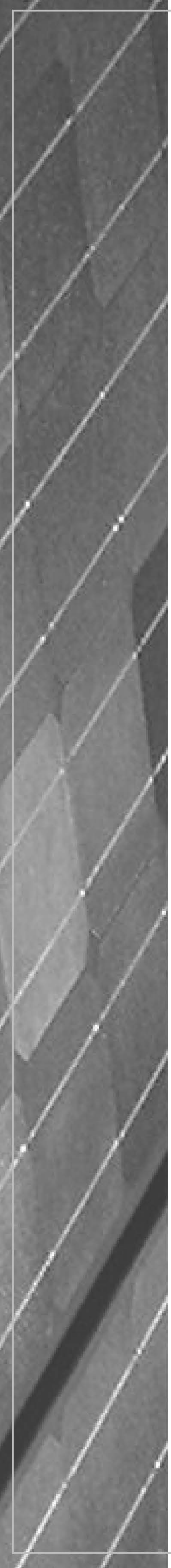
INTRODUCTION

The second problem is limited space between the body and the garment. Regardless of the size of the photovoltaic system, additional space is needed in the garment in order to embed the system. In garments designed using traditional patternmaking techniques there is little possibility to allow for extra space to place the device. As a result wearable computers tend to be mounted on the body instead of being hidden in the garments. Therefore, the notion of deconstruction fashion that I introduce will offer a solution to the problem of limited space.

Different from structured and tailored garments that are especially prevalent in Western fashion design, deconstructivist fashion contains deliberate construction methodologies. As Sally Brampton proposes in the book of 'Yohji'(1983), deconstruction fashion focuses on the sculptural interrogation of form, the nature and tactility of fabric and the interactive space between the body and the item of clothing. Deconstruction fashion does not obey convention in that it does not follow the shape of the human body (Brampton 1983). Simply embedding the photovoltaic system into a regular garment may distort the shape of the garment, and reduce the space between the body and cloth. This disobeys the principle of 'wearability' that is crucial to the consumer of wearable technology. However, by using the techniques from deconstructive fashion, the shape of the garment can be redefined and extra space for the computer created. In other words, if designers put the device in the extra space of a deconstructive garment, the interactivity between the body and clothing could be better than that of embedding a computer in clothing that is based on a highly tailored pattern. By using the techniques of deconstruction fashion, the space between the body and the garment can be created, allowing the PV system to be placed in the space.

Third, for photovoltaic systems, the PV cells require a large surface on which to be placed. However, regular garments have limited surface area. The reason why I choose deconstruction fashion as the design approach is that through deconstructing and reconstructing garments, extra surfaces can be created for placing more solar cells. Besides, solar cells should face towards the sunshine in order to receive more sunlight. Deconstruction garments enable adjusting the angle of the surfaces to make them horizontal.





Research approaches that will be conducted in this study include experimenting, an expert interview and user testing.

RESEARCH METHODS

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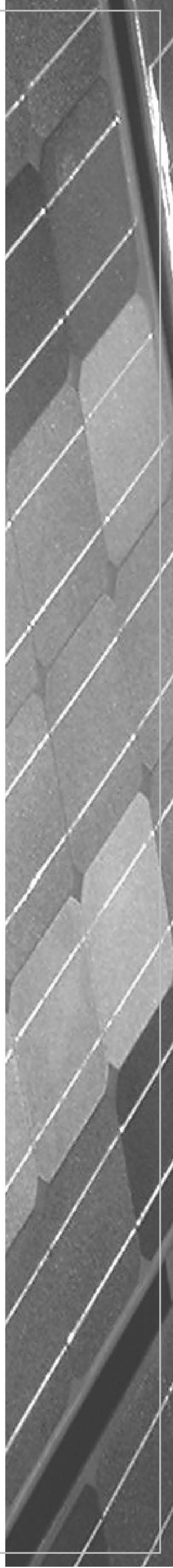
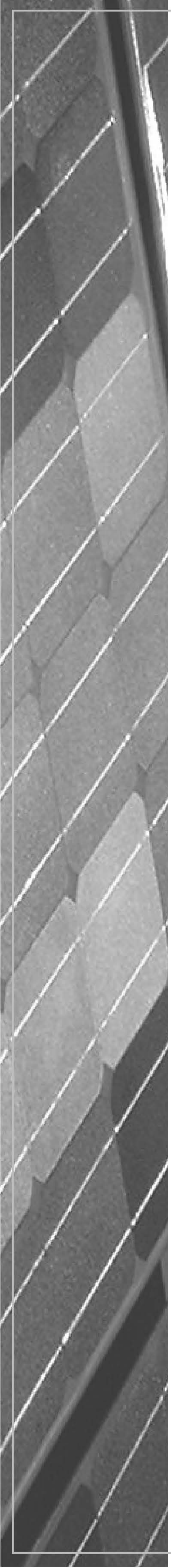
Research approaches that will be conducted in this study include experimenting, an expert interview and user testing.

When developing my prototype, experiments were conducted as a way to gain understanding of the materials and explore new possibilities. The experiments took place in different stages: concept development, material selection, PV system design and PV garment design.

Due to the time limitation, only one expert interview was conducted before designing the photovoltaic system. I telephone interviewed electronics expert Zhen Fang, a professor from the Institute of Electronics, Chinese Academy of Sciences. Due to the limitation of my technical experience, the expert interview helped me gain a theoretical background for designing a photovoltaic system and develop an understanding of how the system works, both of which assisted me in facilitating the following design works. (The detail will be elaborated in 'PV system design'.)

Wearable technology is all about the wearing experience. Wearability is an essential factor for the success of the project. Therefore, user testing is conducted in the refining stage, at the end of the project, where users are involved in several iterations. I will use participants' feedback as a guideline for refining my project. (The detail was included in 'PV system installation'.)





"...as fashion and technology come together now more dramatically than ever before, they reveal their capacity to transform the human experience more than technology alone ever could."

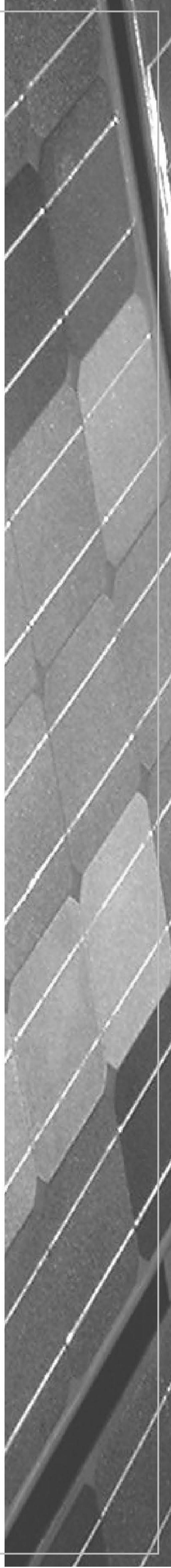
Bradley Quinn, 2013

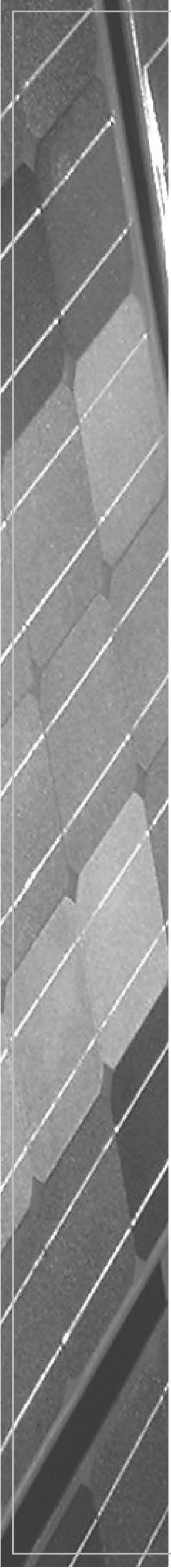
EXPERIENCE
MOTIVATION
INSPIRATION
DECISION

EXPERIENCE

My background is in film studies. Looking specifically at the genre of science fiction movies, I realized that wearable technology was one of the most important components in futuristic films. The 'wearable computer pack' in '2001: A SPACE ODYSSEY' (1968) provides a seminal moment in cinematography in forming public opinion about wearable technology. The illuminating suit in 'TRON' (1982) demonstrated the aesthetic potential of wearables. Then the gloves in 'Minority Report' (2002) and the programed suit in 'Iron Man' (2008) showed the enhancement of human abilities through using wearable devices. The current advanced technologies are able to make those imaginary wearables come true. It is believed that wearable technology, as a new application environment for electronics and computing devices of all kinds has unlimited possibilities and great potential in film, fashion and other industries (Dunne, 2004). Such belief was my motivation for investigating this field more deeply.

In my undergraduate program filmmaking course, I had the opportunity to design and make garments for my own film projects, during which time I developed my skills in costume design and gained a great interest in making clothes. As well, I engaged an art director in a few thesis projects in my class. Along with my pursuit in fashion design, I also incorporated some elements of fashion into their projects and obtained positive feedback. Since then, fashion design has become one of my passions. Combined with my great interest in technology, I decided to investigate an approach to wed wearable technology with fashion, so as to create a synergy between function (technology) and aesthetics (fashion).





MOTIVATION

When I was working on wearable projects, three issues always troubled me along the way. First, the limited battery capacity has traditionally restricted the working time of the wearable computer. As a designer, I have had to test the circuits on garments through several iterations to ensure they were working properly, but they frequently ran out of battery power. Most of the time I had to stop and wait until the batteries fully recharged. For users such as singers, changing or charging the batteries of wearable computers during rehearsal or a live performance must be annoying. Therefore, I concluded that a more user-friendly form with a continuous power supply for a wearable computer should be introduced into the wearable context.

Second, it is hard to embed electronic components into clothes without affecting their wearability. Regardless of the flexibility of electronic components, they require surfaces or space on the garment in order to be embedded in it. Otherwise wearability is affected since the extra weight from their components may change the shape of the clothes. However, most of the standard tailored clothes do not have the extra space to place those electronic parts (e.g. wearable computer, LED or sensors). I propose that additional space or surfaces are needed when embedding electronic components in garments.

Third, the aesthetic design of a wearable project is always limited by its function. I used to work in a medical project that used wearable computers to monitor a wearer’s health status. In this project, electrodes would be mounted on the front chest. The clothes had to be tight enough to hold the electrodes and the material had to be breathable. The features or functions of such wearable projects predetermined the appearance of the garments, which provided limited space for designers to work with and thus reduced their ability to focus on aesthetics.

My motivation is to work through these three issues and provide solutions for designers like me.

INSPIRATION

As my father works in the energy industry, he made me appreciate the importance of sustainable energy. Self-charging garments are able to provide a continuous power supply by collecting renewable energy from the environment or human body and converting it to useable power sources. It not only solves the problem of power supply in wearables, but also meets the future trend of sustainable energy.

However, it is a challenge to embed an energy-harvesting system into the garment without interfering with the performance of the device, wearability and aesthetics of the garment when a suitable design approach is needed. Avant-garde deconstruction fashion designers, such as Yamamoto Yohji, Rei Kawakubo, Issey Miyake and Martin Margiela, have inspired me through their works. Their design pieces place greater emphasis on form and space.

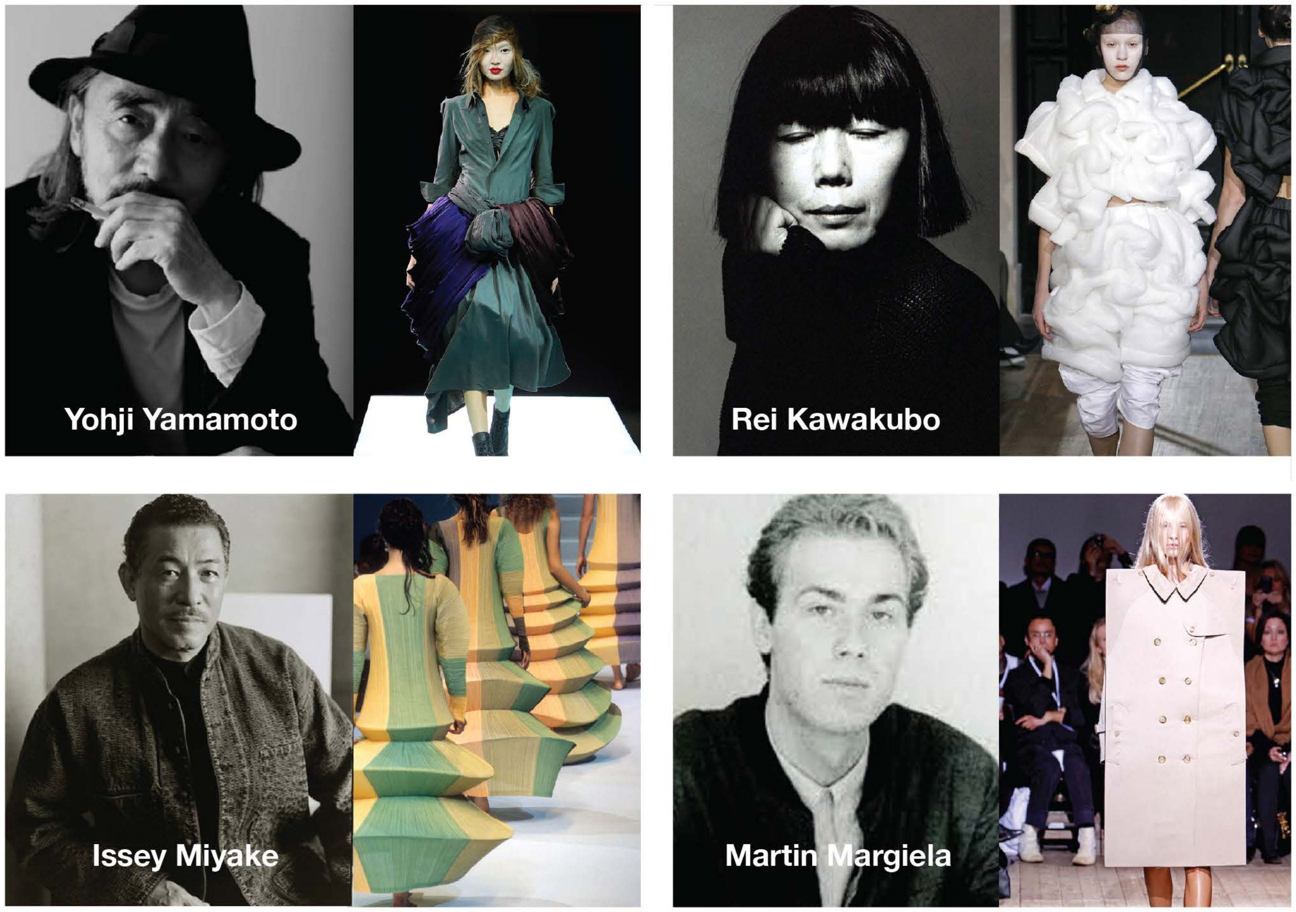


Figure 1: Inspiring deconstruction fashion designers and their works

Retrieved from:

Yohji Yamamoto Portrait Photo
http://www.viamontenapoleone.org/eng/red_carpet_Catalogue.php?id=30

http://multiplefashiondisorder.wordpress.com/category/fashion-week/fashion-week-spring-2011/paris-fashion-week-spring-2011/page/2/

Rei Kawakubo Portrait Photo
http://www.vogue.com/vogue-daily/article/from-the-archives--iconic-female-designers-throughout-the-years-in-vogue/

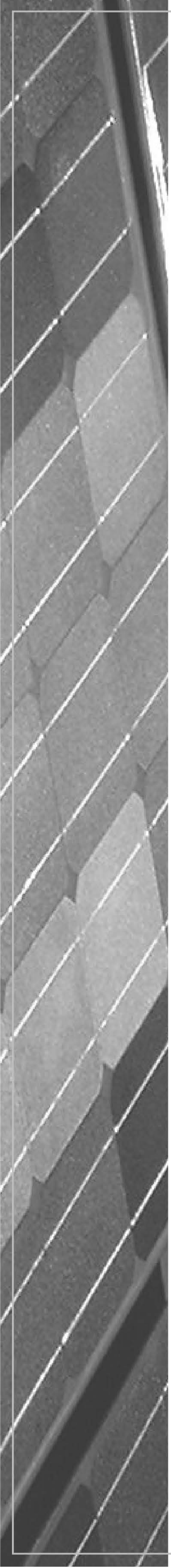
Rei Kawakubo Designed Garment
http://www.grazia.fr/mode/news/comme-des-garcons-revisite-le-carre-hermes-500967

Issey Miyake Portrait Photo
http://www.glamourgoddessfashion.com/irving-penn-and-issey-miyake-exhibition-in-tokyo/m20-3/

Issey Miyake Pleats Garment
http://theredlist.com/wiki-2-23-1249-1258-view-1970s-profile-issey-miyake-3.html

Martin Margiela Portrait Photo
http://oglobo.globo.com/blogs/lula/posts/2008/09/09/vejam-cara-de-martin-margiela-face-oculta-da-moda-124660.asp

Maison Martin Margiela S/S 2011 Garment
http://www.todayandtomorrow.net/2010/10/04/maison-martin-margiela-ss-2011/



INSPIRATION

Differing from tailored garments, deconstruction garments contain extra inside space and outside surfaces.

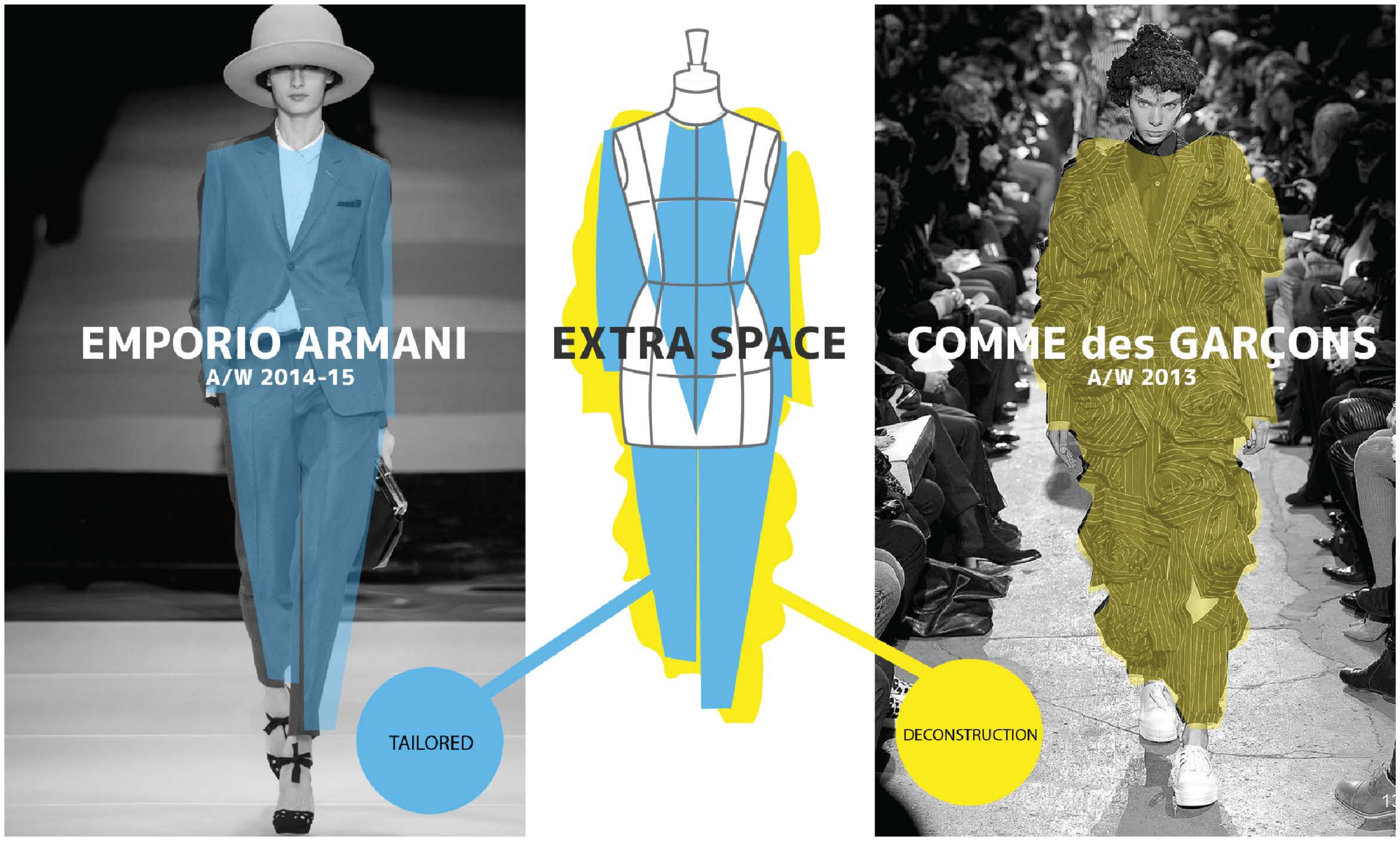


Figure 2: Comparison between well-tailored garment and deconstruction garment
Emporio Armani A/W 2014-15 Retrieved from: http://thebestfashionblog.com/womens-fashion/emporio-armani-fall-winter-2014-2015
COMME des GARÇONS A/W 2013 Retrieved from: http://irenebrination.typepad.com/irenebrination_notes_on_a/2013/03/page/2/

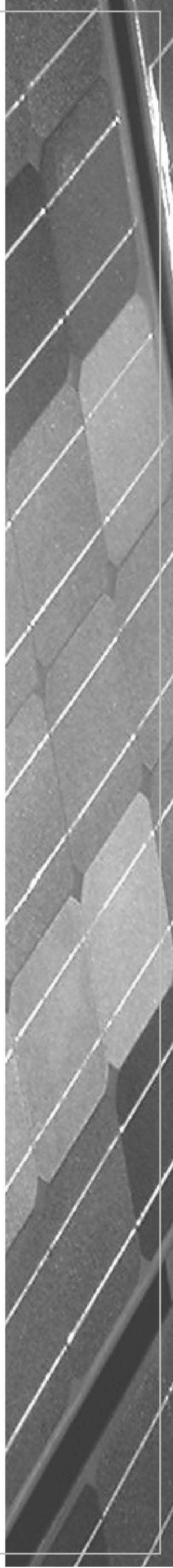
Emporio Armani is famous for its well-tailored suits, while COMME des GARÇONS as a brand from Rei Kawakubo, is well known for its deconstruction garments. The photo shows the additional space (yellow area) in the deconstruction garment.

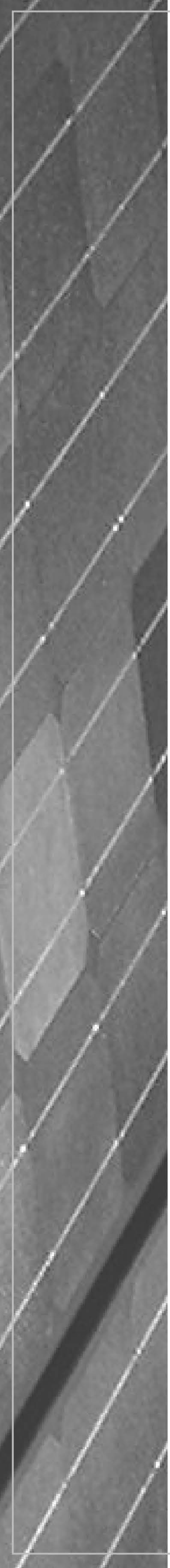
Therefore, using the space and surfaces of deconstruction garments to house the energy-harvesting systems is a suitable design approach. The forms of deconstruction fashion have broken the laws of traditional fashion design, which generated more possibilities of aesthetic designs for designers.

DECISION

I use deconstructivism as a design approach to create self-charging garments, which solves the problems of a wearable system, such as power supply, wearability and aesthetics.

Wearable technology is an intersection between technology and design, and few design guidelines for both sides are provided. It is difficult for technicians to produce an aesthetic garment with good wearability and for designers to create garments that facilitate the technical portion. That is why few wearable projects have met all of these criteria. An exemplar is created here that inspires both designers and technicians. The deconstruction techniques in fashion that will be explored in my thesis can be applied to other wearable projects when involving mounting electronic parts onto clothes. The thesis will form a new design approach towards the function and aesthetic design of wearable technology, especially for a wearable computer.





CONCEPT DEVELOPMENT

CONCEPT DEVELOPMENT

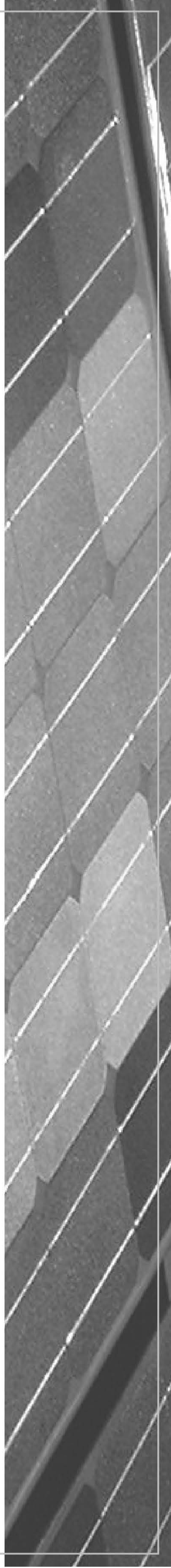
I am aiming to solve the power supply problem in wearables by creating self-charging garments to extend the battery lifetime and eliminate the charging process. Several different mechanisms can be embedded in self-charging garments, such as collecting energy from human activity or derive limited energy from ambient heat, light, radio, or vibrations (Paradiso & Starner, 2005).

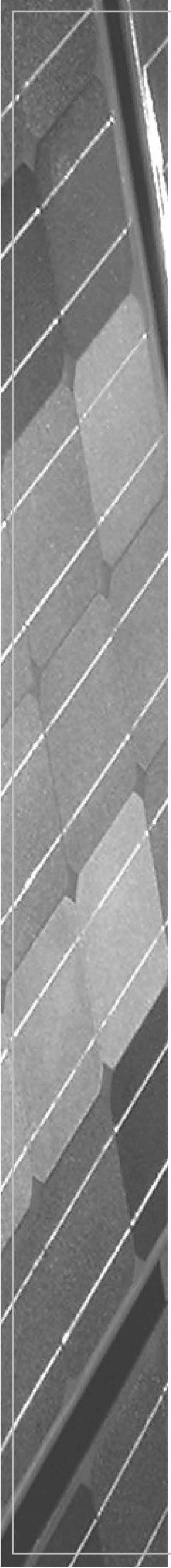
My initial concept of the project was to create a wearable device that could harvest energy from the human body, such as daily movement or body heat, and use deconstructivism as the design approach to house the devices. According to Joseph A. Paradiso and Thad Starner's research, collecting energy from body heat, movement, and piezoelectric material is currently limited by its practicality, comfort and efficacy. To scavenge energy from body heat, the system has to be designed similarly to a wet suit to create extreme temperature differences for conducting higher efficiencies. The latest thermoelectric system 'Carnot cycle' can only obtain 5.5% efficiency from human body heat transfer. Piezoelectric materials are more often mounted on large structures with more frequent and larger vibrations. Vibrations created by the human body are not enough to generate sufficient energy. The motion system that harvest energy from body movement can only support extremely low-power applications due to the extremely small size of the electrostatic generators. (Paradiso & Starner, 2005)

Research Methods: Experiment as Research - Micro-generator

In my first technological experiment I used a micro-generator to generate electricity when the induction coil cuts through a magnetic field while rotating the roller. I concluded that it is hard to affix those small generators to clothing, and this mechanism is not appropriate for a wearable project for long-term use. Based on the research and experiments, using body movements to generate power is not deliverable at this stage, although it is a future possibility as I discuss in 'Moving Forward'

After discussion with experts in China who had experiences with similar projects, I came to the conclusion that the



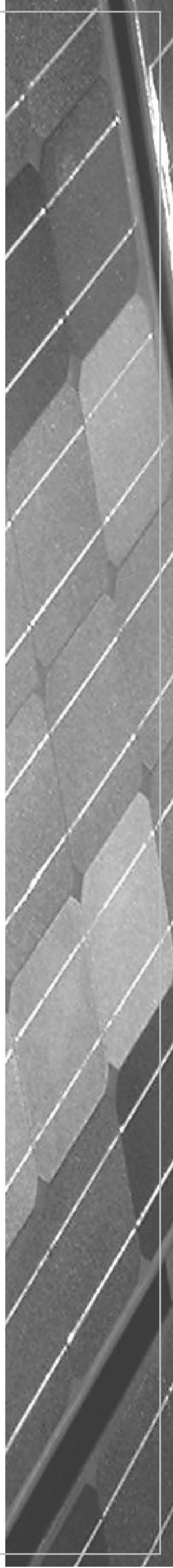


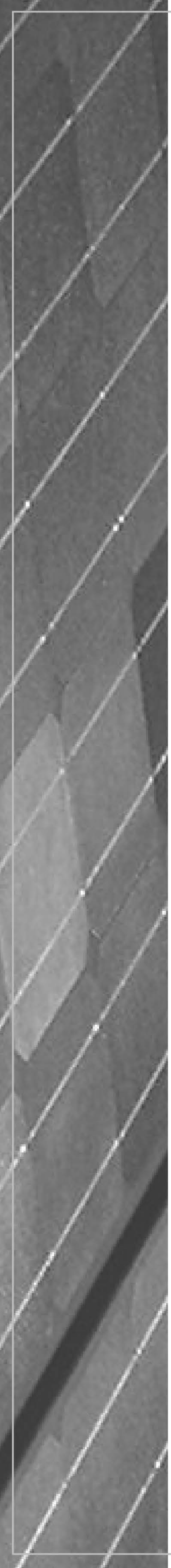
technical components for collecting energy from the human body are still not sophisticated or mature enough. Existing technologies cannot guarantee reliability of the system. Therefore, it would be better to choose a more sophisticated energy harvesting technology with which to work.

As Schubert & Werner suggested, PV is the most advanced way of providing electricity far from any main supply. In clothing where solar cells are integrated, it has been shown that such cells are able to power most mobile electronics (Schubert & Werner, 2006). PV technology is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors to create voltage or electric current in a material upon exposure to light (Pearce, 2013). The PV technology, which first appeared in the 1800s, has approximately 200 years of history. With a longer history than other energy harvesting methods, PV technology was recently perceived as a more sophisticated energy harvesting method. In terms of the sizes of solar cells, solar panels are traditionally huge glass and silicon structures placed on top of office buildings. Nowadays, with technological advancement, solar cells can be created small enough to be incorporated into the structure of clothing (O'Mahony, 2011). Moreover, the efficiency of PV cells has increased from 1% to 44.7% (Bellis, 2014). Therefore, a small number of PV cells is able to generate sufficient energy to power up wearable computers. Moreover, most PV cells are available in the mass market, providing good resources for designers and researchers. The sophistication, high efficiency, and accessibility of PV cells are the reasons for me to choose the use of a PV system as the mechanism for my self-charging garment.

The next step is to think about how to embed a PV system into garments. Solar cells need to be placed on a relatively flat surface. Based on experimentation (which will be elaborated on in chapter 5), it is better to place them so they are facing upwards towards the sunshine. However, traditional pattern cutting follows the shape of the human body, and the only piece of the pattern facing upward is the shoulder pattern. In fact, for the photovoltaic system, the more solar cells in the system, the faster the charging process. But the shoulder pattern is too small to be filled with a large number of solar modules. By deconstructing garments, flat surfaces on different parts of the body can be created or enlarged. In this way deconstruction fashion can improve the efficiency of a photovoltaic system.

Consequently, my project can be defined as a 'self-charging' computer integrated garment, which uses a PV system to harvest energy and deconstruction fashion as the design approach to embed the PV system into the garment, facilitating the performance of a PV system.





"Clothing is our most intimate environment. What makes it a unique environment is that it is carried everywhere with an individual, creating its own room within a room and its own climate within the larger climate of our surroundings. The relationship of clothing to the human body, to other objects that come into contact room or the great outdoors has fascinated people for centries.

Susan M. Watkins, 1984

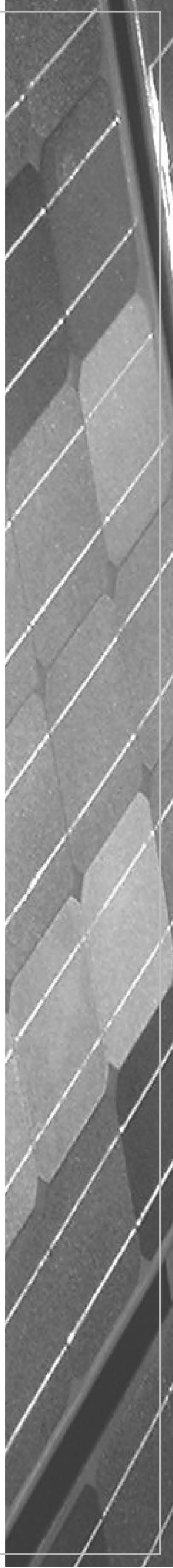
BACKGROUND

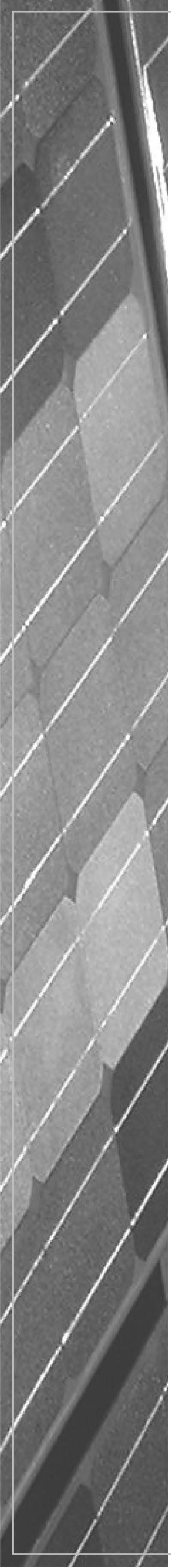
Key Applications of PV System

Solar power, as a renewable, non-polluting source of energy, has been mainly applied in the fields of architecture, transportation and the military. From large-scale solar architectural designs to smaller scaled solar cars to wearable solar systems in the military, solar tech has become more widespread in the last couple of decades. The sophistication of a PV system in function led designers to reconsider the aesthetics of the PV integrated products.

Photovoltaic applications for buildings appeared in the 1970s. In their early stages of development, people simply connected or mounted aluminum-framed photovoltaic modules on roofs of buildings without deep consideration of aesthetics and function. With the development of a PV module, the flexible, transparent, semi-transparent and thin film modules were invented, creating more possibilities for architects. Many aesthetic and detailed sustainable solar buildings were created. Vector Foiltec is one of the leading innovators in Ethylene tetrafluoroethylene (ETFE) foils for architecture. Developments include incorporating solar cells in the transparent membrane. In the extension to Ant Control Pasadena, a Bruce Mau designed pattern was printed onto the material to offer a dappled shade aesthetic (O'Mahony, 2011).

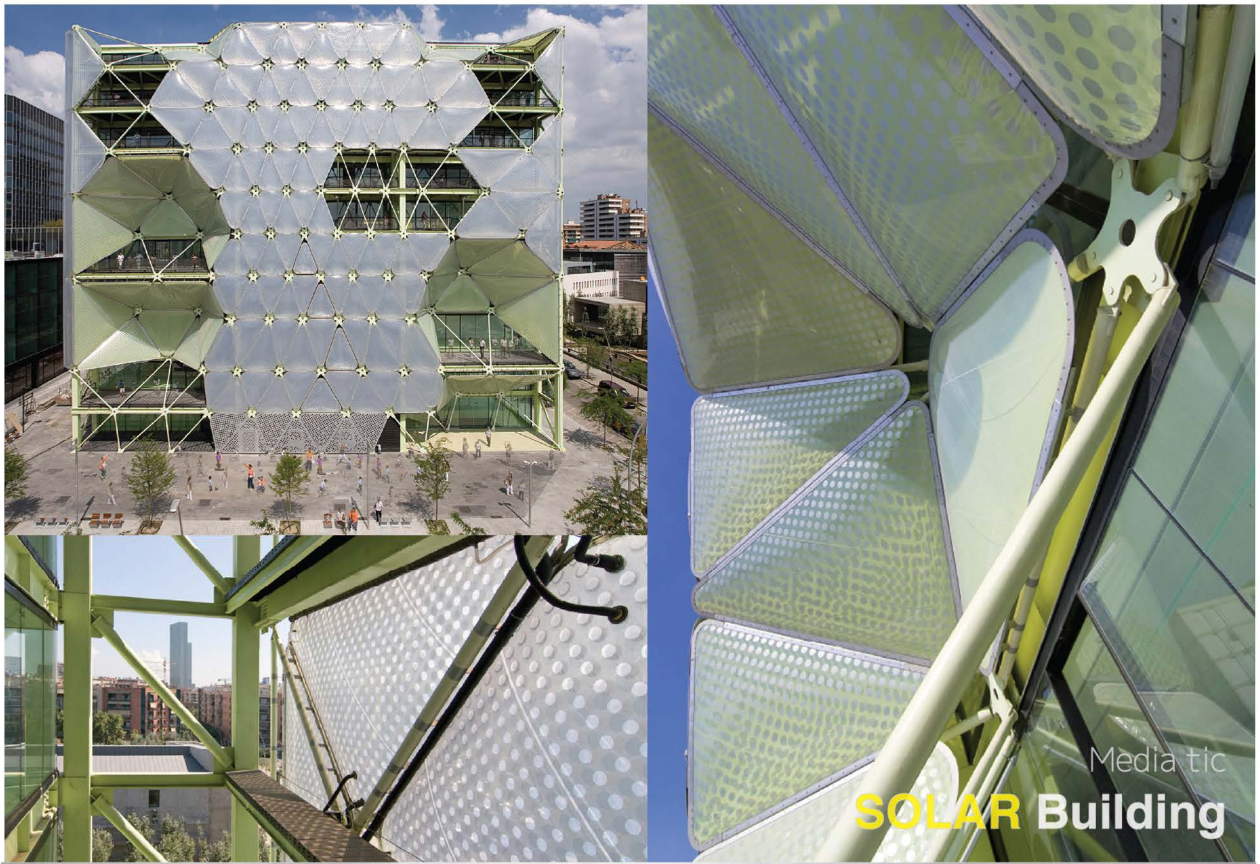
Architect Enric Ruiz Geli's media tic building in Barcelona belies the idea that sustainable architecture lacks any special aesthetic through their visibly 'performative' qualities (AT212, 2010). He created designs to filter solar radiation through a screen of vertical cushioned panels as a 'cloud' sunscreen to demonstrate aesthetics. The inflatable cushions were embedded with sensors reading the heat and the angle of the sun, which combined aesthetics and function. In architecture, the increasing awareness of the aesthetics of sustainable building made more designers take this into consideration.





BACKGROUND

Besides architecture, significant improvements were made with solar cars, increasing their popularity. In 1982, the first solar car 'BP Quiet Achiever' was designed in Denmark by Hands Tholstrup and Larry Perkins and it stressed the fact that solar energy could be a major and sufficiently developed source to replace fossil fuels.



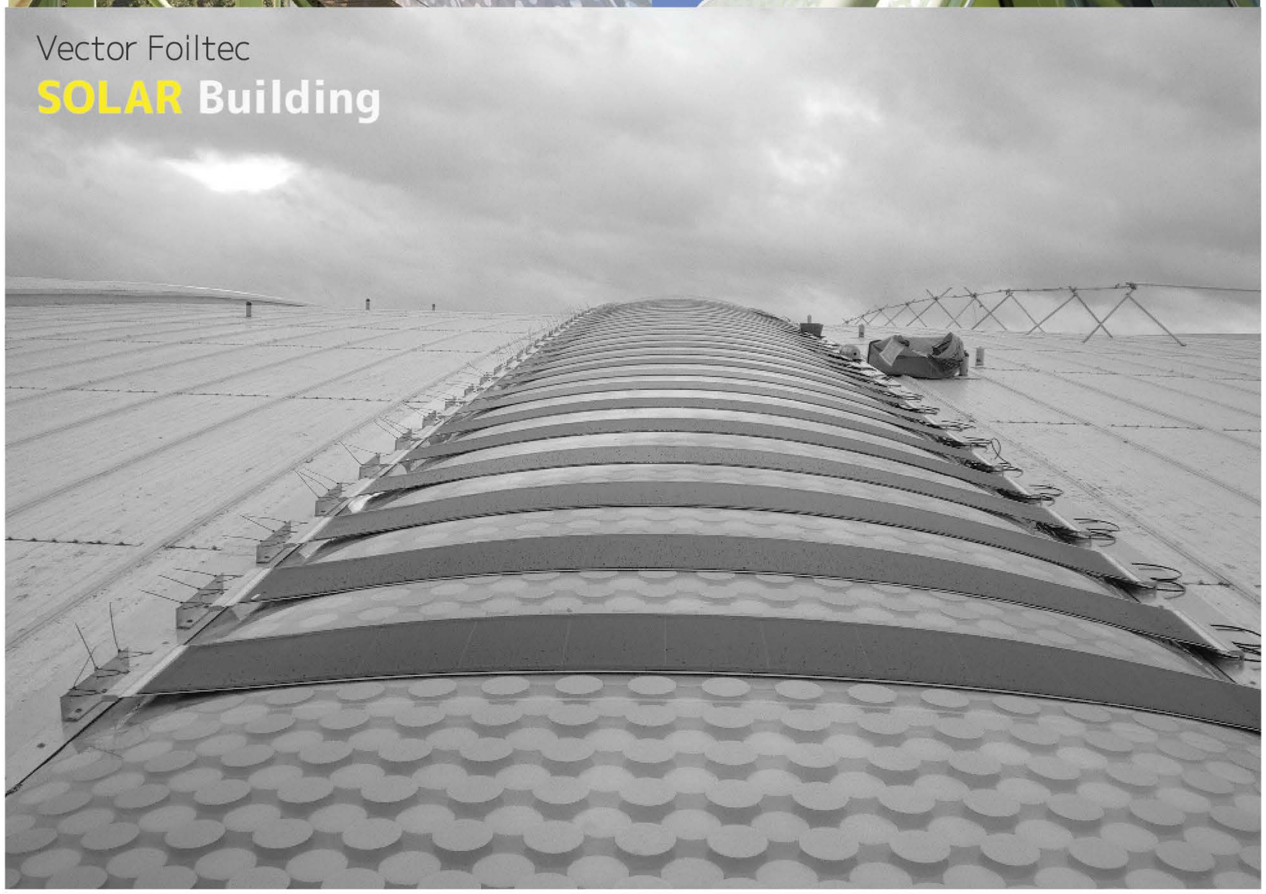


Figure 3: Solar buildings
Enric Ruiz Geli's media tic building
Retrieved from:
http://www.bustler.net/index.php/article/world_architecture_festival_awards_2011_-_grand_prize_winners/

Vector Foiltec
http://cr4.globalspec.com/blogentry/23162/Biggest-Trends-In--Eco-Friendly-Building

BACKGROUND

In 2006, the world's first commercial electro-solar hybrid car 'The Venturi Astrolab' was launched. However, attaching solar cells to the exterior affected the overall look of the car. In the forum, the audience considered the car 'bad-looking' and 'non-practical'. The drivers had to wear a helmet when they drove the car, which was not 'user friendly'. In other words, the importance of the function and aesthetics of the solar car should be stressed and reconsidered.

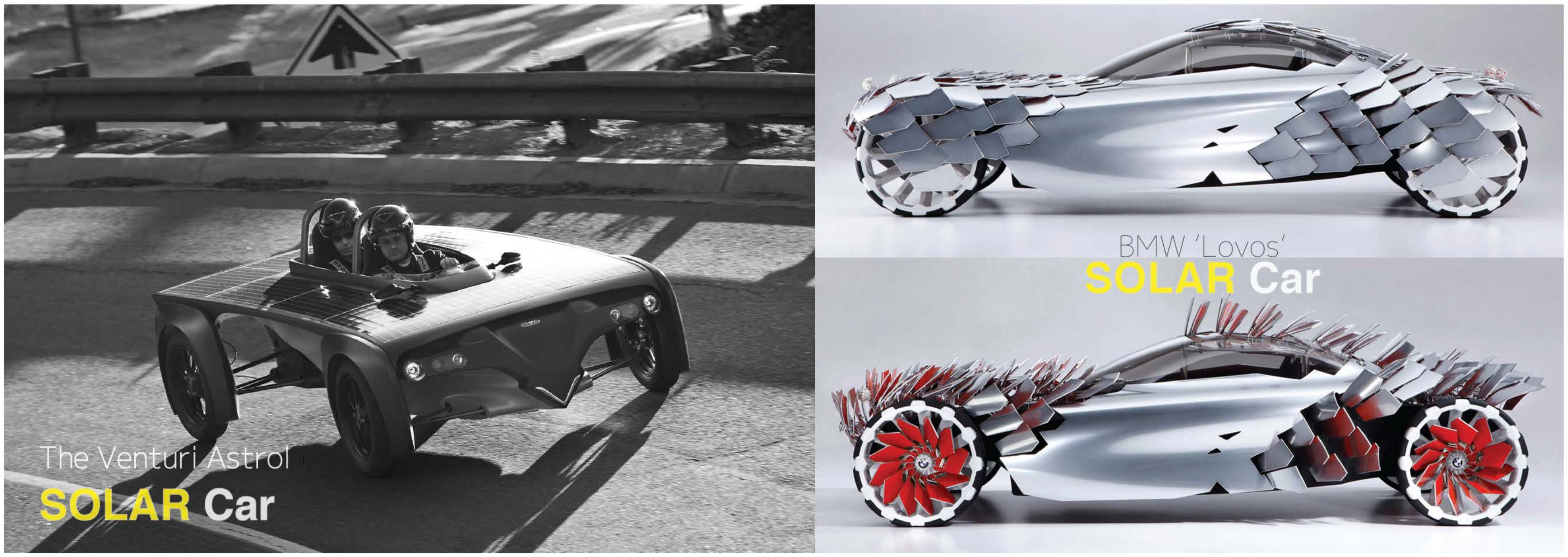


Figure 4: Solar cars
The Venturi Astrolab Solar Car
Retrieved from: http://www.gdefon.com/download/Venturi_Astrolab_Car_machinery_cars/137990/1920x1200
BMW Lovos concept car designed by Anne Forschner
Retrieved from: http://shanmugaraju.blogspot.ca/2012/04/bmw-lovos-concept.html

In 2009, Anne Forschner designed the BMW 'Lovos' concept solar car, which combined function and aesthetics through creating a special structure on the exterior of a vehicle.

It has a body made of 260 identical movable parts, which integrate photovoltaic functions. The project is based on a philosophical idea, which asks critical questions about design, construction and use (Raju, 2012). By defying the traditional methodology of car design, her work has generated more possibilities for aesthetics when designing solar cars. The concept designs demonstrate this aesthetic achievement.

Flexibility and curved systems received some impetus from these industries, which were all important in the development of PV technology for wearable technology. The increasing use of wearable technology in the military has created a strong impetus to reduce the solar weight and the bulk of the energy resource. Batteries, accounting for 25% of the overall payload, are relied on heavily by soldiers to satisfy their power need, leading to a significant increase on the soldiers' physical stress and cognitive burden (Tsekleves & Paraskevopoulos, 2012). The development of renewable energy provided solutions for reducing the weight of soldiers' equipment. A few years later, researchers started to investigate the possibilities of integrating solar cells onto the uniform, which was considered a wearable solar cell. The wearable PV was also included in the 2020 Future Force Warrior project.

Figure 5: Australia solar powered soldiers
Retrieved from:
http://www.ecouterre.com/solar-powered-soldiers-to--revolutionize-australian-combat/

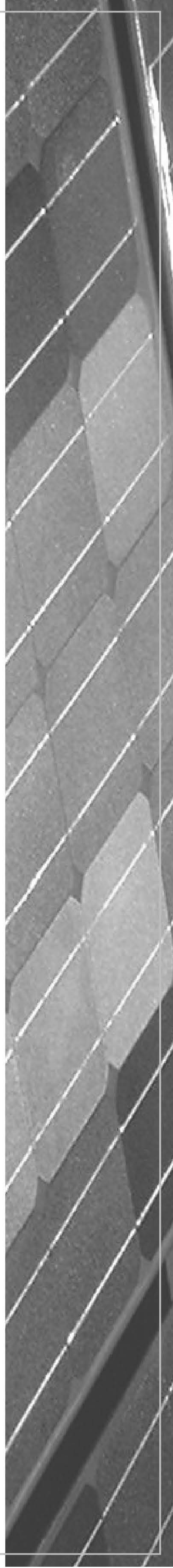
The application of PV in a wearable context began with the military but later on more fashion designers started bringing this concept to their fashion pieces.

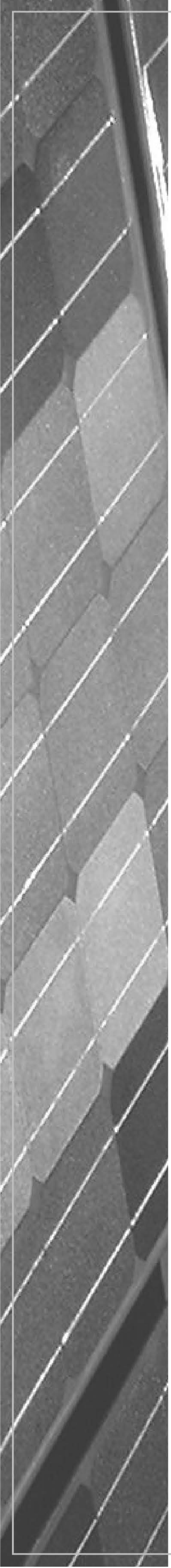
BACKGROUND

Photovoltaic Integrated Wearable Tech in Fashion

The integration of PV into fashion has a relatively short history compared to its use in the military. Fairs and exhibitions started to present design studies on solar cells integrated into clothing in 2000. In that year Hartmann presented a vision of high-tech fashion, which included the use of photovoltaic power. In 2006, Schubert and Werner proposed that the clothing-integrated photovoltaic was attractive to consumers and the fashion industry, but it was hindered or delayed by the availability and performance of solar cells (Schubert & Werner, 2006). The invention of more flexible solar panels or solar film and the development of solar fabric has meant that PV technology can be incorporated into garments with increasing ease (Emmons, 2013). This has lead to the integration of PV cells into the fashion industry began during these years. In 2008, Zegna designed the Solar JKT jacket for the Spring/Summer season. The jacket had two solar panels attached to a stand collar. The first attempt was good, but it had functional challenges. It was difficult to keep the stand collar pattern standing still when the solar panel had added weight to it, and once it fell down, the performance of the solar cell was affected. In 2009, Zegna released a new solar-powered Ecotech Jacket. This time they moved the solar panel from the collar to the sleeves. However, according to the evaluation criteria of wearability, arms have a lot of movements, causing them to be unstable for electronic components. In addition, two solar panels are not sufficient for charging phones, leading to a reconsideration of the function.

Later around 2011, designers started to use solar panels to fabricate garments. Instead of placing solar panels on the clothes, they used solar panels to build the actual clothes. An example was the solar bikini designed by Andrew Schneider. It was designed for beach-goers. The bikini consisted of conductive thread and thin film flexible solar cells. It was water-proof and users could go for a swim while wearing it. It was an interesting design approach because it eliminated traditional fabrics. However, unlike other woven fabrics normally used for making bikinis, the solar cells did not have elasticity, which could cause discomfort. Also, the electrodes were exposed which made it lack sophistication.





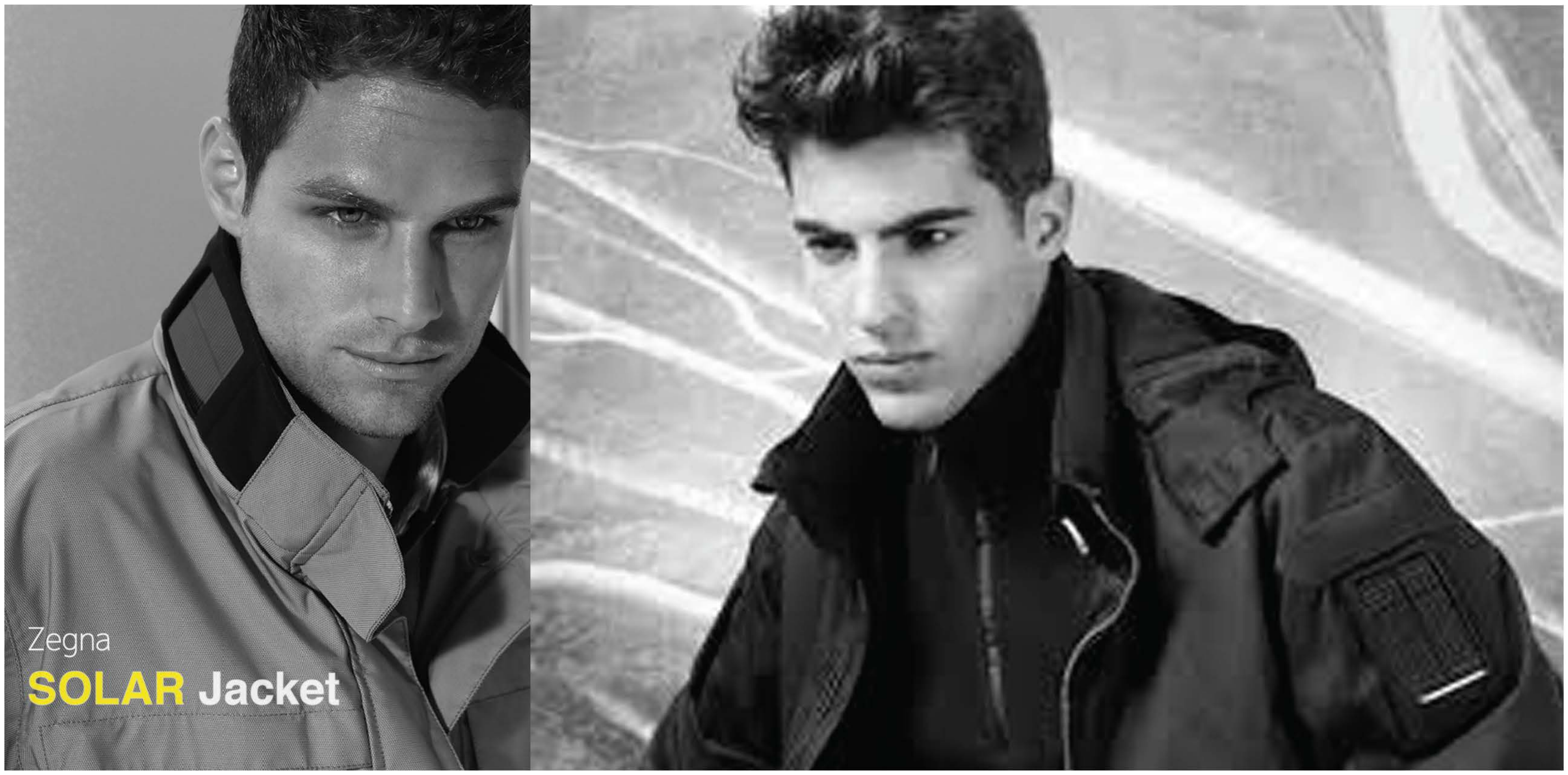


Figure 6: Solar jacket from Zegna
Retrieved from: http://www.presseagentur.com/interactivewear/detail.php?pr_id=1391&lang=en

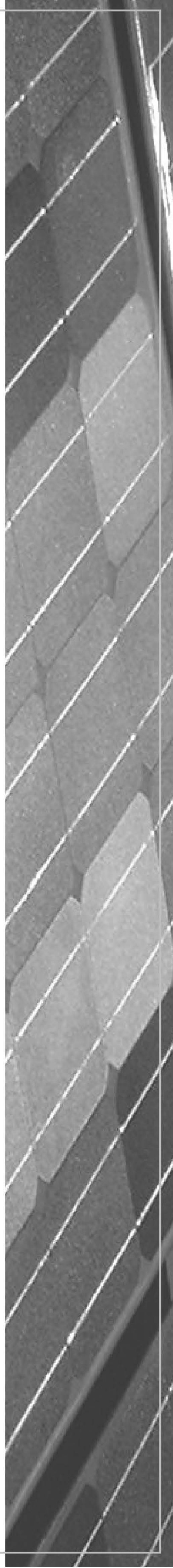
Figure 7: Solar bikini from designer Andrew Schneider
Retrieved from: http://cleantechnica.com/2011/06/29/solar-bikinis-for-iphones-ipods-etc-apparently-yes/

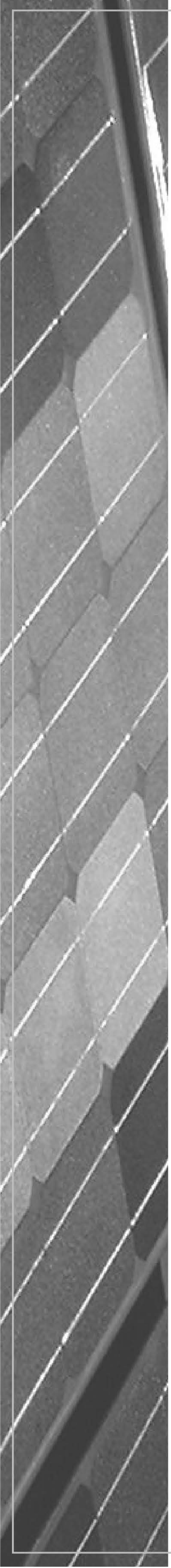
Figure 8: Pauline Van Dongen solar garment
(Left) Retrieved from: http://design-milk.com/wearable-solar-clothing-charges-smartphone/
(Right) Retrieved from: http://thecreatorsproject.vice.com/blog/charge-your-smartphone-and-look-damn-good-doing-it

A team lead by Pauline Van Dongen was working on developing wearable solar cells, aimed at integrating photovoltaic technology into comfortable and fashionable clothing (Griffiths, 2013).

These garments were noticeable and considered as the most sophisticated solar garments in wearable fashion so far, because these pieces demonstrated aesthetics. Solar panels could be hidden if they were not needed. However, they did not include the user interface to enhance the interactivity between the user and the wearable computer, such as a battery level indicator to indicate to the user how much battery power remains, or a simple LED to indicate whether the system was on or off.

Therefore, better-designed solar garments are needed. The solar garments should incorporate aesthetics, provide good wearability and include user interface.





Photovoltaic Integrated Garments Can Be Improved

Some of the existing PV garments are well designed, such as the design pieces from Pauline Van Dongen. However, they still have deficiencies that need to be improved. There are three major problems with PV garments that need to be addressed and resolved.

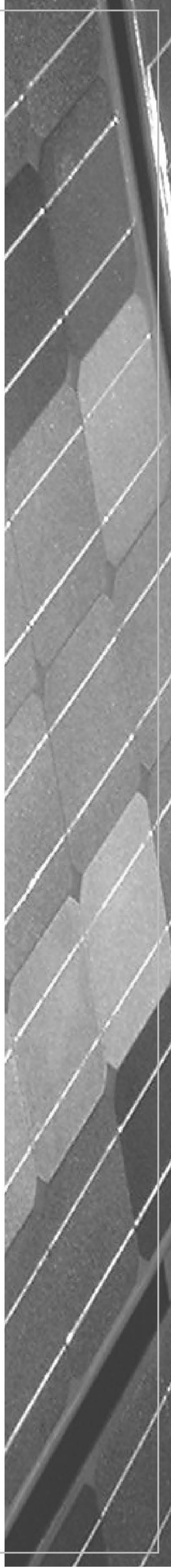
First, the existing PV garments have imperfections in either their functional or aesthetic aspect. A PV garment is an extension of the body, so it should be designed in a way that could combine function and aesthetics. Many body extending clothing items serve as an extra pair of hands (Watkin, 1984). The garment should be able to maximize solar efficiency and provide a good wearing experience while at the same time demonstrating aesthetics. These can be achieved through restructuring the garments. A good structure of a PV garment should contain the flat surface for placing solar cells, and make them face upwards towards sunlight, so as to ensure efficiency. A good shape of garment will provide good interactivity between body and clothes, so as to provide good wearability. A good structure of the garment will meet aesthetic requirements. Deconstructivism in fashion has stressed the structure of the garment. I use it as the design approach to combining function and aesthetics of the PV garment.

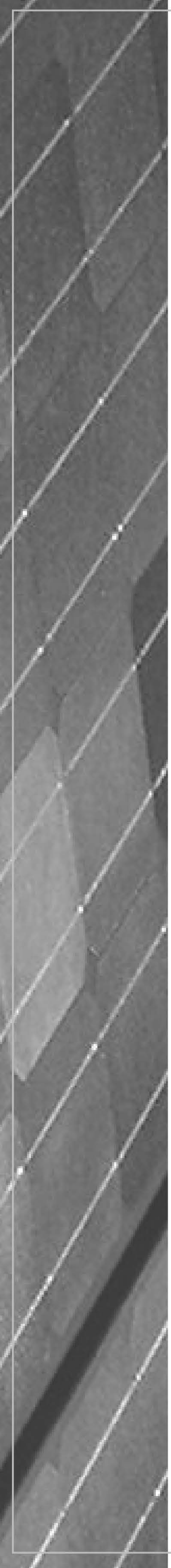
Second, when designing a PV garment as a computer embedded wearable project, the interaction between the computer and the user should be stressed. Fashion designers always focus on how humans interact with clothes, but neglect the importance of the interaction with computing devices. User interface is the only access for users to understand and manage the PV system. It should be well designed. At least, the system should notify users of its status, such as using LED to indicate the battery level or a vibration motor that vibrates when the system starts.

BACKGROUND

Last, there is no PV garment that has been adapted by the mass market, which means PV garments are not accessible to the general public. This is because of the lack of sophistication of the design of PV garments and their low social acceptance. People need to promote the use of photovoltaic technology in clothing to gain social awareness. As Susan M. Watkin purposed, the need for fashion in our lives is an equally strong concern for the function of the garment (Watkin, 1984). I believe aesthetics are one of the essential criteria in the success of a design. Haute Couture fashion garments mean garments with high quality and taste. By taking the high end of fashion as a starting point, it will make it easier for the public to accept this new form of clothing.

Consequently, the PV garment I am creating is a high fashion PV garment with user interface, and uses deconstruction fashion as the design approach to combining function and aesthetics.

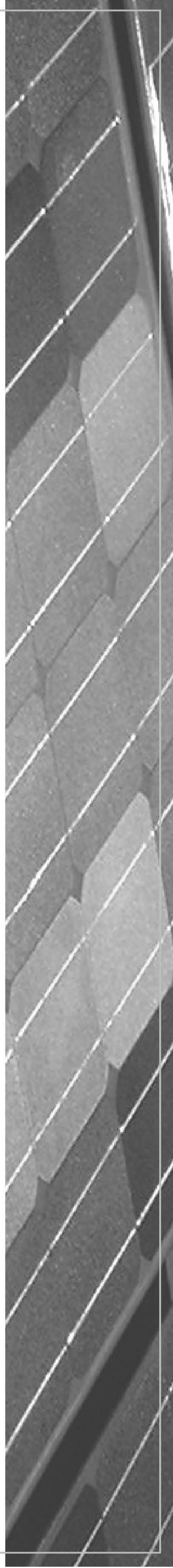


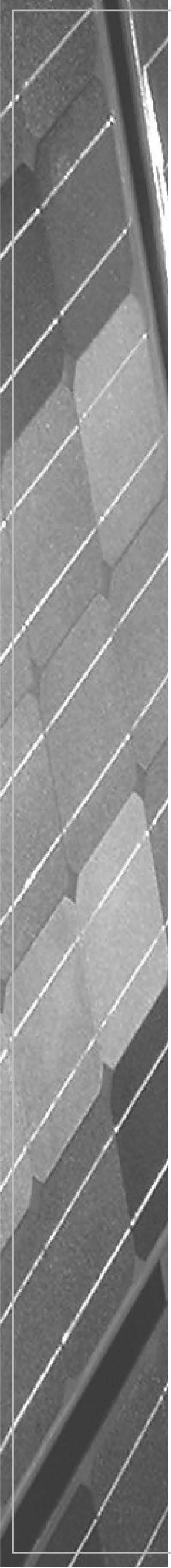


DECONSTRUCTIVISM

The Notion of Deconstructivism

Deconstructivism is skeptical about what it perceives as the universal foundations of modern culture (Fuchs & Ward, 1994). In the 1980s, the term "deconstruction" started to be used by architecture, literature, cinema and fashion. It describes the designs that chopped up, layered, and fragmented forms imbued with ambiguous futuristic indications. Deconstruction was considered an activity rather than a methodology, analysis or critique. In literature, deconstruction was used as an attempt to force a multi-connected concept into a simply connected one without stepping outside the familiar dimension (Tenebris, 2007). In Jacques Derrida's opinion (as the father of deconstruction), deconstruction as an activity that tries to fix the essence (Tiesti) of things has long permeated Western metaphysics. It is a rethinking process of a series of opposing terms, such as subject-object, nature-culture, presence-absence, inside-outside, which are all elements of a conceptual metaphysical hierarchy. As Heidegger explains, 'It is a peculiar disinterring and bringing to light the un-thought and un-said in a way that recalls an authentic experience of what is "originary".' The deconstruction outlined by Derrida ultimately converges, fused by the same intention of mining the petrified layers of metaphysics that have for centuries dominated philosophy. The practice of deconstruction is unending. It is an open and complex way of proceeding (Loscialpo, 2010).





Deconstruction in Fashion

In the early 1980s, a new generation of independently thinking fashion designers appeared. From Japanese designers Rei Kawakubo, Yohji Yamamoto and Issey Miyake then later in the decade the European designers Belgian Martin Margiela, Ann Demeulemeester and Dries Van Noten pioneered a fashion revolution and made the notion of deconstruction a fashion scenario (Flavia, 2010). These designers made fascinating mechanisms that haunt fashion through disinterring the mechanics of the dress structure (Brampton, 1983).

A 'deconstruction' of style in fashion refers to a breaking down of elements, traditions and ideas. The work clearly indicated that the Western concept of structured and tailored garments, which emphasized the sexual nature of dress, was being questioned. Yamamoto and Kawakubo's 1981 joint collection showed that the impact of the Japanese deconstructivist designers was profound: ...their size appeared voluminous, as if the space between the external garment and the body had been exaggerated, emphasized by layering and wrapping (Bonnie, 2011). They placed greater emphasis on the sculptural interrogation of form, the nature and tactility of fabric and the interactive space between the body and the fabric. They defied convention as they defied the shape of the human body (Bonnie, 2011).

DECONSTRUCTIVISM

Retrieved from:

WRAPPING:
http://jonathansimcosky.com/category/uncategorized/

SCULPTURE
http://shows.vogue.com.cn/Comme-des-Garcons/2014-ss-RTW/

REPEATING
http://www.pinterest.com/pin/226094843763978751/

PLEATS
http://www.pinterest.com/pin/451626668852931275/

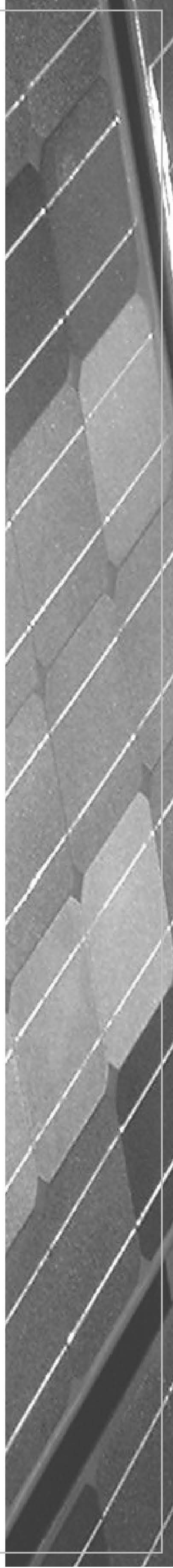
LAYERING
http://msn.lilianpacce.com.br/desfile/comme-des-garcons--outono-inverno-201314/

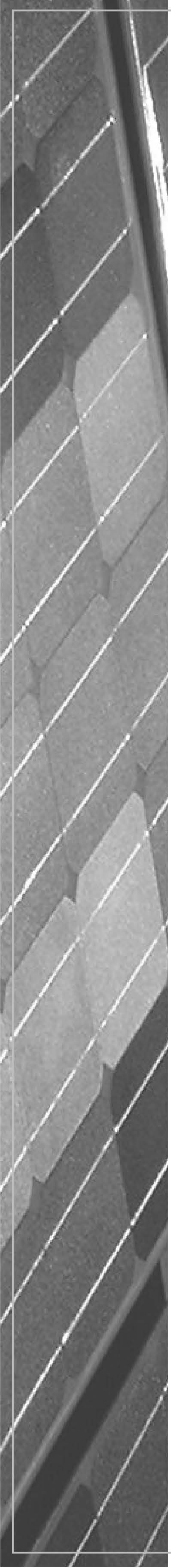
TRANSPOSING
http://midnight-charm.tumblr.com/post/32539240896/comme-des--garcons-s-s-2013

PADDING
http://monsieurzhang.blog.163.com/blog/static/1977081412012533843849/

Figure 9: The techniques of deconstruction fashion

The techniques that have been largely applied in deconstruction fashion are layering, wrapping, transposing, sculpting, padding, pleats and repeating. These techniques are found individually as well as in combination. Repetition for example is used by Niels Klavers as well as Martin Margiela in the sleeve detail. Functionality is retained but additional unites are included for aesthetic reasons and to disrupt the wearing experience. "Jackets are cut to a man's proportions. Once finished, the internal structure is removed and a second, feminine, shoulder line is added through the use of shoulder pads over with the original, man's shoulderline hangs" (MMM, 1997). Repetition is found combined with layering, padding and sculpting in the world of Viktor & Rolf. Collar and lapel details are overlaid and repeated to redefine the body. Such an approach can offer the wearer liberation and constraint. My interest is in wearability and aesthetics. In this Tomoko Nakamichi's Pattern Magic(2012) offers an approach to pattern cutting that allows me the freedom of experiments and the riqor necessary to ensure user comfort and wearability of the garment. By using these techniques, space between the body and clothing can be created. Originally, these spaces were only created for aesthetic purposes. I am bringing it into the wearable context to make use of these spaces.



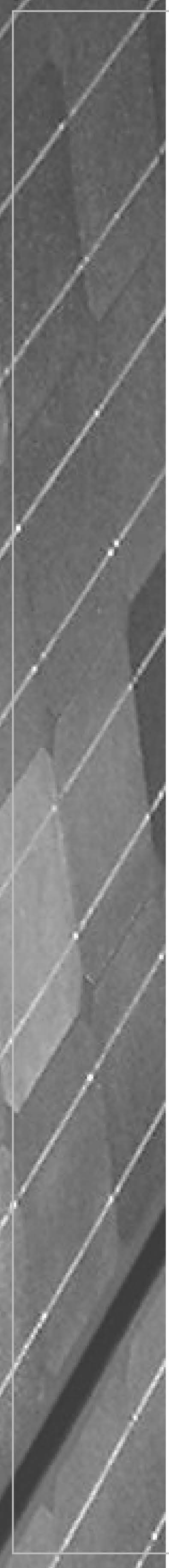


Bringing Deconstruction Fashion to the Wearable Context

A wearable computer system is always accompanied by electronic components that need to be worn by users. Instead of asking users to wear the whole system on their body, it should be designed so that such components become part of the clothing, and are hidden away. This would enhance the wearability of the garment. However, there is a barrier for hiding the wearable device in the garment's limited space. That is, regardless of the size of the wearable device, extra spaces are needed on the garment to embed it. Most of the garment does not have extra space to place the devices.

The wearability of the garment is always affected by the electronics embedded in it and the movement from the body always affects the performance of the computer. By deconstructing and reconstructing garments, designers can create extra space for embedding the wearable device. Without letting a wearable computer and body interfere with each other, deconstruction garments can create separate rooms for housing both body and computer.
In my thesis project, the PV system that needs to be embedded in the garment contains 20-30 photovoltaic cells, an energy harvesting wearable computer and LED.

In order to embed the whole PV system in garments in a way that provides good wearability and demonstrates aesthetics, I have created four pieces of deconstruction garments specifically designed for the PV system.



PROJECT

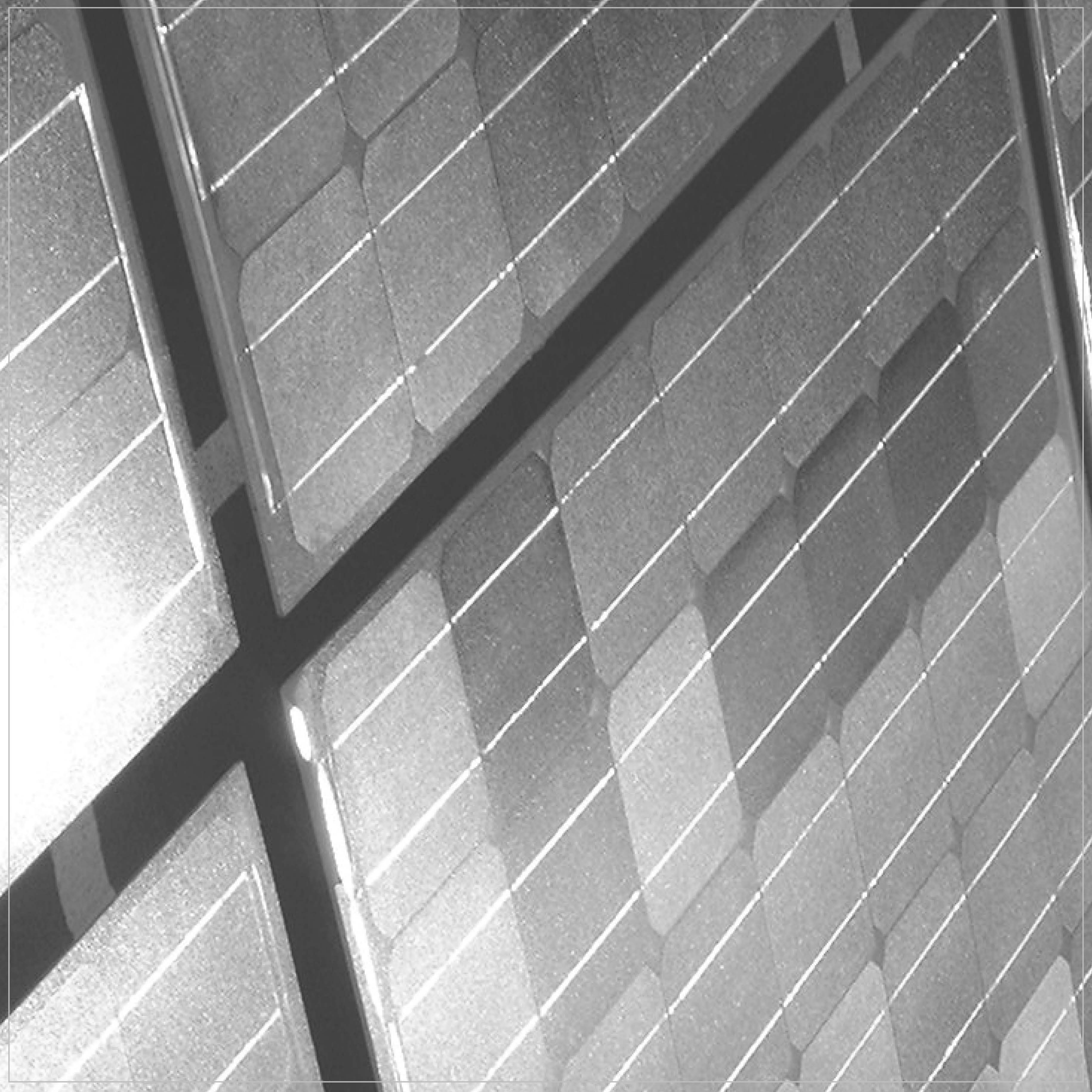
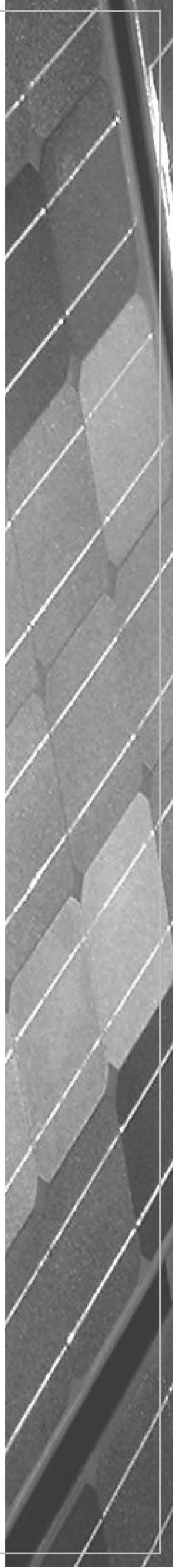
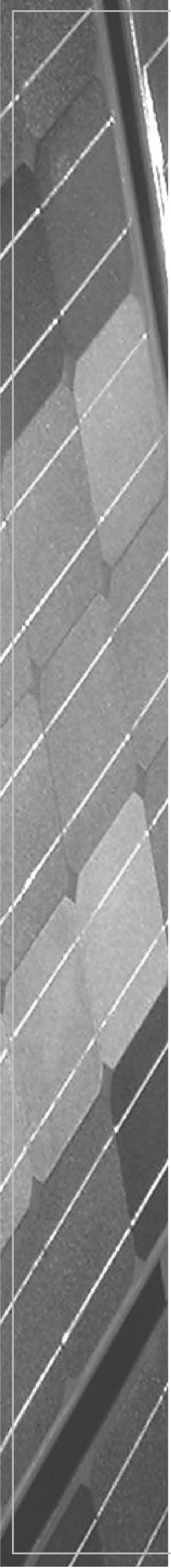


Figure 10: The deconstruction garments before the PV system was installed





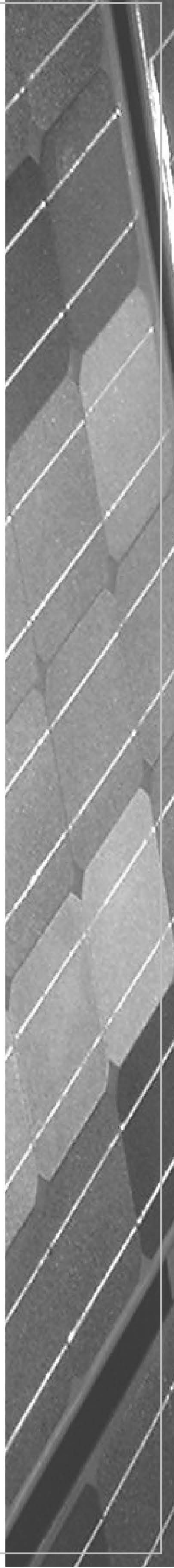
PROJECT OVERVIEW

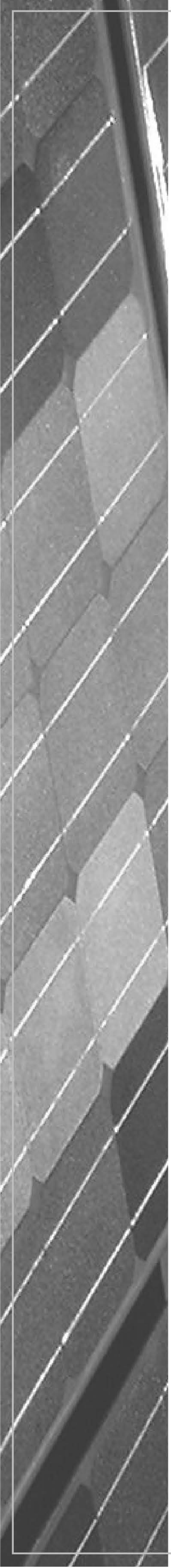
The project 'when deconstructivism meets photovoltaic in high fashion' demonstrates how photovoltaic technology can be integrated into avant-garde fashion. Stressing the intersection between wearable computing, photovoltaic technology, and deconstruction fashion, the project uses four unique deconstruction PV garments as examples for demonstrating the use of deconstructivism as the design approach for embedding a PV system in garments. The PV garments are able to optimize the PV system by providing enlarged surfaces for placing more PV cells to collect more energy. Other than that, the garments also provide good wearability. These garments were designed for the four seasons and include consideration of changes in lighting and climate. They were named in Chinese as '春(spring)、夏(summer)、秋(autumn) and 冬(winter)'. Different techniques from deconstruction fashion have been applied to these garments, such as padding, transposing, layering and repeating. In order to create an exemplar for designers, different garments emphasized deconstructing different parts. PV modules were mounted on different parts of different garments, such as back pattern (spring), waist pattern (summer), shoulder pattern (autumn) and the whole body (winter). Illumination systems on the garments were used as user interface for notifying users of the status of the PV system, and also for demonstrating aesthetics.

PROJECT DEVELOPMENT PROCESS

1. Concept
2. Function
3. Elements
4. Shape
5. Deconstruct
6. Big idea illustration
7. Material/ Experiments
8. Detailed illustration
9. PV system Layout
10. Paper pattern Making
11. Muslin pattern Making
12. Muslin pattern Alteration (iterations)
13. Paper pattern Alteration
14. Fabric cutting (iron the fabric in advance)
15. Sewing keep the stitch line slightly open for installing the wires from circuit board
16. Try on Alteration
17. Details such as zipper and buttons
18. Photovoltaic system installation (include solar cells, circuit board and 0.25 thin wires)
19. Test circuit
20. User Testing
21. Alteration

Figure 11: Photovoltaic garment making process





I developed the project through this process. A key concept is that the PV garments should be able to provide enlarged surfaces for placing more solar cells facing upwards to collect maximum solar energy. Wearability, both in terms of aesthetic design and comfort are essential factors to be taken into account.

Using a PV system to charge batteries as the core function in my project, PV technology has to be well understood. I have conducted a small experiment and tested the degrees of light on different parts of the body by using a light meter. Doing so gave me a general idea about how PV cells work, which facilitated the future development of my project.

Then I started designing the garment. In the conventional approach to fashion design, designers will generally begin by seeking inspiration to develop their concepts. They will then progress to sketch the shape of the garments. During production of the final garment when working with photovoltaic technology a key difference in the design process is consideration of the technology at the outset.

I started designing the PV garments by defining the elements -- the basic structures for holding PV cells, such as layers or ladder-shaped elements. Then I started defining the shapes of the garments while considering placement of the solar cells. This is the first step to determine the general look of the garments, just like other fashion designers.

After the elements and shape were clarified, I applied deconstruction fashion techniques to combine these elements and shapes together to create more detailed designs. The conceptual Illustrations were finished based on these designs.

PROJECT

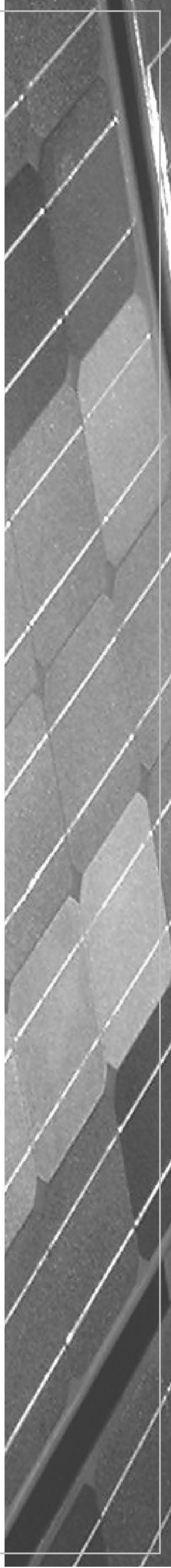
Choosing the right material is very important since some materials are not suitable for the design very well. Therefore I conducted experiments with materials before drawing the detailed illustration, to determine whether the structure could be created, or if the E-textile could replace the wires. Each of these factors could change the design of the garments.

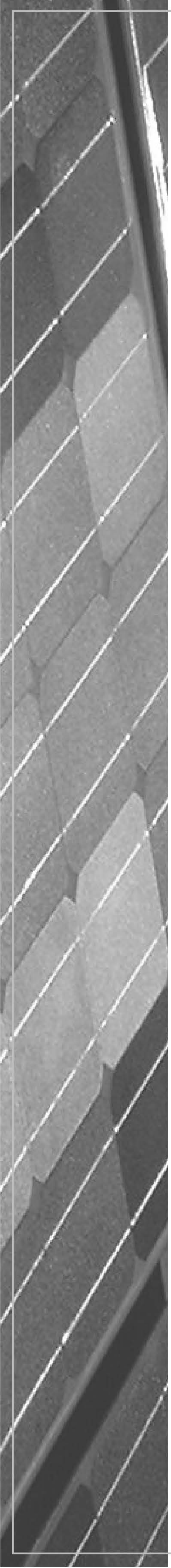
In the fashion industry, the detailed illustration is a communication tool between fashion designers and tailors. The measurement, structure and techniques will all be included in the detailed illustration. The garment can be made after all this information is provided.

The next step is to design the PV system's circuit layout on the garment, considered an essential process. If this step is not well executed, problems can ensue. Designers may have to alter the garment if the circuit cannot be fully embedded in the garment.

In order to ensure the quality of the garment, paper patterns and muslin patterns were altered in several iterations. After the garments were fully finished, the next step was to install the whole PV system into garments. This process would be easier if the circuit layout was well designed.

User testing, as a research method, was conducted after the PV systems were fully embedded in the garments. A PV system needs to be tested before users wear it. After user testing, a few alterations were made based on user feedback.



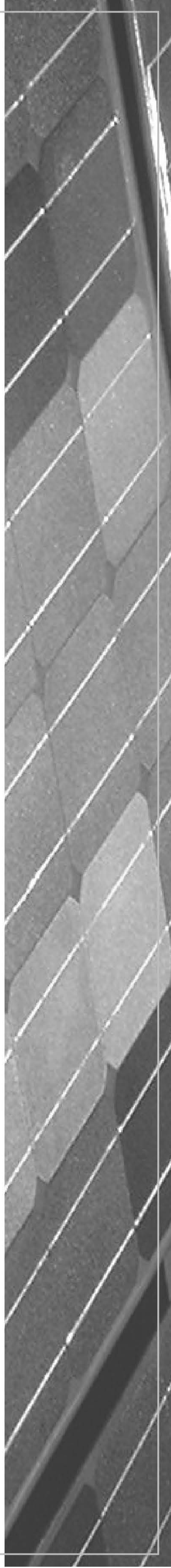


DESIGN FOR FUNCTIONALITY

Functionality: for PV System

Photovoltaic (PV) technology is a method of generating electrical power by converting solar radiation into direct current electricity (Pearce, 2013). Considering the functionality of the photovoltaic system, different environmental conditions would affect the performance of a photovoltaic module. Seasonal factors such as temperature and sunlight could affect the efficiency of solar cells.

Designing four season photovoltaic garments based on different seasonal conditions could improve the efficiency of the PV system. The first step is to understand the PV cells. The US military's project 'The Solar Soldier' focuses on how one could integrate PV technology by incorporating the Solar Soldier concept from a human interface and design perspective (Tsekleves & Paraskevopoulos, 2012). Actually, they have simulated the solar harvesting process in a 3D virtual environment. In the virtual environment, they have tested to see which part of the body can receive more sunlight. They simulated different seasons and different military scenarios. In the end, the project created a set of data for designers to reference. Inspired by this project, I conducted this experiment and tested out the degrees of light on different parts of the body by using a light meter (e.g. back of the neck, back, shoulder, waist and hip). It was done during a sunny day in four different sessions on October 26th, 2013. The spreadsheet includes all the data that I collected during the experiment.



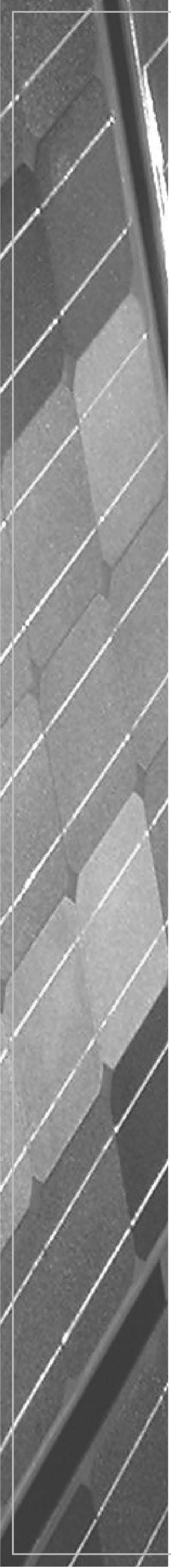
Research Method: Experimenting as Research - Degrees of Light on the Body

	Outside of the room – natural light Unit: foot-candle			
	8-10	11-13	14-16	17-19
Back neck	80-100	180-220	90-110	27-32
Back	80-90	200-240	100-120	27-30
Shoulder	180-240	300-310	120-130	30-35
Waist	150-180	240-280	110-120	30-32
Hip	80-100	240-250	90-120	15-25

	Inside of the room – natural light Unit: foot-candle			
Back neck	5-10	40-45	10	5-8
Back	5-10	40-45	10	5-11
Shoulder	20-40	60-65	20	10-10
Waist	20-30	70-80	35	6-8
Hip	15-20	50-55	15	4-7

Figure 12: Experiment for testing the efficiency of photovoltaic on different parts of the body

As the results of my experiment show, the shoulders always receive more sunlight than other parts of the body. The waist is the second best area for receiving sunlight. Also, the angle of the light meter is very important. It received more sunlight when it faced upward. In fact, how much solar energy we get depends heavily on the angles of the solar cell. Due to the Earth's orbit around the sun and its own rotation around its tilted axis, the amount of solar energy received on the surface of the Earth is a direct effect of the sun angle(Usoskin, 2009). The trajectory of the sun appears to be semicircular. Therefore, positioning solar panels horizontally could reduce the length of time of the panels would stay under the shading or shadow. It is important and optimal to position the solar panels horizontally as the panels can receive the most sunlight of the day than placing them with other angles. That's why shoulder can receive more sunlight than other parts of the body. Therefore, the space or surface of created garments has to be able to hold solar cells that face upwards towards the sunshine to make them more productive. I developed four different elements as solutions for creating the enlarged flat surfaces on the garment.



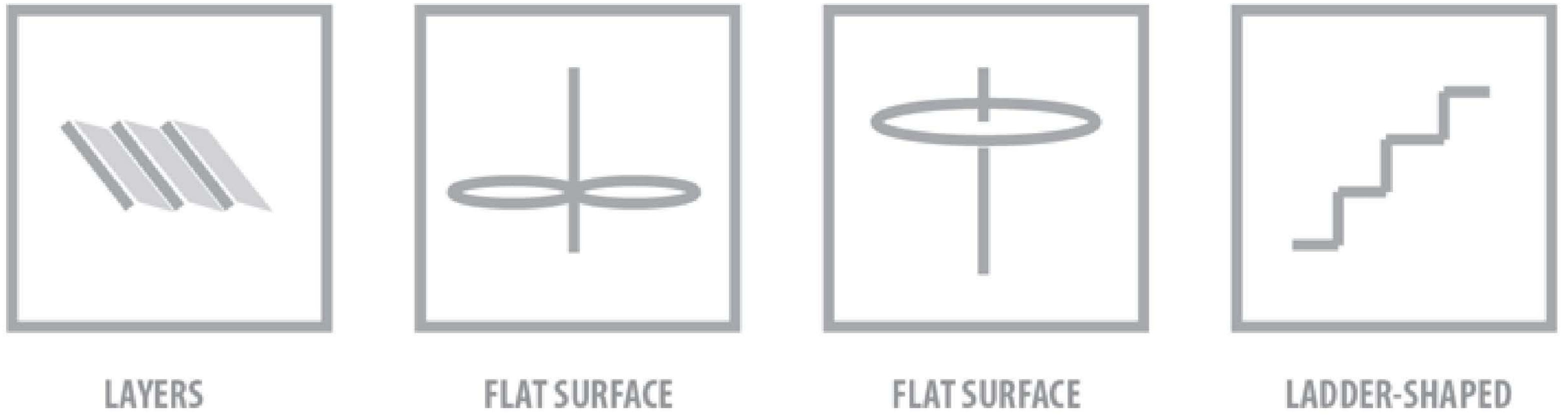


Figure 13: Elements for creating the enlarged flat surfaces on the garment

In the first design, I have used a layering technique so that an enlarged surface can be created. This allows the photovoltaic cells to be placed on different layers without interfering with their individual performance. In my second design, I have used two elements that are flat surfaces. As the diagram shows above, the second one has two flat surfaces, each of which has its own axis. Instead, the surface shown in the third one uses the human body as the axis. The last one is a ladder-shaped structure which was inspired by bench terrace. I took inspiration from farmers in my native China who use a ladder-shaped farmland along the mountain, which allows those crops to grow on a horizontal surface. I decided to create such a shape on the garment and place photovoltaic cells on those ladders to make the cells face upward.

Defining shape is the starting point of fashion garment design. The basic shape of the garment will determine the future look of it. In this step, I integrated those elements into the garments.

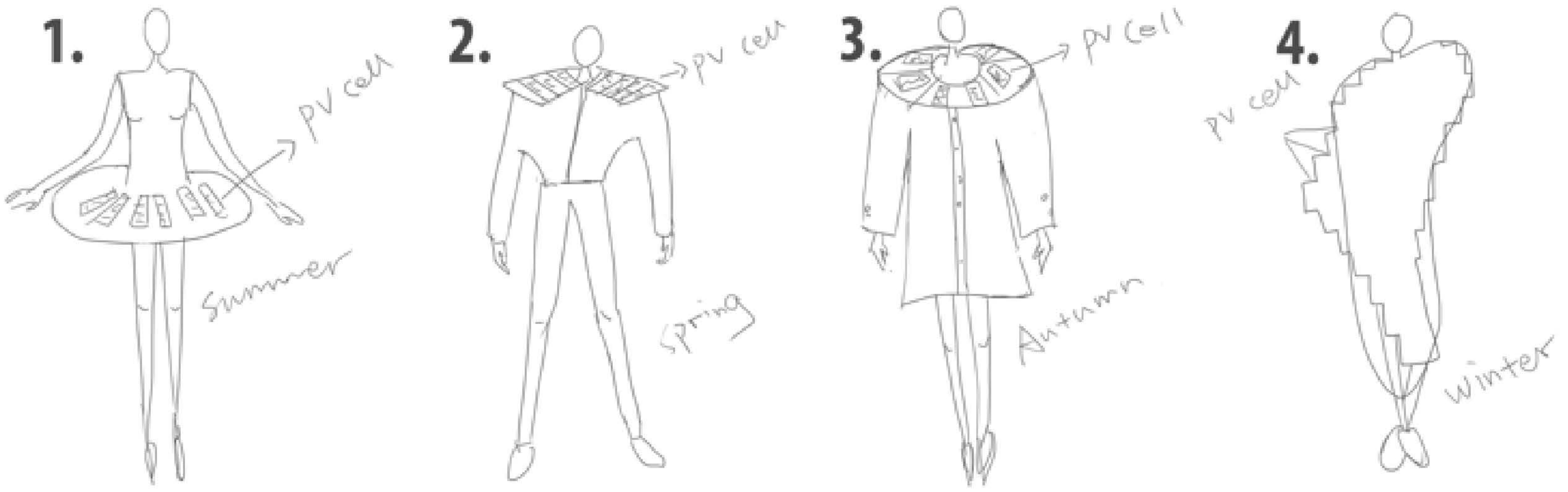
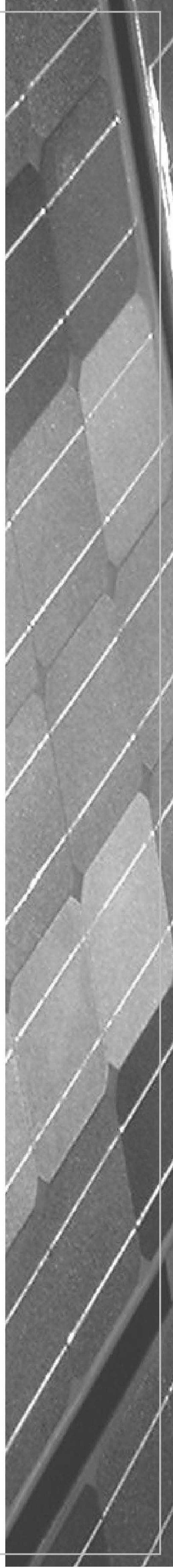
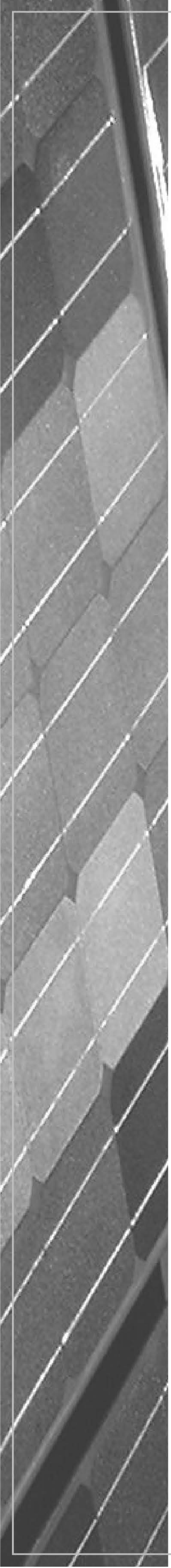


Figure 14 : Defining the shapes of four garments

For the summer season, I chose to create a surface surrounding the waist and make a skirt-like dress and placed the photovoltaic cell on the 'skirt'. For the spring season, the enlarged surface made by layering was placed on the front chest for placing photovoltaic cells. The autumn season garment design focuses on deconstructing the shoulder pattern. The enlarged flat surface surrounding the neck was created by multiple shoulders. For the winter season garment, I used the ladder-shaped element all over the body to create a ladder-shaped garment and placed solar cells on each step of the ladders. These shapes gave me a general idea of the future look of the garments. However, to turn them into real clothes, the techniques of deconstruction fashion were incorporated here to conduct further design. The wearability of the clothes was also considered at this stage.





DESIGN FOR FUNCTIONALITY

Functionality: For Wearability

The wearability in high fashion is less important than aesthetics in some contexts. However, a good design of a high fashion garment should not cause much trouble when worn by the users, such as when they are walking or sitting. In addition, the way users put on the garments should be designed as simple as possible.

The criteria for evaluating wearability includes physiological considerations, thermal comfort, mobility and textile. For the physiological consideration, the demands of the body should be considered so that users are more comfortable when there is a certain space between the body and clothes (Bryson, 2007). For thermal comfort, because the body constantly generates and loses heat at the same time, a balance must be maintained between the rates of heat production and heat loss (Ariyatum, 2013). In other words, the clothes have to be breathable. For mobility, the wearer should not be limited in comfort, and technological devices must not be damaged or lose the efficiency by any external interruption (Bryson, 2007; Dunne et al., 2005; McCann et al., 2005; Koscheyev, 2000).

Based on these criteria, I have incorporated the techniques from deconstruction fashion and developed further design.

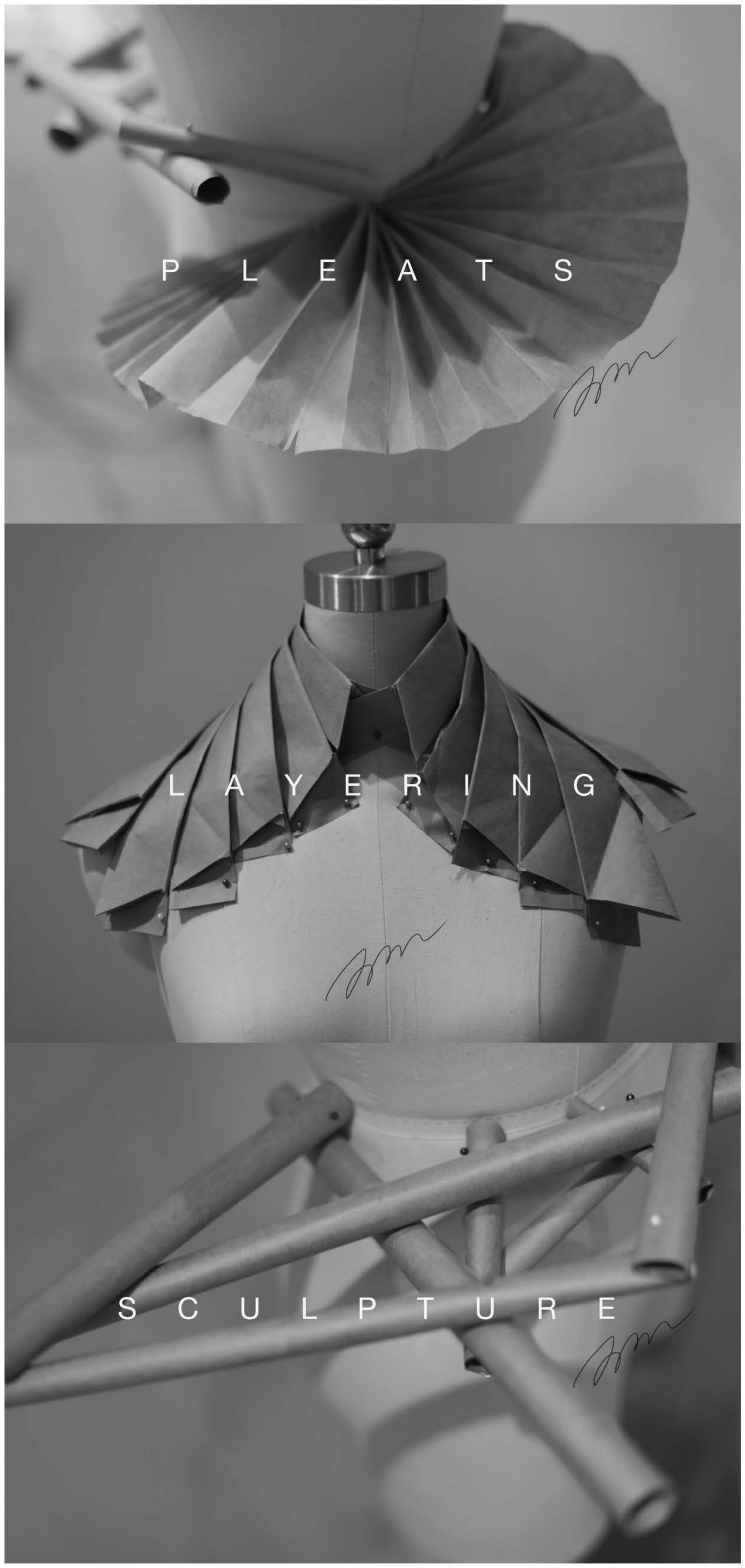


Figure 15 : Paper prototype as experiments

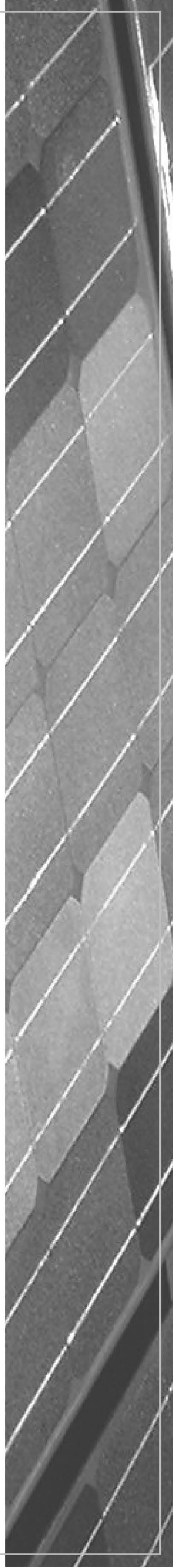
Research Method:

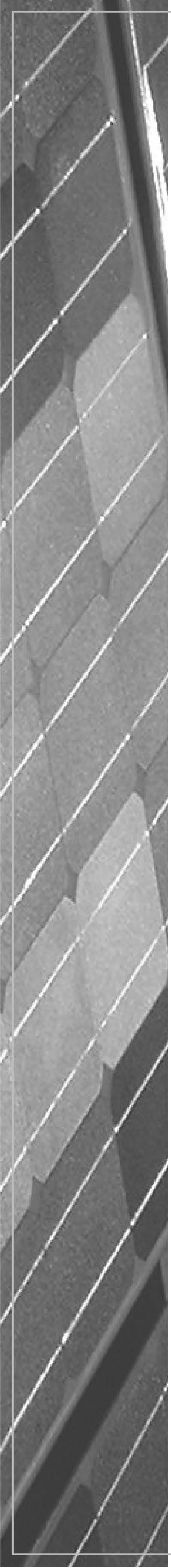
Experimenting as Research-Paper Prototypes

In order to further develop the design, the techniques of deconstruction fashion were implemented at this stage. Before I drew out the design illustration, I made a few paper prototypes to test out which techniques of deconstruction fashion are suitable for each shape.

The techniques that have been largely applied in deconstruction fashion are layering, wrapping, transposing, sculptural, padding, pleats and repeating. I first experimented with pleats. However, although it works well on paper, it is really hard to maintain the shape when applying it to fabrics. It is therefore not applicable to my project. The second prototype is layering. I have used this concept in the spring garment and I have used layering to create a surface on one side of the shoulder. The last prototype used sculpting as the technique, using tubes to build a structure. However the real plastic tubes are too heavy for garments. It is hard to connect those tubes with the clothes. I modified this idea and applied it in the summer garment and used polymer boning to build structure.

Based on experiments and deep consideration, I chose four techniques for these four garments, which are layering, transposing, repeating and padding.





Combining Function And Aesthetics Through Using Deconstruction

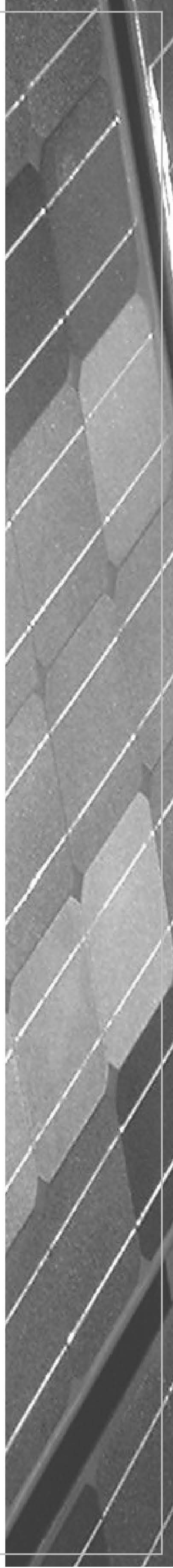
For the spring season, the enlarged front chest surface is created through 'layering'. Inspired by a traditional Chinese fan, the larger surface can be created when unfolding the fan. Seven layers of front plackets were designed for enlarging the surface on the front chest for placing the PV cells. On the back of the garment, different lengths of collars have also created layers to correspond to the front layers. The complicated structure made the upper body relatively heavy, so I designed it into a jumpsuit. The pants are connected to the upper body for sharing the weight, so as to improve wearability.

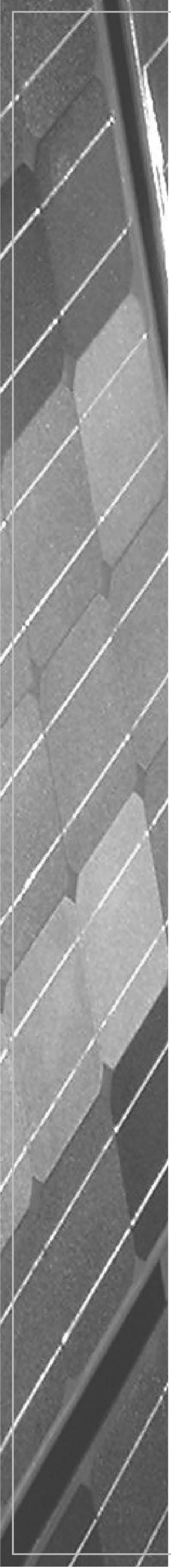
In the summer season garment, I chose to use the technique of 'transposing'. I placed two incomplete hats on the waist and used the wide brim of the hats as the surface for placing PV cells. PV cells were not placed on the body so as to not interfere with the wearability of the garments. The system was embedded in the space around the body, so the user's movement will not interfere with the performance of the PV system. The two hats created the skirt-like shape for aesthetic purposes, but also for covering up the hip area in order to provide a secure feeling for users.

For the autumn season garment, a surface area needed to be created surrounding the neck. I chose again to use the technique of 'repeating'. The surface was divided into seven sections which formed repeated sleeves surrounding the body. Seven shoulders formed an enlarged surface surrounding the neck. PV cells were mounted on these shoulders. The shoulder pattern was enlarged for placing more PV cells. In order to improve the wearability of the garment, those fake sleeves were fixed onto the garment, so it would not interfere with the mobility of users.

For the winter garment, the 'ladder-shape' structure was created by the deconstruction technique 'padding'. In terms of wearability, I gave it a round shape. Eleven round padded circles in different sizes stacked together and offset one another to create the ladder shape. The big zipper was installed on the back of the garment, making it easier for users to put on the garment. I kept a certain space between those padded circles, so it would not affect the thermal comfort of the garment.

Figure 16 : Concept illustrations for four garments





Material

Photovoltaic Cells

Suitable photovoltaic cells were essential for the project. Since this would be a wearable project, I considered the flexibility of the PV cell as the most important prerequisite. The cells in the photo below were the currently available ones. They had different shapes, sizes and voltage outputs. Some of them have 12 V power outputs, which are too high for a wearable project (the safe voltage level for the human body is 12V). For the first prototype, I chose the flexible photovoltaic (second left), but its size proved too big for a wearable project and it was not flexible enough. After further research, I found the thin film flexible photovoltaic cell (second right), which is smaller in size, thinner and has better flexibility, and is available in different shapes.

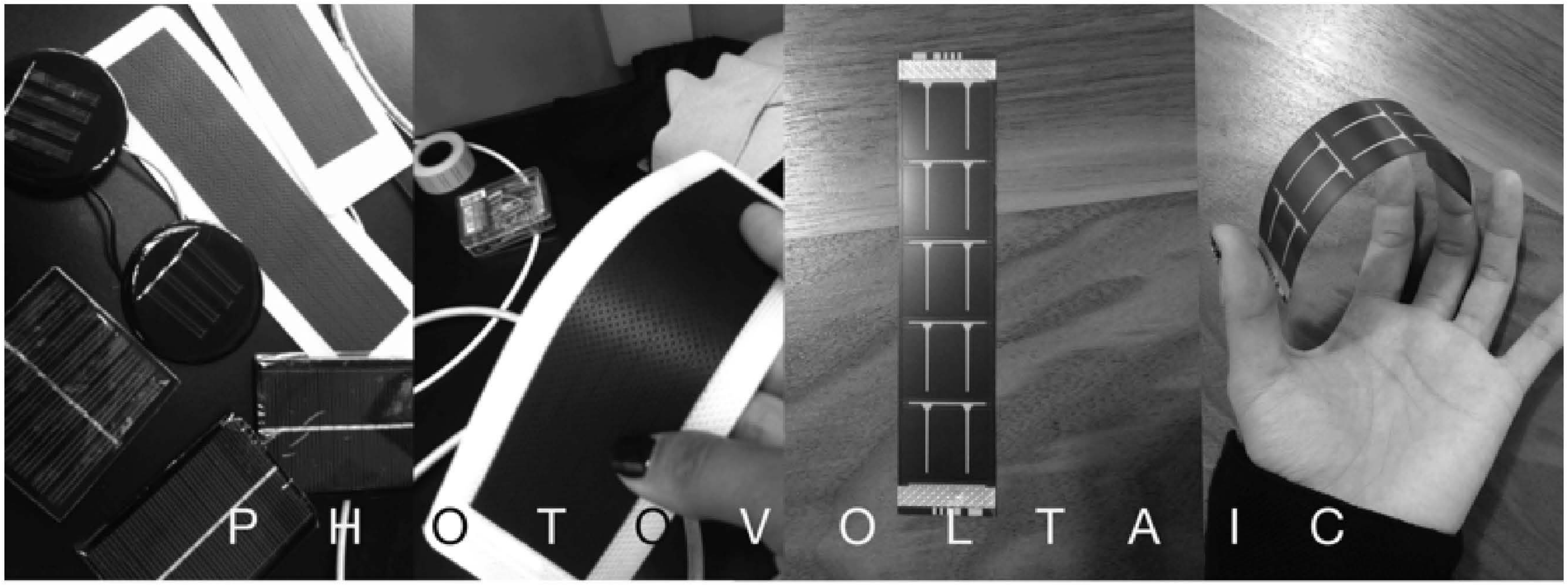


Figure 17: Selection of photovoltaic cells

The voltage it generates is 3V, and the current is different for different shapes, which are 25mA, 30mA, and 50mA. After testing the quality of this PV cell, I decided to use that in my project.

Material

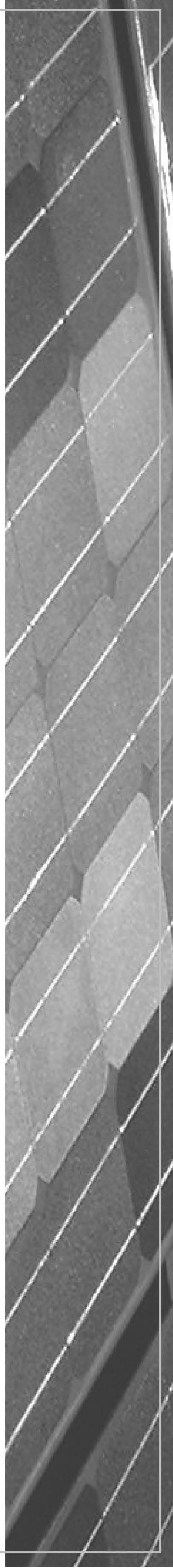
Fabrics& Accessories

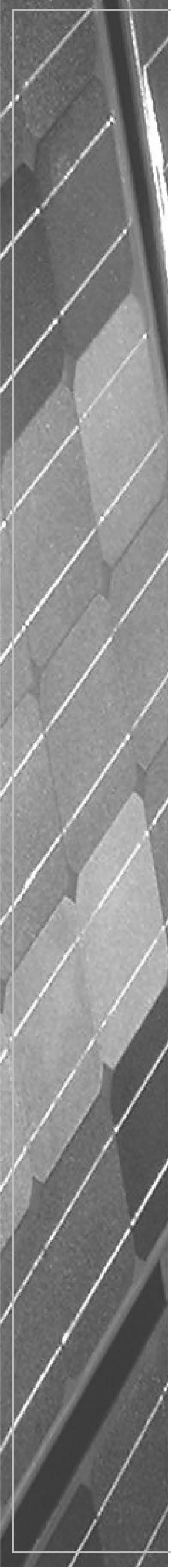
The interaction between fabric and human skin will stimulate various sensory receptors on the skin and may cause uncomfortable feelings such as tickling, itching, prickling, and abrasion of the skin (Textile Institute, 2006a)

Choosing appropriate fabrics is essential for creating good wearability of a garment. The cotton mixed poly pique has elastic and can be stretched out to 10-20% more in length. It provides flexibility, which is suitable for garments for different seasons, from stretchable summer dresses to loose winter jackets. The tactile nature of the fabric could provide comfortable feelings for users. It has a texture as smooth as skin, and it can also be used as material for digital printing. I used digital printed fabric in autumn season garment. The dark blue grid pattern were designed based on the appearance of the solar cells.

In order to keep the four garments holistic, I used the same fabric for each of them, but in different thicknesses, 285g and 315g. I chose to use a creamy-white fabric because white could highlight the futuristic nature of the design. Also, white is an easier background on which to do printing.

After I chose the main material for the garments, I conducted two small experiments for choosing other materials. In the first experiment I tested smart-textiles. Smart-textiles are fabrics that enable digital components to be embedded in them (Harris, 1993), such as conductive thread or conductive fabric that can deliver electricity. I conducted the experiment to see if I could incorporate these fabrics into my project. The second experiment was conducted for the purpose of choosing material for parallel connecting solar cells. My third experiment was aimed at testing which linings were able to create the structure that I designed for my garments.





Material

Research Method: Experimenting as Research-Experiments with Material

1. Experiment with Conductive Textiles

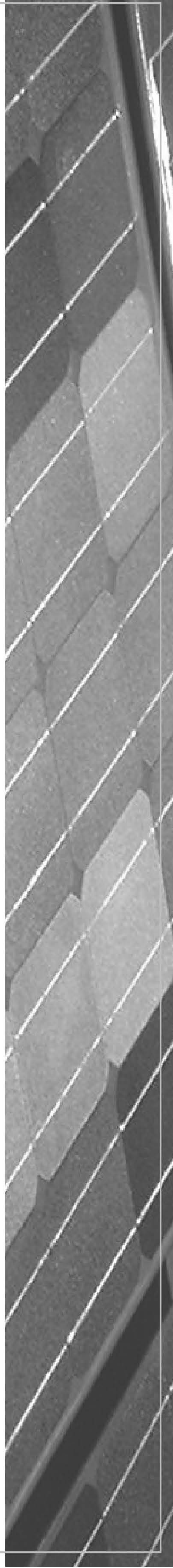
Conductive textile is the basic material for e-textiles, which includes conductive thread and conductive fabrics. My goal was to use them to deliver electricity to the system. Two different types of conductive thread and two types of conductive fabrics were used. However, all of these conductive textiles have a high level of resistance, which would largely reduce the efficiency of the PV system. Also, the connection between a soft circuit and hard circuit will affect the reliability of the PV system. Therefore, I experimented with 0.35mm thin copper wire, which is not textile. It turned out that the flexibility, conductivity and reliability of the copper wire were all suitable for my project. So I decided to use copper wire instead of smart textiles.

2. Choosing Material for Connecting Solar Cells

In my design, I needed to parallel connect several solar panels together to form one solar module. I experimented with copper tape. I connected solar panels together by placing short wires underneath the copper tape. However, the copper tape is too thick to be flexible and it is not very adhesive. It loosens up easily, which causes weak connections between solar cells. After testing different materials, I chose to use aluminum foil tape. This kind of tape has more stickiness and is thinner, allowing very good connections between panels.

3. Experiment with Linings

These garments have to be structured. However the fabric I chose cannot deliver such characteristics. An additional layer on the fabric was needed. I purchased two different linings in different thicknesses and stiffness. The non-woven lining felt like paper and was strong enough to build the structure but it was easy to distort, wrinkle or tear. The woven lining is thinner, but it is not strong enough to hold the structure. After repeated experiments, I decided to use these two linings together. I placed the woven lining on the top of the non-woven lining to increase the durability and the level of hardness.



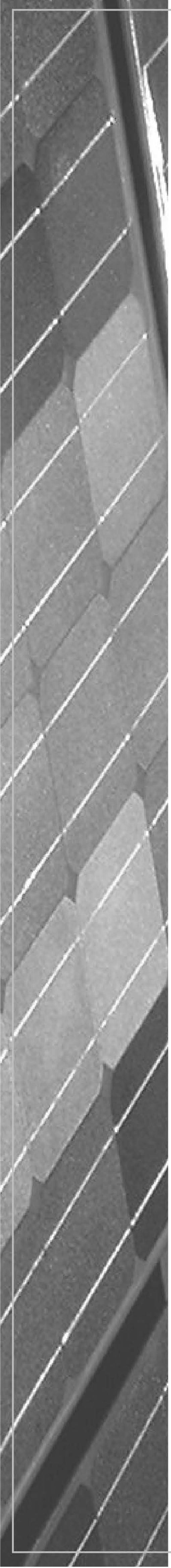
Material

Research Method: Experimenting as Research-Material Experiments

After I conducted three experiments, I determined the materials that would be used in my project and here I have provided a spreadsheet for all the materials that I ultimately used.

	Fabric	Accessories	PV system
Spring Garment	285g cotton mixed poly pique (3.5-4 meters)	Shoulder pad, concealed zipper, small hooks, lining	18 PV cells 4 LEDs Aluminum 0.35mm wires foil tape
Summer Garment	315g cotton mixed poly pique (1.5 meters)	Concealed zipper, shoulder pad, non-woven lining, polyester boning	16 PV cells 8 LEDs 0.35mm wires
Autumn Garment	315g cotton mixed poly pique (3 meters) and Digital printed 315g cotton mixed poly pique (3 meters)	Fabric wrapped buttons, non-woven lining	21 PV cells 7 led tubes 14 LED Aluminum foil tape 0.35mm wires
Winter Garment	285g cotton mixed poly pique (11 meters)	1 meter zipper, EPE cotton, fluffy cotton	34 PV cells 10 LEDs Aluminum foil tape 0.35mm wires

Figure 18: Materials that I used for the project



PV SYSTEM DESIGN

Research Method: Expert's Interview – Electronics Expert from China (See Appendix for telephone script.)

An expert's interview was conducted before I designed the photovoltaic system. Due to the limitation of my technical experience, the expert's interview was intended to provide me with a greater theoretical background for designing a photovoltaic system, and to gain a solid understanding of how the system works. Electronics expert Zhen Fang is a professor from the Institute of Electronics, Chinese Academy of Sciences. He has focused on wearable and wireless projects for the previous 2 years, and the PV system was involved in one of his previous projects. I felt that these qualifications made him suitable as my choice of expert.

He generally stressed the difficulties of creating a wearable project. Specifically, it is hard to install the circuit board onto the garment. First, the dynamic structure of the human body needs to be considered. The movements of the human body sometimes send signal noises to the circuit board. However, his opinion was that the exemplar I created should solve these difficulties. Second, the material chosen for a wearable project is important since wrong materials may affect the wearability and reliability of the system.

Since the major component in my project is the integration of solar cells into clothing, he gave me a general suggestion on how to accomplish that. The first step is to build the integrated-circuit board. He stressed that the board should be as small as possible. Also, he suggested not using a flexible circuit board because it is not stable or reliable. That would render the thesis project quite risky. The second step would be to consider the material of the garment and the circuit layout on the garment. He continued by advising me not to rush when making the garment, but instead to start it after creating a very sophisticated design. The final phase is to embed the system into the garment.

In the end of the interview, he gave me a working process for designing the PV system (shown below), and offered his help for building up the PV system. As I worked in his institution during a summer term and I developed a good relationship with the people there, they agreed to become my thesis industry partner.

The PV system design was a collaboration work with my industry partner, the 'Institute of Electronics, Chinese Academy of Sciences'. We developed two prototypes. The working process is shown above. We built our first prototype based on the simple concept of 'creating a circuit board that could collect energy and convert energy'. More functions were added to the second prototype, such as 3.7V and 5V output pin for charging batteries or other devices.

Before we started designing the circuit board, we conducted research for parts selection. Two core electronic parts were selected: the micro controller C8051F99x-C8051F98x from Silicon Labs, and the constant voltage boost converter bq25504 from Texas Instruments. After we obtained these two parts, we conducted testing to determine if they worked well together. (See photo below.)

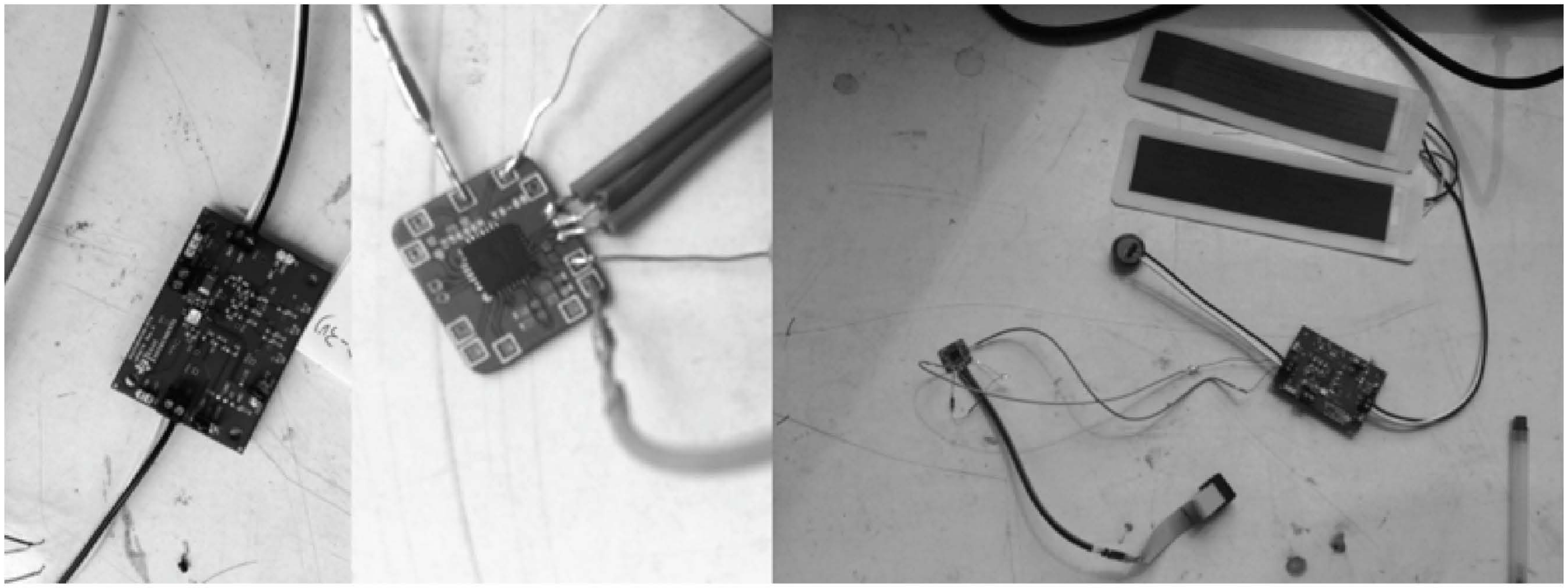
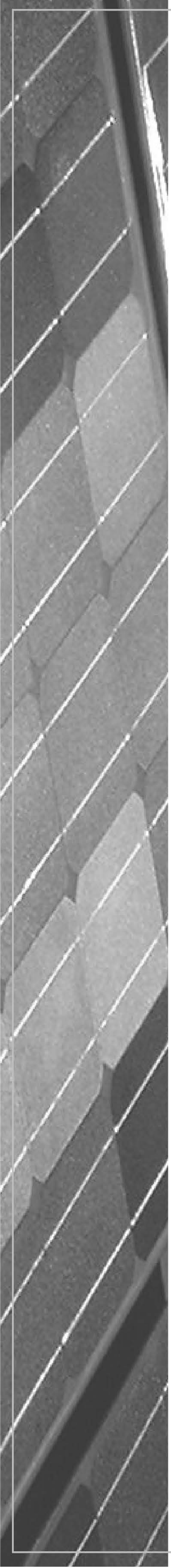


Figure 19: Constant voltage boost converter bq25504 (Texas Instruments), micro controller C8051F99x-C8051F98x (Silicon Labs) and the circuit



Then we started designing the printed circuit board. The first step was to define the working flow of the system.

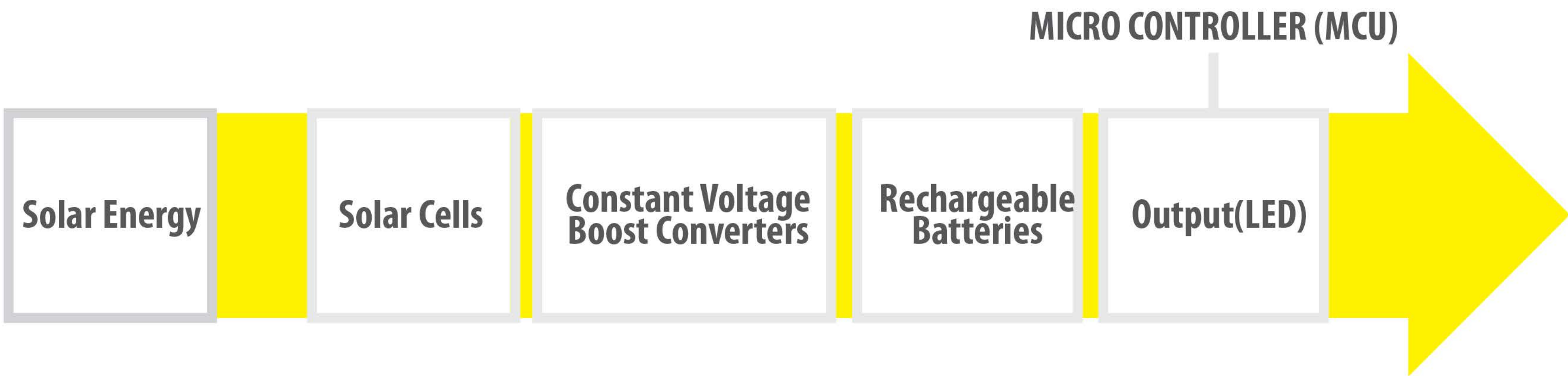


Figure 21: The working flow of the PV system

The energy harvesting or conversion modules refer to PV cells that convert solar energy into electricity. The thin film flexible PV cell I chose could provide 3V voltage, so the whole system would have 3V voltage input. This input voltage from solar cells is erratic and the current input is not large enough for running the system. A voltage boost converter is needed for creating constant voltage and also increases the current output. The constant voltage boost converter (bq25504 from Texas Instruments) that we are using generates 3V of constant electricity. This module has a "Maximum Power Point Tracking (MPPT)" function. MPPT is a technique used for maximizing the power output (Power=Voltage*Current). Since the power from a PV cell can be affected by the conditions of the environment, MPPT can monitor the changing power in real-time. The higher the power point is, the more power the system can convert. Therefore, tracking the highest power point and using it can improve the efficiency of the whole system. Theoretically, the MPPT controller could provide 50% higher efficiency than the traditional method. The conversion efficiency for the whole system is around 90%. However, since changing factors of the environment can cause energy loss, the efficiency of the system could possibly decrease by 20% to 30%.

For electrical storage, the most direct solution is to charge capacitors that can be drained for power during periods of no power generation, so simply charging the capacitor results in the loss of half of its available power. Rechargeable batteries may be employed (Starner, 1996). Most of the rechargeable lithium batteries require at least 3.7V power input. Therefore, in the second prototype, I have added a Li-ion charge Management IC to regulate the voltage and provide 3.7V constant voltage for charging batteries.

In addition, the converter's quiescent current IQ is 330 nA, which means the system should have at least 330nA of electricity flowing through it to keep it working properly. Also, input voltage must be larger than 330 mV in order to start the system, and it needs to stay larger than 80mV after the system starts. The micro controller (MCU) we chose to use is C8051F99x-C8051F98x from Silicon Labs, which can be programmed. It was used for managing the output device, such as LED. The programing language of this MCU is C, and the working environment is Keil C.

Based on the working flow, the circuit board design was created and made.

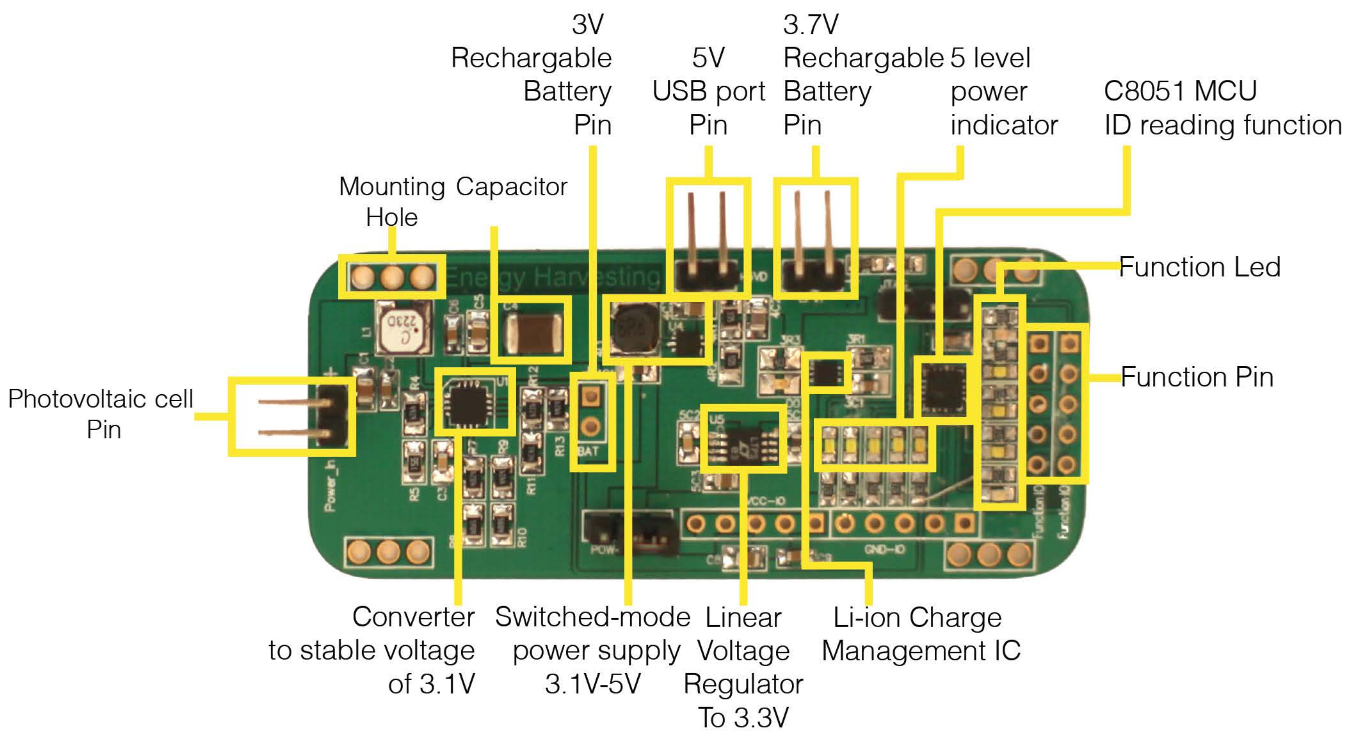


Figure 20: The layout of printing circuit board

PV SYSTEM INSTALLATION

The photovoltaic system includes solar cells, a circuit board, 0.35mm wires, and flaps or tops for hiding the electrodes of solar cells. The illuminating system includes LED and LED tubes, which need to be connected to the function pins on the circuit board.

Before I installed the PV system into garments, I created a circuit layout for each of the garments as shown below.

For each garment installation, I have focused on 5 criteria: connectivity of the circuit, durability of the system, access to the circuit board, wearability of the garment, and user interface design and the aesthetics of PV integrated garment.

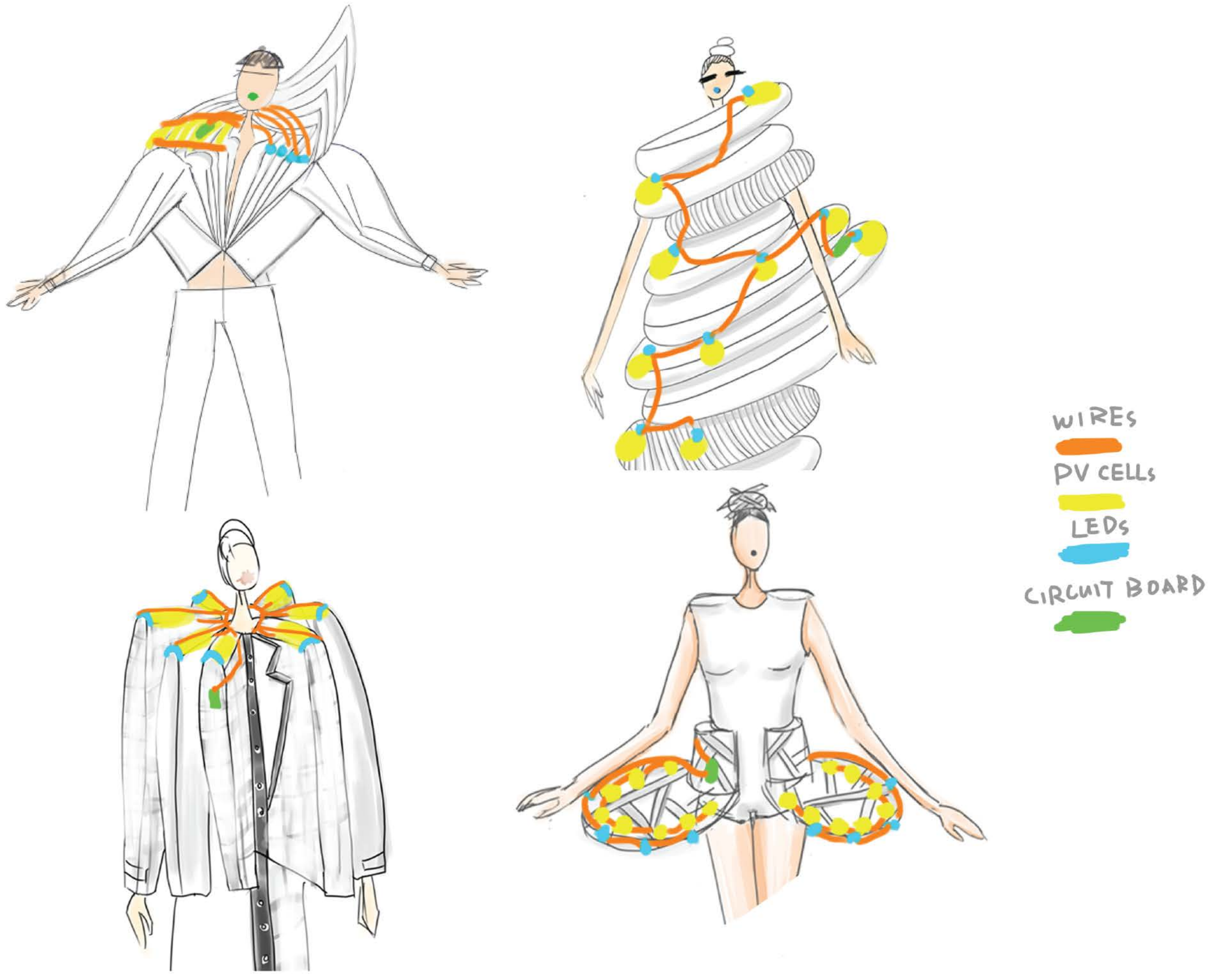


Figure 21: Circuit layout on the garments

Autumn Garment Installation

I started off by installing the autumn season PV garment. The solar panels were placed on top of the shoulders. The enlarged flat surface on the shoulder allows the PV cells to maintain an upwards direction and receive more sunshine. On each shoulder, three solar cells were connected in parallel fashion to form one big solar panel, which can ideally provide a current with a 75mA charge. The PV system includes seven such panels, which can generate a maximum 525mA charging current. For aesthetic purposes, additional fabric straps were added on the top of the cutting line. In this case, none of the electrodes of the solar cells are exposed. An illuminating system was embedded in each garment to serve as the activity indicator of the PV system, The LEDs should be visible for the wearers and also give a pleasant look to the garment. For this garment, using a single LED to create a hard light spot may affect the aesthetics. So I decided to use an LED tube to enable the light to merge into the design of the garment. In order to create a reliable circuit connection on the garment, the LEDs were well soldered and heat shrink tube was used for strengthening the connection. LEDs were fixed on the tip of the tube, so the light could go through and light up the entire tube. Seven LED tubes were placed on each sleeve. The user is able to see the LED tubes on the front sleeves, and other people can see the LEDs from any of the directions. The PV circuit board was placed inside of the front fake sleeve. Because LEDs need to be plugged into the circuit board individually, in order to create the connections between the circuit board and the LEDs, I used eyelets inside the garment to create cleanly finished holes for allowing wires to be inserted. For solar cells, they all connect together, and only one pin is required to be plugged into the circuit board. Each shoulder has an invisible zipper for users to access the circuit. An on/off switch was placed on the fake sleeve, so users can turn the system on or off through pressing the on/off switch.¬¬

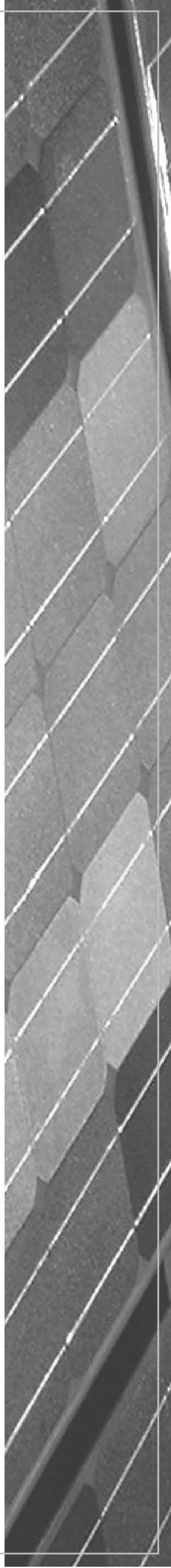
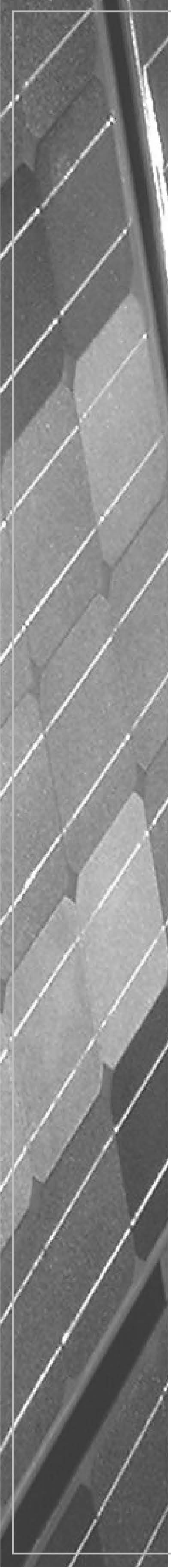


Figure 22: Autumn Garment Installation

Figure 23: Autumn PV Garment on Mannequin



Summer Garment Installation

In the summer season PV garment, I have added additional layers on each side of the hat, in between the boning layers and the brims. PV cells cannot be cut or damaged, so I snipped nine holes on each side of the additional layers and placed the PV cells underneath. In this way, solar cells appear round, corresponding with the round shape of the skirt. The dark blue solar cells have created a pleasant look as they were highlighted from the pure white dresses. The PV systems were embedded on the additional surface outside of the body so that body movement would not affect the performance of the solar cell. Therefore the durability of the garment was guaranteed. There are more spaces to place more PV cells but for aesthetic purposes, I only placed 9 cells on each brim. There are 18 solar cells in total and a 450 mA maximum charging current can be generated. The wiring system used the same material as the autumn garment, such as the female 2 pins connector that used for creating better connectivity between circuit board and wires. The LEDs were sewed onto the fabric so it would not fall or move around. They were placed at the edge of the brim, so users are able to notice the change of the LEDs by slightly lowering their heads. The structured boning on the top with a few LEDs underneath the brims has created a special texture and a layered look. The harmonious combination demonstrated the aesthetic of the garment. The circuit board was hidden in the crown of the hat, so the user's movement will not affect the performance of the circuit board. It is easy for the user to access the circuit when removing the dress. An on/off switch was placed under the brim so users can turn the system on or off easily by touching the edge of the brim and the switch was hidden away so it will not influence the look of the garment.

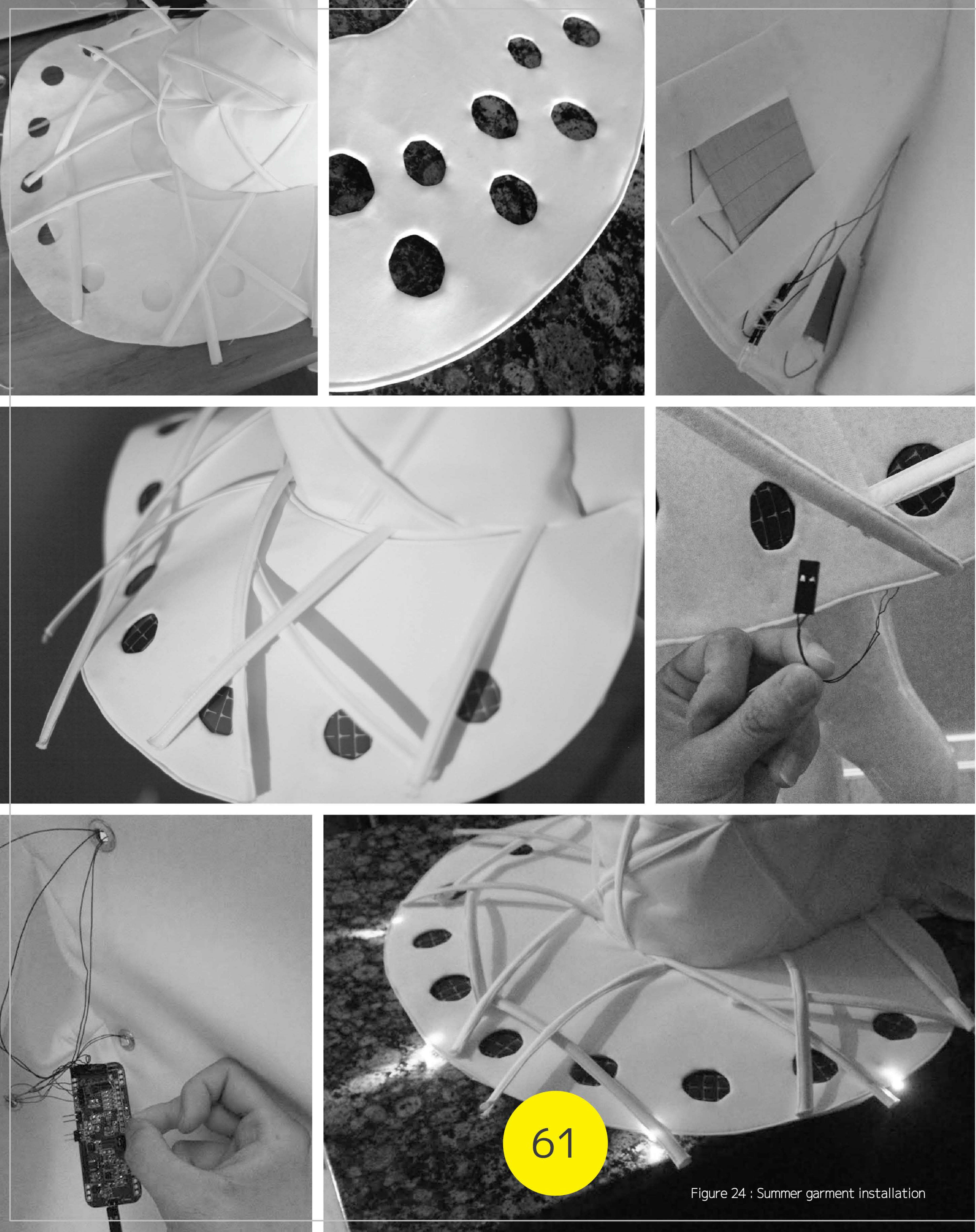


Figure 24 : Summer garment installation

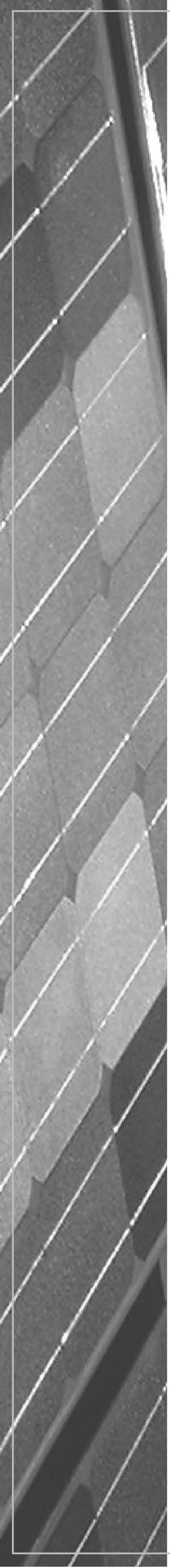
Figure 25 : Summer PV garment on mannequin

Winter Garment Installation

For the winter season PV garment, to correspond to its overall circled look, I choose to create round-shaped solar cells. As with the summer garment, solar cells must not be cut or damaged. So I sandwiched them with a round-shaped cut out on the top. When I made the garment, I double layered the fabrics, so I could hide the squared corners of the solar cell in between. It is hard to make the stretchable fabric remain round in shape, so a round-shaped cut out on the top is made by using a non-woven lining. By using this material, a neat circle shape can stay on top of the solar cell. I have experimented with different ways of fixing the linings on the garment, such as hand-sewing it onto the garment, or by using Velcro or glue. It turns out that the fabric glue worked the best. The shape of the circle will change as it is sewn onto the fabric, and the Velcro is too thick to remain neat. Ten panels of solar cells in different sizes were embedded in the garment. Different sizes of the panel were designed based on the size of the surface. Each panel has an LED on top. When LEDs light up they will create a glow on the solar cells, so the user can easily discern the change of the LED from the reflection of the solar cell. It also provides additional light for the solar panels. The panels were created using 34 solar cells, which can provide a maximum 850 mA charging current. I used the same wiring material on this garment as with the summer garment. The wires go through the double-layered fabric. The circuit board was hidden in the biggest padded circle. It was packaged in a bag and surrounded by cotton. Therefore, it will not be affected by the user's movement. The on/off switch was hidden under the first padded circle so the user can easily access it.

Figure 26: Winter garment installation

Figure 27: Winter PV garment on mannequin



Spring Garment Installation

For the spring garment, the unbalanced structure of the collars created a large surface on the right shoulder for embedding solar cells. The surface is designed as a slight arc shape so the solar panels will not interfere with each other. To keep the shape, I padded some cotton underneath the collars. Sixteen solar cells were connected together. A maximum 400mA charging current can be generated. The collars were cut out into solar panel sizes. The edges of the fabrics were turned inward and glued together for creating a clean look. The left side of the collar was made into a layered stand collar and its length is sufficient to protect the user from sunshine, while not creating shadows on solar cells most of the time, unless the light is directly shining onto the left collar. LEDs were embedded in the edge of the left collars. In order to allow wires to be inserted, I kept a 2 centimeter length unstitched line on the back of the collars. LEDs were half hidden in the collar to allow users to see the tip of the LEDs. The circuit board was packed in a bag and hidden under the right shoulder in the cotton padding, so the user's movement will not affect the circuit board performance. The on/off switch was hidden under the right hand side collar where users can easily reach.

Performance Varies Between Four Seasons Garments

Temperatures and sunlight conditions are the main factors that differentiated the performances of these four seasons garments. In terms of the temperature differences between four seasons, garments were designed into various thicknesses. In summer season, I kept the arms and legs part revealed, which allows the wearer stays cool. The autumn season garment was designed in a loose and comfortable way, so the wearers are able to add clothes underneath the garment. In winter garments, I chose to use cotton to add the thickness of the garment for providing warmness. Spring season garment was designed into a tight jumpsuit, which provides good wearability as it is light enough. The sunlight condition determined the amount of solar cells that I mounted on the garments. Summer and spring sunlight exposure is sufficient for charging the PV system, which explained why spring and summer garments contain less solar cells than autumn and winter garments.

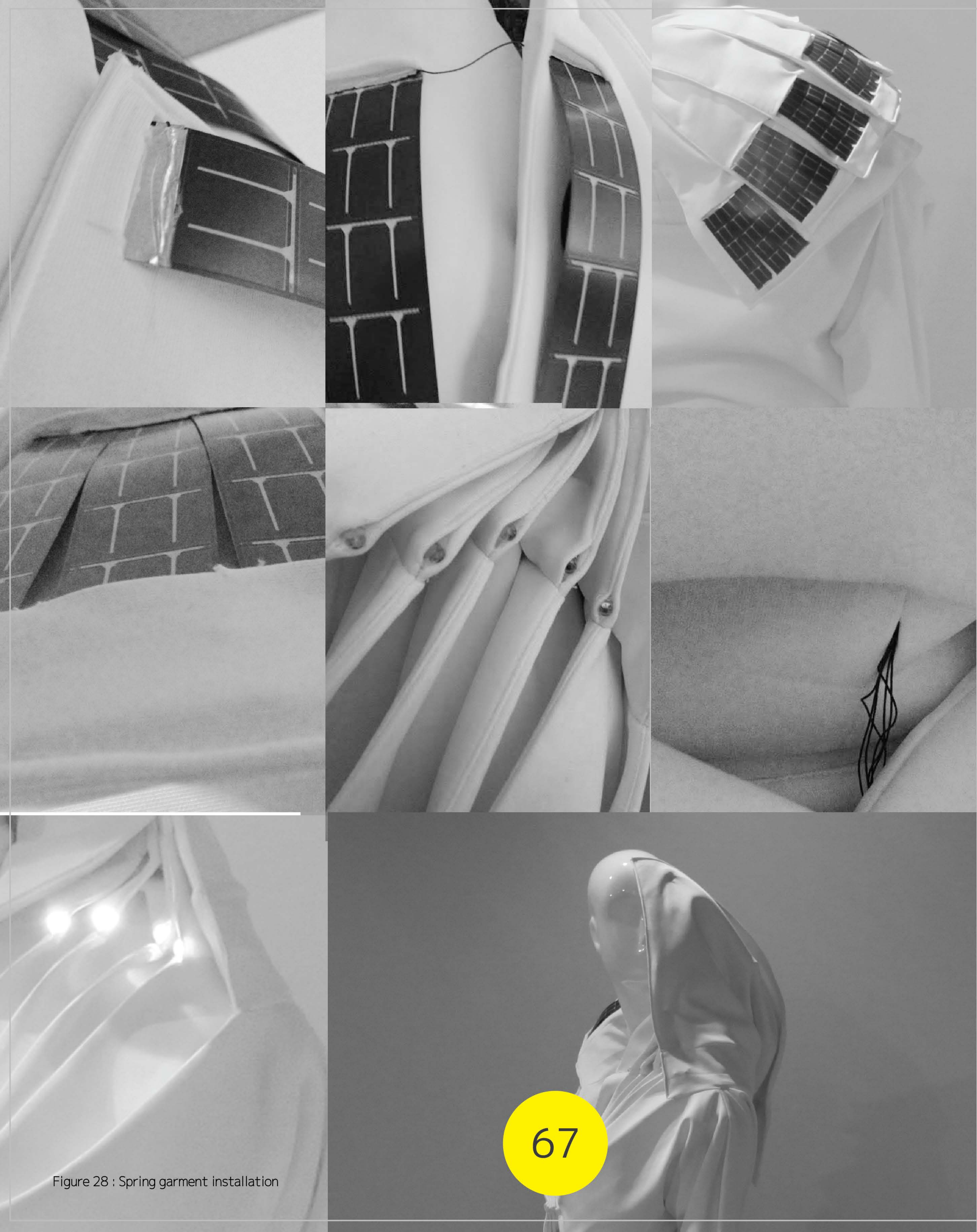


Figure 28 : Spring garment installation

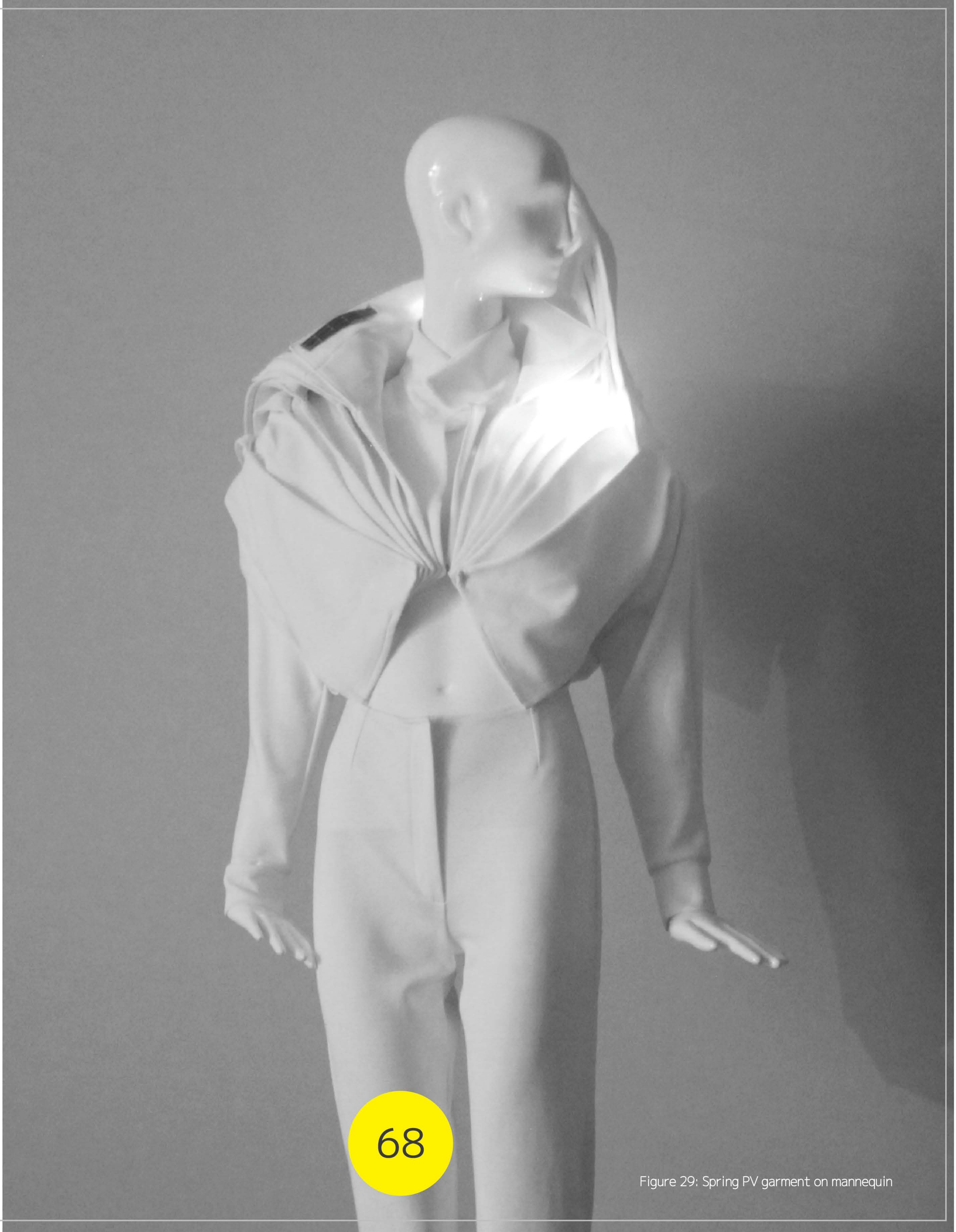


Figure 29: Spring PV garment on mannequin

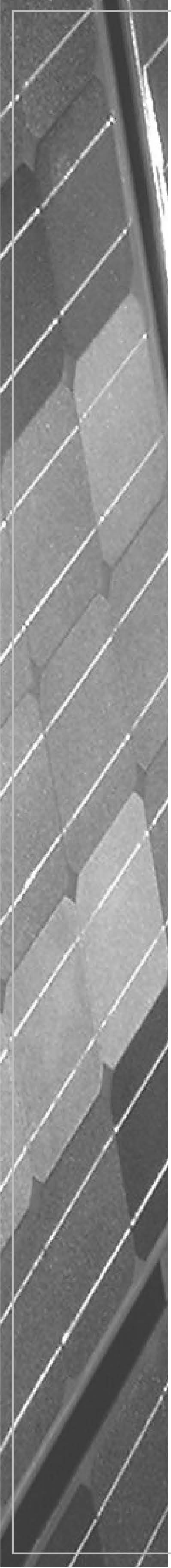
Research Method: User Testing

Figure 30: User testing questionaires

User testing was conducted in the garment refining stage toward the end of the project. I used participants' feedback as guidelines for polishing the work. Because wearable technology is all about the wearing experience, wearability is an important factor. I wanted to ensure that people could at least walk properly while wearing these garments. (The user-testing questionnaire is included in the Appendix B.)

User testing was conducted in two sessions involving two of my female friends, Dina and Kindy. Their feedback on the wearability is shown in the separate spreadsheets on the following pages.

In general, from my observation, they could walk and sit properly while wearing the garments. Details were refined based on their feedback, but some of the changes cannot be delivered at this stage. Runway fashion does not consider the wearing experience as the most important factor, but instead emphasizes concept and design. So, I also asked about their thoughts on the design and the concept of the garments. My friends come from different backgrounds but both were interested in the concept. They thought the design of the garments was very interesting. I had only finished the circuit board installation on two of the garments when I conducted the user testing, specifically the autumn garment and the summer garment. Based on my users' feedback, they did not realize the circuit board existed and they thought the LED was well positioned.



	Spring	Summer	Autumn	Winter
The placement of the wearable device	NA	Good	Good	NA
Any inconvenience when walking sitting or working	No	Good	The sleeve on the back will change shape while sitting	The collar part is tight while sitting
Body is breathing or not	Yes	Yes	Yes	Yes
The aesthetics of the garment	Well designed	Well designed	Well designed	Well designed
Weight of the garment was unbalanced?	Well balanced	Well balanced	Well balanced	Well balanced
Intimidated by the electronics components in the garment?	NA	No	No	NA
Long-term use	Yes	Yes	Yes	Yes

Figure 31: User feedback from Dina

Figure 32: User testing photos of Dina

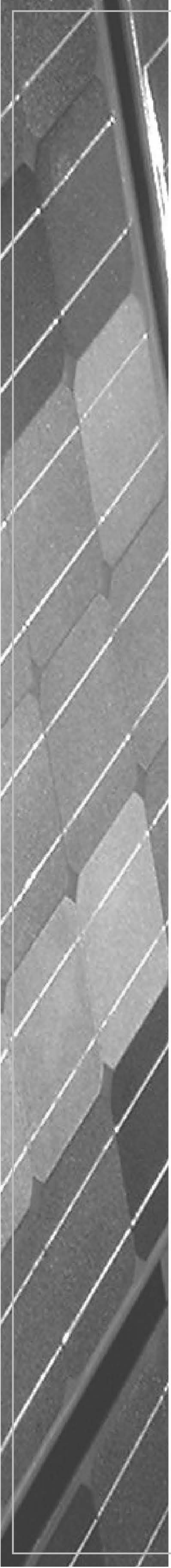
Dina's experience of wearing the autumn garment was that the two sleeves on the back would change shape while she was leaning back on the chair. This garment is intended to be very structured, so I used very thick linings for structuring it. This lining can be folded, but the shape will return. So a change in shape would not be a big issue in terms of wearability. For the winter garment, Dina suggested that the collar part becomes tight while sitting, so I have removed some cotton from the collar section to increase the neck circumference and make it less tight.

	Spring	Summer	Autumn	Winter
The placement of the wearable device	NA	Good	Good	NA
Any inconvenience when walking sitting or working	No	'Walking sitting are fine, but when I put my hand on the skirt, it may change the shape of it.'	No	It's heavy
Body is breathing or not	Yes	Yes	Yes	It's tight for me
The aesthetics of the garment	Well designed	Well designed	Well designed	Not my style
Weight of the garment was unbalanced?	Well balanced	Well balanced	Well balanced	Well balanced
Intimidated by the electronics components in the garment?	NA	No	No	NA
Long-term use	Yes	It's not meant to be for daily wear	Yes	Not sure

Figure 33 :
User feedback from Kindy

Figure 34: User testing photos of Kindy

Kindy's experience of wearing the summer garment is that when she places her hand on the brims of the skirt, the shape of the brims will change. Actually, users should feel free without being inhibited while wearing this garment. Even if the skirt changes shape it will spring back to its original shape. For the winter garment, she thinks it is too tight for her. The garment is intended to be tight to maintain its structure. The size is designed based on international standards. The reason for her tight feeling might be due to the weight of the garment. Due to the time limitation, I did not find any lighter materials with which to pad the winter garment, but that will be done in the future development of the garment. I will experiment with a greater variety of materials to refine the winter garment.



REFLECTION

In designing the photovoltaic garment, the design of the circuit layout is one of the most important processes. In my design development I found that the design of the garment sometimes needed refinements based on the circuit layout. Alterations of the finished garment can be challenging, so the circuit layout should be considered at an early stage. Ideally, the layout should be drawn in a detailed manner before the garment design is refined, such as where to cut holes that wires will go through or where to place the pocket for housing the main circuit board. Also, the size of the electronic components should be measured to ensure there is enough surface area and space to accommodate them.

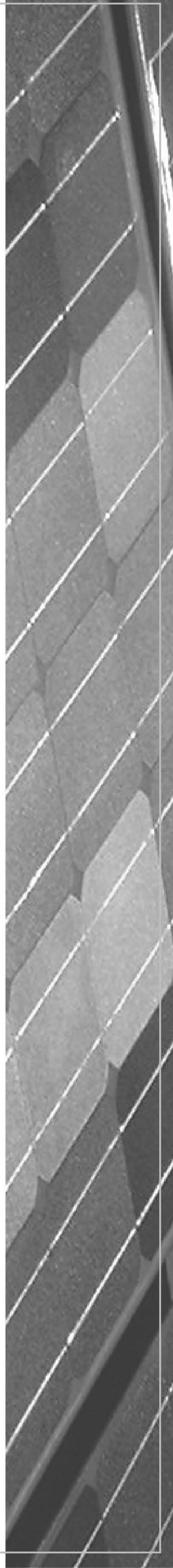
In my choice of fabric, I decided that stretchable fabric can provide better wearability in terms of comfort, tactility, and flexibility. However, it is not an easy material to manipulate in creating a garment. Extra layers are needed for structuring the deconstructivist garment. The fabric choice always influence the weight and drape of the garment. This in turn impacts the aesthetics and the wearability of the garment. From a weight point of view, nonwoven fabrics would be easiest to work with, but I decided to work with a lightweight cotton fabric as the best all around solution.

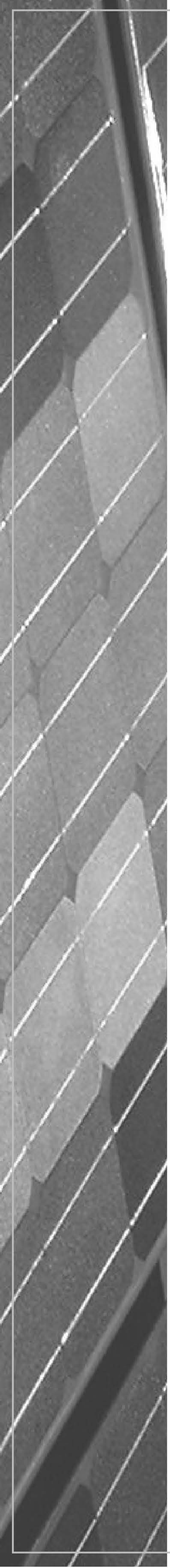
Defining the function is very important for designing the PV system, such as determining how many function pins the system requires. The development process I found could not be rushed at this stage. I have placed five function pins onto each circuit board, but it turned out that I needed seven function pins for one of the garments.

When choosing PV cells, I chose the thin film flexible PV cell, but its efficiency is not as good as the non-flexible PV cell. However, the flexibility and thinness of the film PV cell is the best choice for a wearable project. Selection ultimately depends on what designers really want for their projects.

REFLECTION

For PV system installation, the important criteria are connectivity of the circuit, durability of the system, access to the circuit board, wearability of the garment, and the user interface design. Good connectivity of the circuit is necessary for the success of a wearable project. The durability of the system is essential for the long-term use of the garment. Access to the circuit is very important for future maintenance, such as replacing the electronic components. Wires have to be hidden away for improving wearability. Since user interface is the only way for users to understand or control the system, system indicators or on/off switches should be included.





CONCLUSION

Based on my research, deconstruction as an activity that seeks to fix the essence of things has long permeated Western metaphysics (Loscialpo, 2010). In fashion, it describes the breaking down of elements, traditions and ideas (Bonnie, 2011). Deconstruction fashion stresses the space between the human body and clothing, and additional space or surfaces can be created for placing additional electronic components.

In the context of wearable technology, there has been increasing interest in creating renewable and wearable energy sources from solar power or a wearer (Ariyatum, Holland & Harrison, 2013). Solar power as a renewable energy source will be applied to the wearable context with increasing ease.

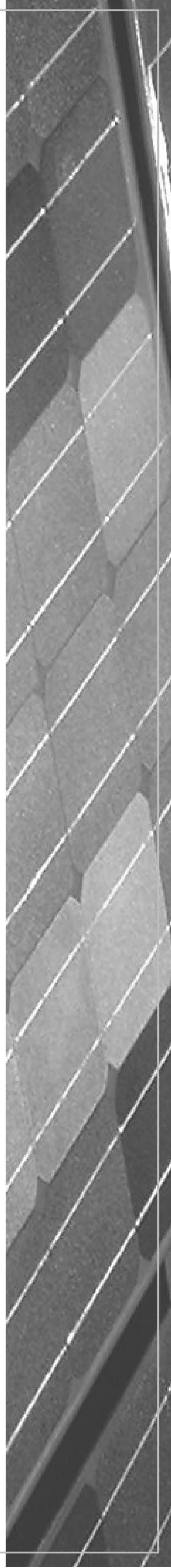
In this project, four garments have covered the four different techniques from deconstruction fashion: layering, padding, repeating and transposing. These techniques were applied on different areas of the garments: the front chest, back, shoulders and waist. By using these techniques from deconstruction fashion, enlarged surfaces on the garments were created and more PV cells could be mounted onto the garments. The flat surfaces on the garment made the PV cells face upwards so they could receive more sunlight. Therefore, the special structure of the garment improved the efficiency of the PV system. By deconstructing the garments, separate rooms were created for placing the body and electronic components. In this case, the electronic components would not be damaged or lose efficiency by external interruption stemming from the human body, and wearers would not be inconvenienced by the electronic components or limited by comfort. Garments met the wearability criteria of physiological considerations, thermal comfort, mobility and textile. Therefore, deconstructivism in fashion is proved to be a successful approach. It can be used as a design approach to optimize the PV system, to improve the wearability of the garment and also to give the garment aesthetics.

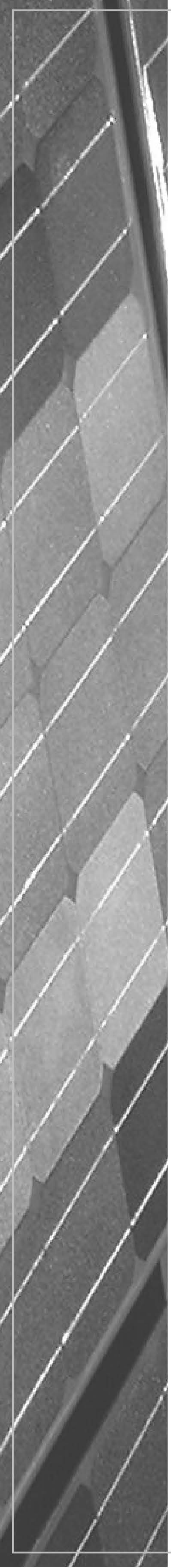
CONCLUSION

The design approach I have created can be modified by designers based on their own needs. They can use other deconstruction techniques to enlarge the surfaces or create spaces on any areas of the garment, and place wearable computers or PV cells on/in them. The most commonly used techniques in deconstruction fashion are layering, wrapping, transposing, sculptural, padding, pleats and repeating. By incorporating these techniques, more approaches can be made by designers based on their needs.

These are haute couture garments and not intended to be worn in daily life. Designers who are willing to create more practical PV garments for people to wear in daily life can also use deconstruction fashion as their design approach. They only need to make the design less extreme.

In conclusion, deconstructivism is a design approach that can be used as an exemplar for designers, enabling them to combining function and aesthetics when incorporating photovoltaic technology into high fashion.





MOVING FORWARD

The next step would be to incorporate smart-textiles into my project. It would further improve the wearability of the garment by incorporating soft circuits. I have experimented with a few E-textiles in my prototype, but I found that in their current stage of development they have limited electrical conductivity, which would reduce the efficiency of the system. In order to improve electricity delivery, I chose to use copper wires instead. The US military is going to field-test a PV garment in 2014. The garment uses smart textiles to transfer the power (Tornquist, 2014). Smart textiles with lower resistance should be released to the mass market soon. I need to investigate that further. In addition, in the year 2012 Japanese researchers invented PV fabric, but to launch the product may take years. Once the product is released, I can experiment with the solar fabric and incorporate it into my projects.

In developing this body of work I've come to realize how important it is to consider the pace of change in technology in the design process. PV technology is a prime example of this and I have seen how architecture membrane manufacturers have used pockets to allow for upgrading their system without having to change the whole roof. In the future, I anticipate looking to incorporate solar cells that can change direction based on the angle of the sun or the posture of the human body. Another possibility may be to combine solar with the body's own kinetic energy.

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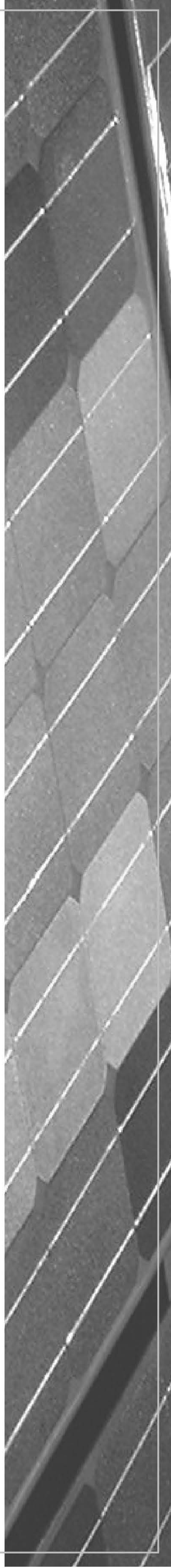

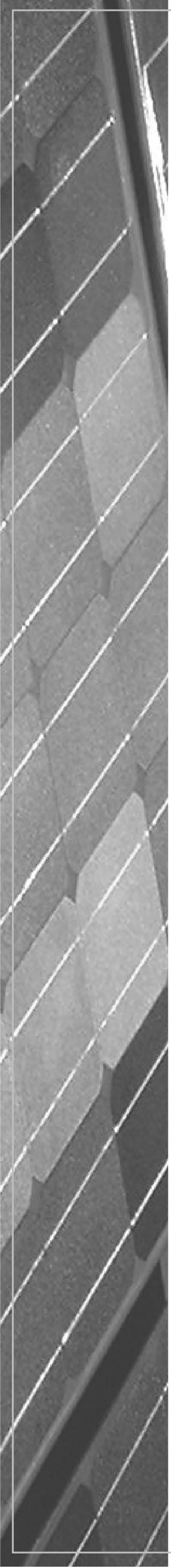

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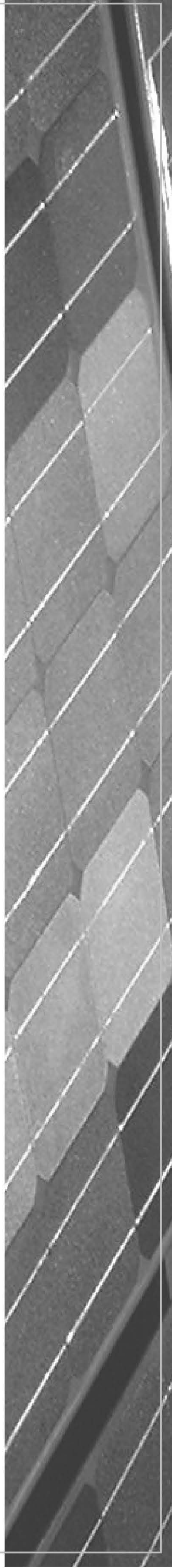
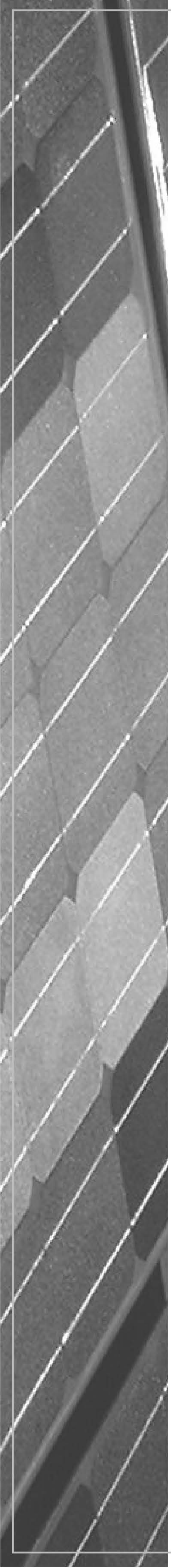




APPENDIX A

Expert Interview Guides

Telephone Interview guides

Takes approximately 20 minutes / person

(Preparation: I will prepare a brief introduction of my thesis topic)

1. Can you please introduce yourself briefly?

2. Can you please talk about one published wearable project that you have done before? Which of the elements do you think has determined the success of that project?

3. Can you please define wearable technology in your own term?

4. Can you please define what key factors will define the success of a wearable product?

5. How do you rate the importance of functional aesthetic design of wearable technology?

6. Have you ever heard or participated any similar projects?

7. Do you think there will be any major challenges that are not easy to overcome in this project?

8. Can you please give me some suggestions regarding the development of this project?

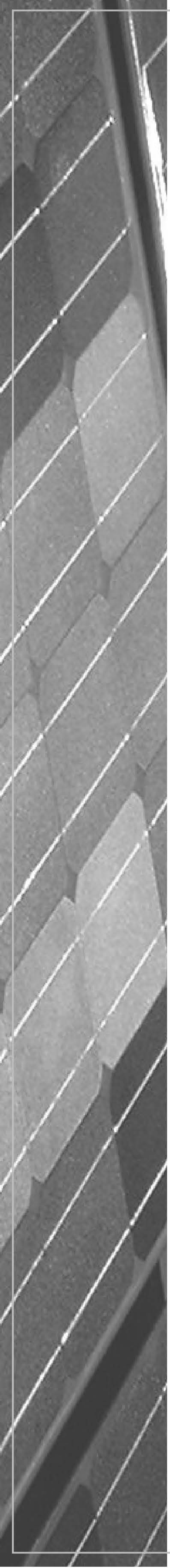
9. Do you know anyone else that would be a potential help to this project? Can you introduce them to me?

APPENDIX B

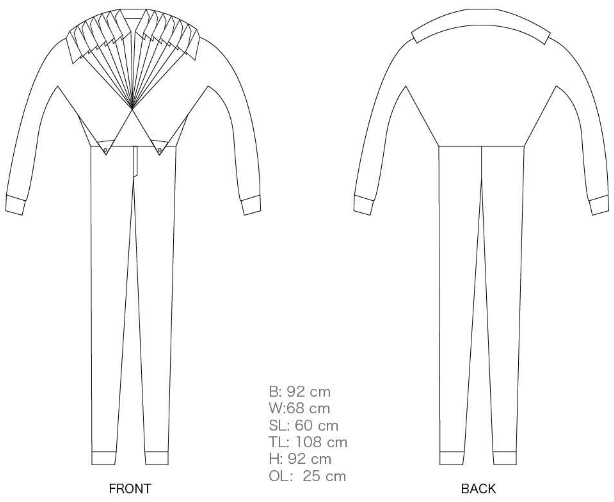
User Testing Questionnaires

Takes approximately 20 minutes / person

1. Do you think the placement of the wearable device makes you comfortable?
A. No, it will be better if the device was placed at__________
B. Not bad, it did not cause any troubles, but it bothers me sometimes.
C. Good, I did not even notice that.
2. Did you feel any inconvenience during daily activities such as walking, sitting, or working?
A. Yes I did, it happened when I______
B. No I did not. It felt the same as wearing normal clothes.
C. I am not sure. I should wear it for a longer time.
3. Did you feel your body is 'breathing'?
A. No, it is very tight, and I was sweating while wearing it.
B. Yes, my body breathed freely
C. I am not sure if the size is right for me
4. How did you feel about the aesthetics of the garment?
A. It was well designed.
B. No, it was not my style.
C. Comments____________________
5. Did you find the weight of the garment was unbalanced?
A. Yes, I felt the front is heavier than other parts of the garment.
B. Yes, I felt the back is heavier than other parts of the garment.
C. Yes, I felt the right part is heavier than other parts of the garment.
D. Yes, I felt the left part is heavier than the other parts of the garment.
E. No. The garment was well balanced for me.
6. Were you intimidated by the electronic components in the garment?
A. Yes, because___
B. No
7. Are you going to be confident enough to wear the garment in a long-term base?
A. Yes
B. No, because___
8. Any suggestions for future improvements?



Detailed illustration



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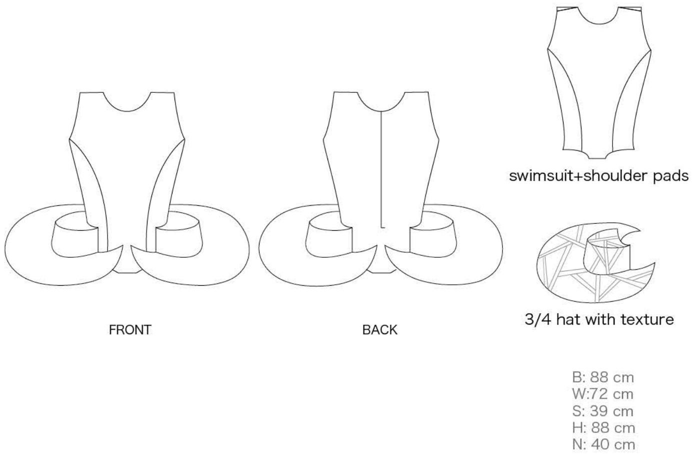

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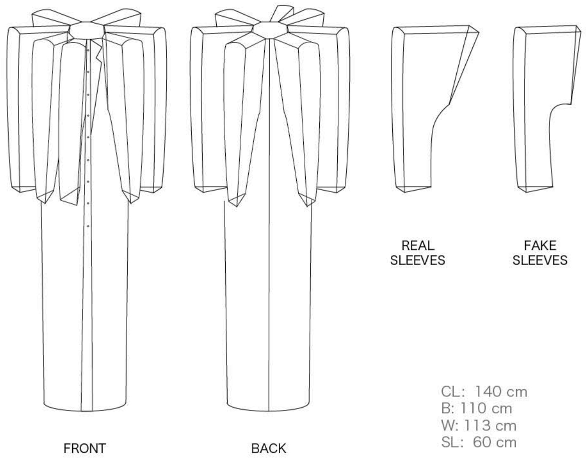

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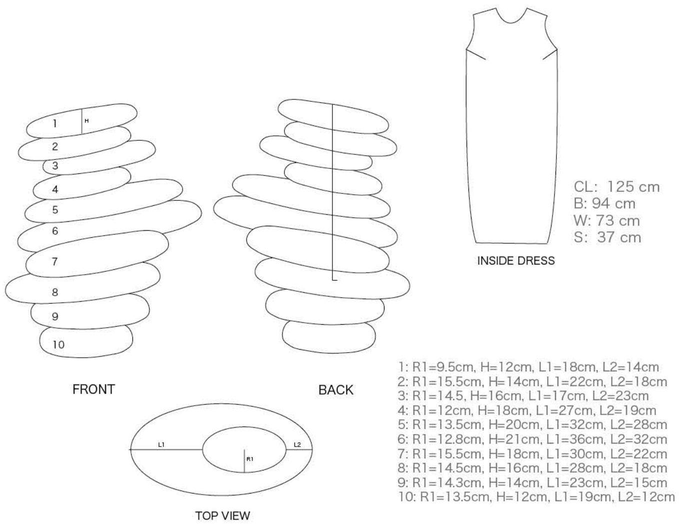
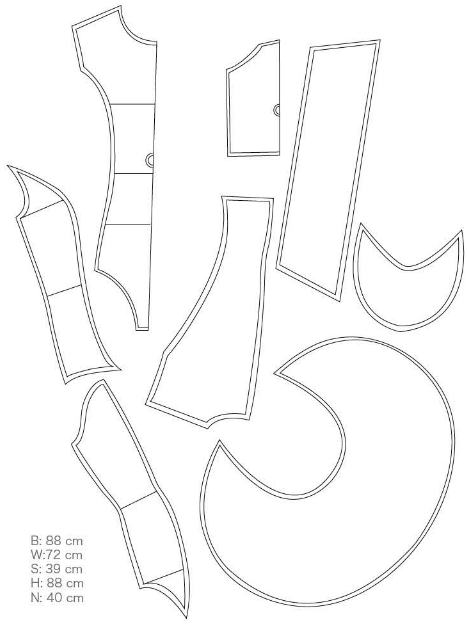


WINTER

APPENDIX C

Additional photos for garment making

Pattern Making and Alteration



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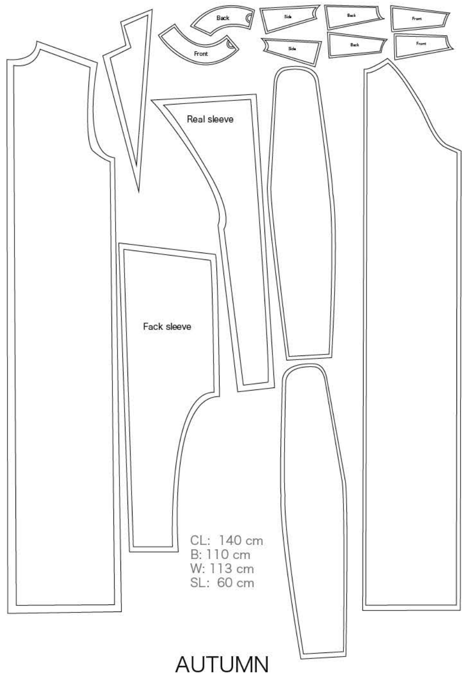

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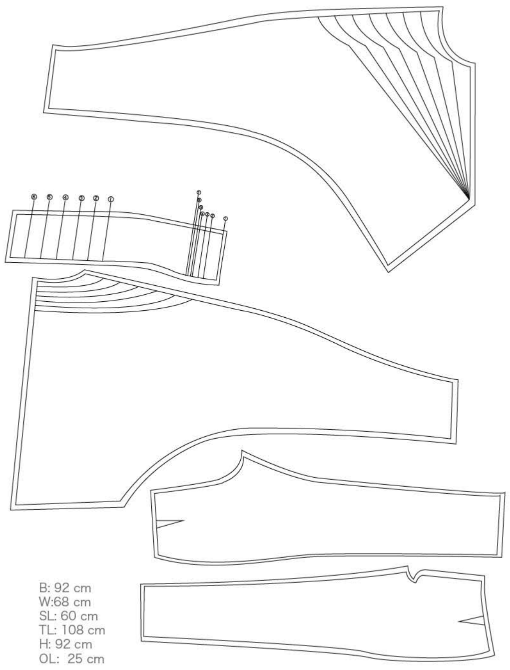

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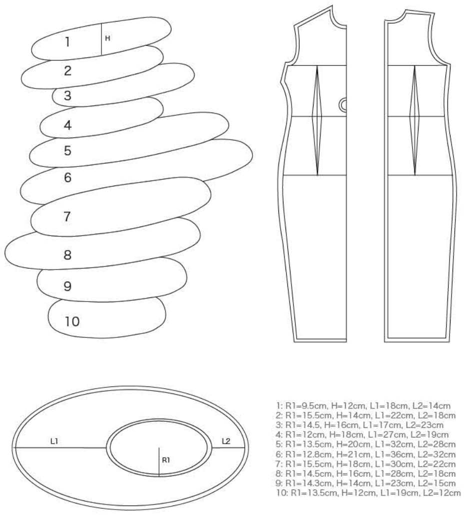
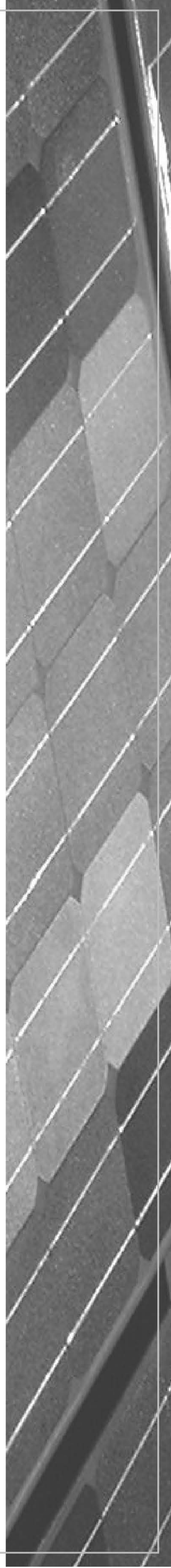


WINTER



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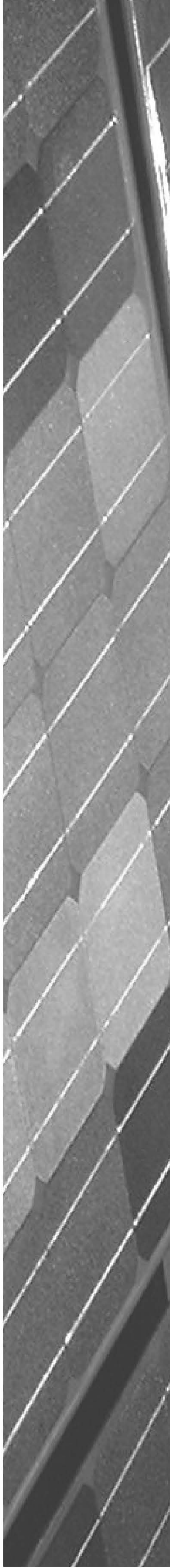

1. System Overview

C8051F99x-C8051F98x devices are fully integrated mixed-signal system-on-a-chip MCUs. Highlighted features are listed below. Refer to Table 2.1 for specific product feature selection and part ordering numbers.

- Ultra low power consumption in active and sleep modes.
- High-speed pipelined 8051-compatible microcontroller core (up to 25 MIPS)
- In-system, full-speed, non-intrusive debug interface (on-chip)
- 10-bit 300 ksps or 12-bit 75 ksps single-ended ADC with analog multiplexer
- 6-bit programmable current reference (resolution can be increased with PWM)
- Precision programmable 24.5 MHz internal oscillator with spread spectrum technology.
- 8 kB , 4 kB, or 2 kB of on-chip Flash memory
- 512 bytes of on-chip RAM
- SMBus/I^2C, Enhanced UART, and Enhanced SPI serial interfaces implemented in hardware
- Four general-purpose 16-bit timers
- Programmable counter/timer array (PCA) with three capture/compare modules and watchdog timer function
- On-chip power-on reset, V_{DD} monitor, and temperature sensor
- One on-chip voltage comparator
- Up to 14 Capacitive Touch (QuickSense™) Inputs
- Up to 17 Port I/O

With on-chip power-on reset, V_{DD} monitor, watchdog timer, and clock oscillator, the C8051F99x-C8051F98x devices are truly stand-alone system-on-a-chip solutions. The Flash memory can be reprogrammed even in-circuit, providing non-volatile data storage, and also allowing field upgrades of the 8051 firmware. User software has complete control of all peripherals, and may individually shut down any or all peripherals for power savings.

The on-chip Silicon Labs 2-Wire (C2) Development Interface allows non-intrusive (uses no on-chip resources), full speed, in-circuit debugging using the production MCU installed in the final application. This debug logic supports inspection and modification of memory and registers, setting breakpoints, single stepping, run and halt commands. All analog and digital peripherals are fully functional while debugging using C2. The two C2 interface pins can be shared with user functions, allowing in-system debugging without occupying package pins.

Each device is specified for 1.8 to 3.6 V operation over the industrial temperature range (–40 to +85 °C). The Port I/O and $\overline{RST}$ pins are powered from the supply voltage. The C8051F99x-C8051F98x devices are available in 20-pin or 24-pin QFN or 24-pin QSOP packages. All package options are lead-free and RoHS compliant. See Table 2.1 for ordering information. Block diagrams are included in Figure 1.1 through Figure 1.9.

Texas Instruments

Application Report

SLUA632–March 2012

bq25504 Optimization of MPPT Algorithm

Umar Lyles and Yogesh Ramadass

Battery Charge Management System and Design

ABSTRACT

The bq25504 is an ultra-low-power charger IC intended for interfacing DC sources like solar cells, thermal harvesters and high-impedance batteries. The bq25504's industry-leading low-quiescent current and high charger efficiency make it an ideal choice for charging batteries and super-capacitors т from a variety of energy-harvesting sources. This application note details how to optimize the bq25504 maximum power point tracking (MPPT) network to accurately regulate different types of solar cells to their maximum power point (MPP). For details, see the bq25504 data sheet (SLUSAH0).

Introduction

The Texas Instrument's bq25504 uses the open-circuit voltage (OCV) technique to regulate the solar cell to its maximum power point (MPP). This technique relies on the fact that for most solar cells, the MPP is achieved at some fraction of the OCV, typically 80%. A resistor divider (R_1 and R_2) is used to obtain the appropriate percentage of the solar panel's OCV. During normal operation, the bq25504 periodically turns off the charger so the solar panel can return to its OCV. During this time, the fractional voltage generated from the divider network is sampled and held by the capacitor, C_{REF}. The voltage on C_{REF} is used as a reference voltage to regulate the panel's operating voltage.

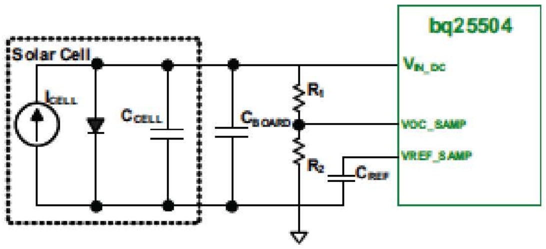

Figure 1. bq25504 MPPT System Diagram

The bq25504 has a preset 256-ms OCV sampling period that is refreshed every 16 s. For most commercially available solar cells, the 256-ms time interval is adequate for I_{CELL} to charge the solar cell's internal capacitance (C_{CELL}) and the board capacitance (C_{BOARD}) to settle the voltage at V_{IN_DC} to the OCV of the solar cell, even under low light conditions. This is true for most solar cells because the capacitance at V_{IN_DC} is approximated as C_{BOARD}, because C_{CELL} is usually small and I_{CELL} is usually greater then 20 μA. However, some solar cells have a very large C_{CELL} and/or a very small I_{CELL} such that the voltage at V_{IN_DC} no longer settles to OCV in the 256-ms sampling window. Under these conditions, the sampled voltage will actually show up as something less than the target fraction of OCV that R_1 and R_2 are normally set to achieve. To better understand how this phenomenon affects the selection of the MPPT resistor divider network the solar cell is approximated as a simple RC settling network.

APPENDIX E

REB Approval

Research Ethics Board

December 4, 2013

Dear Yuxi Wang,

RE: OCADU 122 “When Deconstructivism Meets Photovoltaic in Fashion.”

The OCAD University Research Ethics Board has reviewed the above-named submission. The protocol and the consent form dated December 4, 2013 are approved for use for the next 12 months. If the study is expected to continue beyond the expiry date (December 3, 2014) you are responsible for ensuring the study receives re-approval. Your final approval number is **2013-53.**

Before proceeding with your project, compliance with other required University approvals/certifications, institutional requirements, or governmental authorizations may be required. It is your responsibility to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the OCAD U REB prior to the initiation of any research.

If, during the course of the research, there are any serious adverse events, changes in the approved protocol or consent form or any new information that must be considered with respect to the study, these should be brought to the immediate attention of the Board.

The REB must also be notified of the completion or termination of this study and a final report provided before you graduate. The template is attached.

Best wishes for the successful completion of your project.

Yours sincerely,

Tony Kerr, Chair, OCAD U Research Ethics Board

OCAD U Research Ethics Board: rm 7520c, 205 Richmond Street W, Toronto, ON M5V 1V3
416.977.6000 x474

APPENDIX F

Photos of model wearing the garments

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