Designing for the daily-life applications with functional textiles:

Case study of working with Taiwan Textile Research Institute

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Abstract: Functional textiles aim at supporting fabric by providing users with five senses experience by light, temperature, water, electronic, and Biological… In developing such products, designers are faced with many interdisciplinary challenges. Typically, the designs and evaluations of these advanced textiles lack foundations in daily-life applications design methodology. This research was sponsored by Taiwan Textile Research Institute (TTRI) and The Institute of Polymer Science and Engineering (IPSE) at the National Taiwan University (NTU). The paper first investigate definitions and technologies of functional textiles (e-textiles and smart textiles are included) which provide a guideline for starting design workshop. Through the exploration of the functional textiles technologies in a field trial such as 'LED embedded Yarn', 'electro-thermal isolation fiber', 'weaving conductive textile' 'Thermoresponsive Luminescent Electrospun Fibers'(IPSE), the inspiration workshops were held to probe out the application concepts of these advanced textiles in daily-life. Therefore, more than 60 design concepts were explored and discussed in the workshop and with members of TTRI and professional experts. 12 design proposals and mock-up were selected by participants from TTRI according to the criteria of Innovation (30%), Practicable (40%), and Presentation (30%). Finally presents 6 experience prototypes were evaluated to find out the validity of the extrasensory physical characteristics of the fabric touch applied in daily-life which are 1)Flora postcard, 2)Thermoresponsive tableware (cooperate with IPSE at NTU , 3)digital printing lamp, 4)night light slippers, 5)Energy storage knee-pad, 6)portable heat-pad. Interviews and log-data show that participants' evaluation of the design experiences, and that is contribute to relationship saliency and closeness as dimensions of the five sense experiences of the user. Key design aspects and methods were found for designing functional textile product.

Key words: Functional Textiles, Tangible Experiences, Design Case Study, Field-Trial

1. Introduction

Textiles are indispensable, light and soft materials surrounding in our daily life and activities. In general, functional textiles are considered as fiber rather than end products. A review of the existing work of in this domain such as E-textile (Kholiya & Jahan, 2010), smart-textiles (Park & Jayaraman, 2003) showed these paradigm envision electronic devices woven into fabric and at the same time maintaining the fabric specific organic qualities of knitting, stitching, folding, extending, etc… or with special function such as light, sound, electricity and adsorption, dialysis, ultrafiltration, reverse osmosis, and ion exchange fiber. Functional fabrics can not only achieve temperature control and contribute to the transmission of electronic messages, but also with the emotional features of friendly, intimacy, and affinity.

Taiwan Textile Research Institute (TTRI) the integrator of technology and the leader of textile industry. Offer variety textile business with customized service the multi-integrated and transformation service. The established of TTRI by Ministry of Economic is to help and assist the manufacturers in Taiwan in raising the added-value of products. The following table shows the nature and functions of 10 fabric categories in TTRI Annual Report published in 2011.

Table 1. Classification of functional textiles. (Source: Sustainable innovation, TTRI 2011)

Nature	Functions of the Application
Water	absorbent, water, moisture, water repellent, waterproof, anti-fouling
Fire	flame retardant, heat-resistant, flame
Thermal	insulation, thermal break, fever, exothermic, fast fitness, anti-financial, adhesion
Electronic	conductive, electrostatic, electromagnetic wave reflection or absorption, microwave, dielectric
Mechanical	High strength, high strength and resistance rate, the rubber elastic modulus, extended, telescopic, shrinkage
Biological	antibacterial, deodorizing, aroma, pest control
Chemical and other	Contraction in swelling, dissolving, decomposition, naturally crimped potential crimping, dividing, splitting
High durable	light resistance, weather resistance, heat resistance, chemical resistance, abrasion resistance, fatigue life
Ultra-high performance	ultra-high-strength, high elasticity, ultra heat-resistant, flame retardant, ultra-high absorbent
Special function	light conduction, light gathering, dialysis, reverse osmosis, ion exchange, gas exchange, photo catalyst form

These raw materials listed above all have identical and useful function for business sectors but still way too far to image as profitable consumer product existing in daily life. Mostly, functional textile topics are still about designing wearable from a human centered point of view to reshaping electronics for the body. Most wearable computing projects today are ugly. The few good looking e-textiles projects are limited in fashion and cloth. A blinking LED on a jacket or wedding dress is just not smart enough to use the advanced textiles. The study took advantage of advanced functional textiles' soft, weaving, stitching, folding, stretching, organic qualities and unique tactile experience; reshape products of daily-life for wellbeing. We will have a look at different conductive and non-conductive fabrics and threads and introduce the most meaningful application for functional textiles available on TTRI today. We will find new ways of embedding function textiles into application potentials in the areas of interpersonal, healthcare and automotive.

In this study, we examine and implement the functional textiles as described by TTRI of Taiwan. Base on this conceptual understanding of functional textiles, we started to explore the possibility of functional textiles applied in daily-life product and broaden the possibility of functional textiles applications. According to soft and amiable characteristics of fabric incorporated into the relevant conceptual design, we try to build a design development framework and provide other opportunities of materials for product designers.

The paper provides an overview of the related in the field of functional textiles, followed by a description of the iterative design process that may relate to functional textiles, and evaluation methods applied are outlined. According to the finding from the experience prototypes are provided in terms of use and effects on user feedback. Finally we discuss the design approach taken for applying functional textiles in daily-life product, and we provide design insights and suggestions for the future. Discussion has focus on both with respect to applications and to industrialization schemes, in which Industrialization and reliability are evaluation and measurement criteria.

2. Related Work on Functional Textiles

Functional textiles give us many diverging research directions and possible definitions. The pioneering examples of functional textiles product were target at wearable electronic cloth and they have their roots mainly in the domain of military, health care, recreation, communication and fashion (Kholiya & Jahan, 2010). There are pragmatic applications such as military research into interactive camouflage or textiles that can heal wounded soldiers. On the other end of the spectrum, work is being done by artists and designers in the area of reactive clothes: "second skins" that can adapt to the environment and to the individual (Berzowska, 2005). The research into these technologies co-emerged with the following classifications which are Technical textile, Electronic textiles, Smart textiles, Wearable technology, and Interactive textiles:

Table 2. Difference of technical textiles, e-textiles, smart textiles, wearable technology, and interactive textiles. (Berzowska, 2005)

Classifications	definitions
Technical textile	Textiles for automotive applications, medical textiles (e.g., implants), geotextiles (reinforcement of embankments), agrotextiles (textiles for crop protection), and protective clothing (e.g., heat and radiation protection for fire fighter clothing, molten metal protection for welders, stab protection and bulletproof vests, and spacesuits).
E-textiles (Electronic textiles)	Fabrics that enable digital components (including small computers), and electronics to be embedded in them. The emphasis is placed on the seamless integration of textiles with electronic elements like microcontrollers, sensors, and actuators. Furthermore, e-textiles need not be wearable. For instance, e-textiles are also found in interior design.
Smart textiles	Passive textile structure capable of responding to external stimulation i.e. from pressure, temperature, light, low voltage current etc.
Wearable technology	Any electronic device that is small enough and light enough to be worn or carried on the body.
Interactive textiles	Wearable technology which is woven / sewn into clothing and operated / controlled by an integrated control panel or operation button.

This research is to build up a design framework of functional textile product by setting the design workshop, making the experience prototypes, and analyzing and evaluating the user respond to consumers' wants in the meantime to be industrial able and reliable. Functional textiles adapted in this paper were from the technologies of TTRI, we can categorized the essential R&D result as following：

Table 3. The essential R & D results of functional textile as from TTRI are summarized as following:

Light	LED Embedded and photonic Textiles, light-storing poly(ethylene terephthalate) fiber
Water	Waterproof and Moisture Permeable Textiles
Electronic	All foldable Fabric Ultra-Capacitor, Conductive Materials,
Thermal	Electro-thermal Textiles
Biologic	Flora Garden
Sensor	Feedback Perceivable Clothing for Interactivity Edutainment; Biophical Monitoring Textiles

2.1 Blending functional textiles in our daily life

Functional textiles are an alternative to plastic-based product, with potentially significant advantages in hardware cost and energy consumption. Research took the advanced functional textile's unique technical characteristics as a starting point, via the product design principles, used in experiments of high value-added innovation products or services. The purpose is to take advantage of fabric unique touch, softness, and insulation features to development a new look in daily life, exploration new demands from the possibility of providing brand new five senses experience. By exploring the concept design and building the working prototypes of potential market, a feasible development design model was studied to set up.

1. Cognitive –mapping of the function textiles from 'thoughtless act' observation

Research took IDEO and Jane Fulton Suri's 'thoughtless act' (Suri & IDEO, 2013) and Naoto Fukasawa's 'Without Thought' theories (Fukasawa, 2007), Designers watched and looked, and then pressed our observations on by cognitive mapping (Ackermann, Eden, & Cropper, 1992) (Hanington & Martin, 2012). The data collected was mapping to gain possible concepts. These mapping present outlines based on simulation and physical experimentation for quantifying applications on a functional textile that blending into daily life of the users. Studying with the ethnographic observation method from the people, objects, environments, and events in every aspect of daily-life to search for the possible design opportunities by notes, sketches, images, situational movie analysis record, in order to generate a series of proposals of applications

People and the environment: design team involved and explore in the actual use of the field, observation, interviews and focus group discussions, data collection and concept generation;

Activity: Advanced fabric material and technology application in design products, good design sharing, cross-analysis of the good examples, exploring a variety of fabric material ... and so on.

Record of the event: via awareness of the user "habit" and "demand", and thinking about the experience of the application on the functional fabric of everyday life, and to reflect on how to convert the observation into the product features.

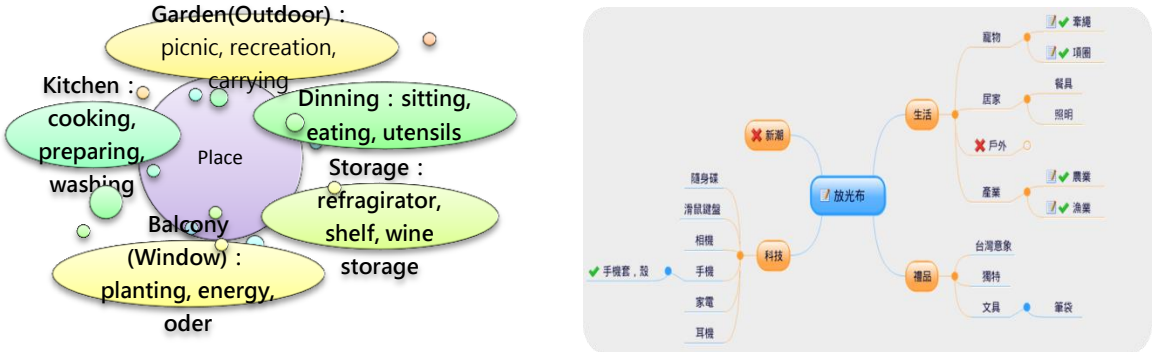


Figure 1: Cognitive –mapping of the textiles from observation of the 'thoughtless act'.

2. Inspiration Workshop

An inspiration workshop (Hanington & Martin, 2012)was held to help designers find users insight in the shortest timing and test ideas' Industrialization and reliability. Workshop was divided into three sections. First: the inspiration workshop after finished the thoughtless act observation of possible functional textiles' daily applications. Second: brain storming meeting with expert of TTRI. Third: several parallel prototypes (Dow & Glassco, 2010) (Nielsen, 2011)have be made and a meeting was held with electronic engineers , The Institute of

Polymer Science and Engineering (IPSE) at the National Taiwan University (NTU) and related departments of TTRI to inquire technical support.

Table 4: inspiration workshop, brain storming meeting and prototyping meeting

		
Stage1: inspiration workshop	Stage2: Brain Storming meeting	Stage3: prototype meeting

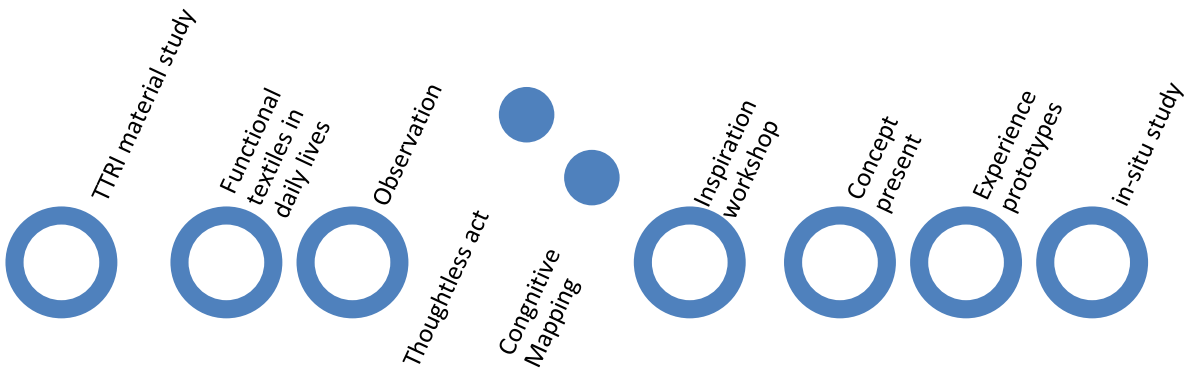
2.2 Evaluation and Measurement

The workshops discuss aimed at functional textiles blending into daily lives of users. However, some effort was made to deeply evaluate the efforts of the design in terms of user experience. Empirical **in-situ evaluation** (Consolvo, 2007) (Visser, Vastenburg, & Keyson, 2011)can be done as part of the development. In this case, working experience prototypes (Buchenau & Suri, 2000)were made and evaluated by target users in an exhibition held in TTRI showroom. By asking open-ended questions and collecting qualitative data to evaluate the effect of the experience prototypes. The design panels and prototypes were evaluated in context for three weeks and the criteria of the outcomes are creativities, reliability and aesthetics (Davis, 1989).

2.3 Study Procedure

To gain deeper understanding on how the use and functionalities of textile technologies affect product design process, the following steps were defined for the current study.

1. **Develop understanding of functional textiles.** An understanding of underlying theories and technologies is considered essential, as it enables identification of design decisions that optimally support daily-life.
2. **Design and prototyping of functional textiles applications.** Following the empirical Research through typical product design method, several prototypes were built to understand integrating knowledge gained from theory and the design iterations.
3. **In-situ evaluation.** A longitude field evaluation will be performed. Evaluation criteria are based on the conceptual definition of functional textiles.



3. The Design of Functional Textile

The design process can roughly be described in three phases: a design exploration (textiles +people), the design of final prototypes for technical implementation (textiles +concept), and the field trial in an exhibition (textiles +communication). The goal for the field trial was to build a design framework that (1) increase connectedness for users, (2) could be built with the resources available and that (3) would be reliable to be placed in the product developing process.

The research started from set up three design teams, each consisting of one professional instructor and 20 undergraduate students from a design course in our institute conduct the first design explorations. They were instructed to design products that transfer in the field of e-textiles in TTRI to support daily-life of users. They were to consider making working prototype, rather than screen based designs, and aim to for solutions that were interwoven into the daily lives of people. Also, the students were asked to focus on supporting usage and feeling of textiles, rather than the looking of fashion.

More than 60 design concepts were explored and discussed in the inspiration workshop at first stage (textiles +people). 12 design proposals were evaluated by five committee members of management and production departments from the sponsors TTRI according to the criteria of Creativity (30%), Reliability (40%), and Aesthetics (30%). The evaluation sheet design as showed in table 3. This sheet was with the 12 design panels and prototypes sent to the experts of TTRI for three weeks' evaluation. (Textiles +concept)

Table 5. Design Proposal Evaluation Sheet

[Creative advanced technology research project - functional textiles daily-life application design] Design Proposal Evaluation Sheet																
Code		A：good			B：fine			C：bad								
X：others（please note in reference column）e.g. Lack of Scenario Descriptions, Content is not complete, etc…																
No.	name	**Result (please check)**			**Total votes**	Reference / Code of not suggest (or reasons)	Record of evaluation									
		creativity	reliability	aesthetics			Creativity 30 %			Possibility40%			Aesthetics 30%			
							good	fine	bad	good	fine	bad	good	fine	bad	

Finally presents six workable prototypes 1)Flora postcard, 2)Thermoresponsive tableware, 3)digital printing lamp, 4)night light slippers, 5)energy storage knee-pad, 6)portable heat-pad were rated top 6 (table 6). Therefore, functional textiles such as 'LED embedded Yarn', 'electro-thermal isolation fiber', 'weaving conductive textile' 'Thermoresponsive Luminescent Electrospun Fibers'(IPSE) were applied in the working prototypes to be evaluated in a field trial to find out extrasensory physical characteristics of the fabric touch.

Table 6: Design Proposal Evaluation result

No.	name	**Result (code check)**			**Total votes**	Ranking	Committee				
		A	**B**	**C**			1	2	3	4	5
1	Odor eliminate BRA	0	1	4	2	9	C	C	C	C	B
2	Thermoresponsive tableware	3	0	2	12	3	A	A	A	C	C
3	Flora postcard	3	2	0	16	1	A	A	A	B	B

4	LED Yarns Volleyball net	0	3	2	6	7	C	B	C	B	B
5	portable heat waist guard	1	2	2	8	6	C	B	A	B	C
6	Heat pad Fan	1	0	4	4	8	C	C	A	C	C
7	energy storage knee-pad	2	2	1	12	3	B	B	A	A	C
8	night light slippers	3	1	1	14	2	B	C	A	A	A
9	Clothing BOOT	0	1	4	2	9	C	B	C	C	B
10	LED Yarns book Slipcase	0	1	4	2	9	C	B	C	C	C
11	Turning digital printing lamp	2	2	1	12	3	A	A	C	B	B
12	Heart to heart /hand to hand glove	1	0	4	4	8	C	A	C	C	C

Through the exploration of the functional textiles, the working prototypes were experienced and evaluated with users in an exhibition, where qualitative data with open-ended questions were provided. Participants experienced the prototypes as a complementary form of daily products and giving the feedback. Finally, 1)Flora postcard and 5)energy storage knee-pad were rated and sponsored with patents.

3.1 Design Explorations 1: Functional Textile + Interpersonal Behavior

Among these six prototypes, one group focuses on interpersonal behavior. This group of proposal explored various ways for giving the gift made by the functional textiles. The end result, called Textiles +gift, consists of three proposals (Figure 2). The evaluation indicated that users particularly liked the 'Flora Postcard'. Users also expressed they experienced

1. Flora postcard	2. Thermoresponsive tableware	3. Turning digital printing lamp

Figure 2: Group A, the (Textiles+Gift) prototype

1. Flora Post card

Flora Postcard adapted the single unit of 'Fabric Garden' from TTRI and insert appropriate seeds inside to growing after watering. It is also applied polyester waterproof film technology on base to prevent leaking. The soil and the surface was replaced by fiber extracted from recycled bottle; It is a simple and lightweight way to applied textile as gift item or for nature science education purpose and good for distribution.

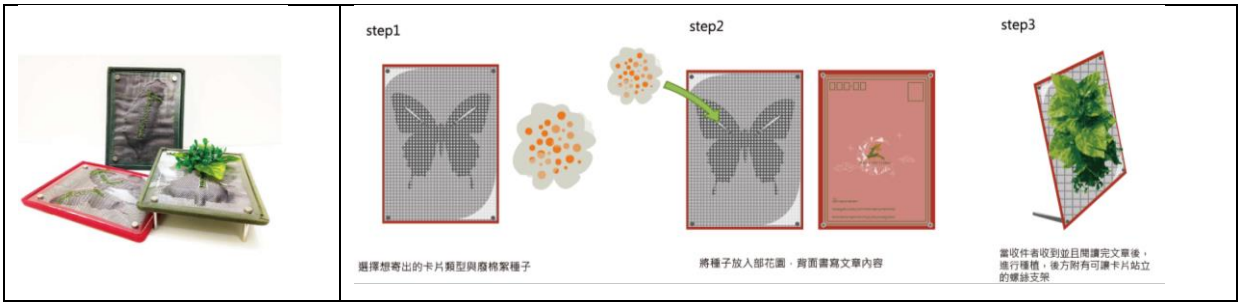


Figure 3: 'Flora Post card' Prototype

2. Thermoresponsive Placemats

The thermoresponsive Placemats was tested together with the Institute of Polymer Science and Engineering (IPSE) at the National Taiwan University (NTU). Graphic items will change their color because of the heat of the pot. The product can be placed in the dining room at home to draw children's attentions while eating or in the restaurant for wedding banquet. After the bowl be moved, some "surprise" will be found due to the thermoresponsive effect.

Figure 4: thermoresponsive Placemats

3. Rotating digital printing lantern

Rotating lantern is a customizable concept by taking the advantage of digital printing technology. Lantern is basic form but can be replaced to any other product that is good for using customized graphic and assemble the print out fabric by users' choices of product.

Figure 5: Rotating digital printing lantern

3.2 Design Explorations 2: Functional Textile + Interaction

The second group closely linked the textiles to the well-being concepts. Each of the concept may be embedded embedded in objects, worn, or carried by the user throughout everyday life, it is essential to use methods that accommodate the often unpredictable, real-world environments in which the technologies are used (Consolvo, 2007). 3 working experience prototypes were used in-situ evaluation in TTRI showroom to aid in illustrating a proof of concept. an exhibition held in TTRI showroom.

4. night light slippers	5. energy storage knee-pad	6. portable heat waist guard

Figure 6: Group A, the (Textiles+Gift) prototype

4. night light slippers

The indoor slippers made of led yarn usually have no different than any other slippers, but when put the shoes on dedicated carpet then it will trigger the switch, carpet's edge will light on as night light. When the user needs to go the toilet on unexpected situations wearing the slippers and leave the carpet, the slipper will be automatically shiny to provide the user to light up the working trail to secure his safety. Carpet will detect the power of slippers if leave outside of carpet for too long, and warning with blink to remind users to put the slippers on the carpet.

Figure 7: night light slippers

5. Energy storage knee-pad

The concept started from [electro-thermal isolation fiber] which restore walking and running energy sources and release as heating power for relieve knee and muscle discomfort, fatigue and aches after exercise. Energy can be transferred while exercising and able to enable users to achieve relaxation purposes by diastolic pressure to become heat sources, and to achieve the goal of sustainable resource.

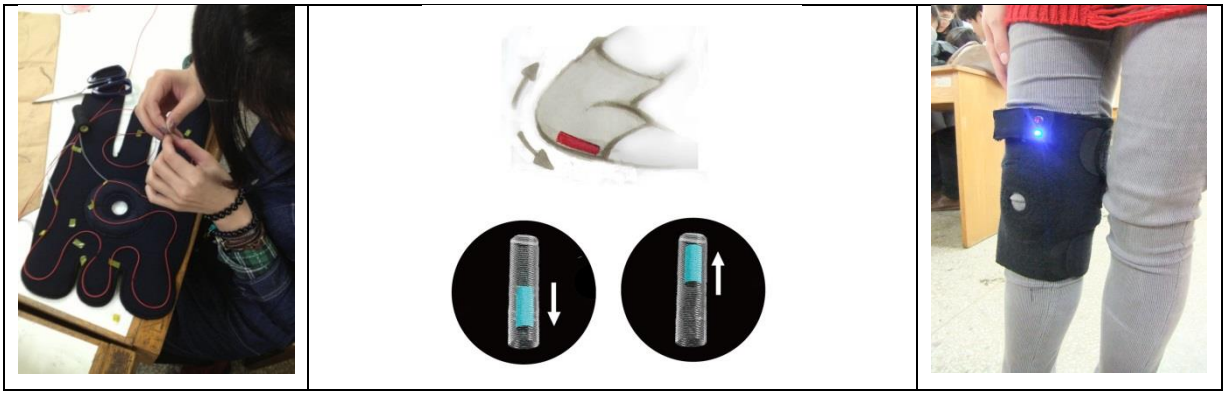


Figure 8: Energy storage knee-pad

6. portable heat waist guard

Portable heat waist guard adapted the [weaving conductive textile]. The use of textile is conductive cloth combined with a lightweight battery turbocharger which can generate heat on the waist guard wherever you go.

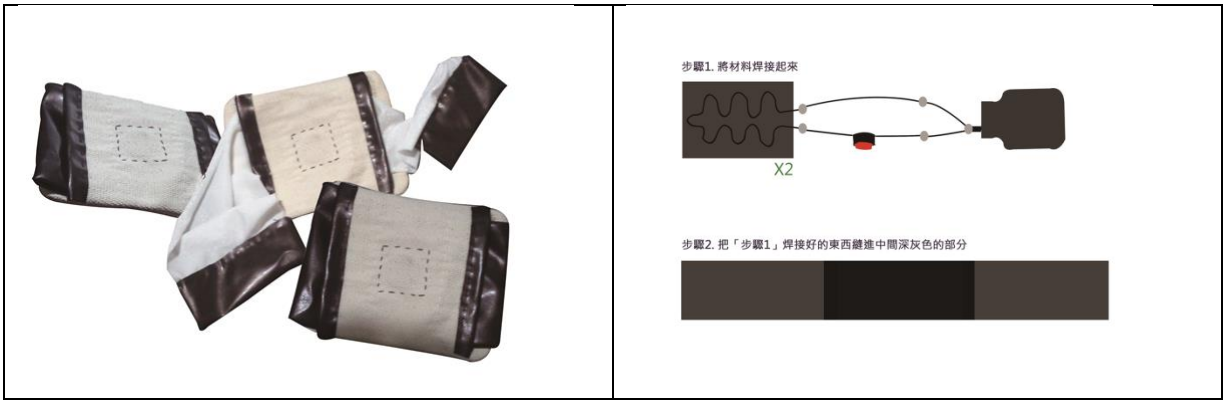


Figure 9: portable heat waist guard

3.3. Measurement Instruments:

Due to the prior evaluation from the inspiration workshop, the creativity, reliability, and aesthetics were evaluated for making working experience prototypes. In this way, we could be able to investigate the effects of the workable prototypes without involve too many impossible tasks and have better interpretation of underutilized materials and manufacturing processes.

The evaluation aimed to gain insight into the effects of functional textiles on two levels:

1. Effect of apply on interpersonal behavior. We are interest in how interpersonal behavior was affected by the use of functional textiles. We aimed at understanding what effects of functional textiles affected the dimensions of emotion.
2. Use and adoption of the functional textiles. We were interested in how the functional textiles could be properly used to provide better benefit than 3C product. Also we wanted to grasp how the design was appreciated in terms of interaction, usability, and reliability. The evaluation concerned senior users and possibilities of Patentability or technology licensing for industrialization.

3.4. Evaluation Procedures

The trial consisted of three stages but the duration varied due to the availability of the reviewers and the participants. Stage 1 (design proposals) lasted for a month, 6 experience prototypes to make selected from 12 proposals primary screening of design proposals (Table 6: Design Proposal Evaluation result). In Stage 2 (Patentability period), which last for a week approximately, 6 experience prototypes were introduced to 3 Patent Attorneys and experts for the possibilities of technology licensing for industrialization. Later, 5 out of 6 were recommended with patentability and 2 out of 5 proposals were funded to actually go on the patent application procedure. Reviewers were asked to fill out the questionnaires. The review guild included the following topics:

- Novelty
- Unique technology
- The Application potential (including authorized manufacturers and commercial value)

In Stage 3 (experimental condition), 6 prototypes remained in the exhibition and the functionality was activated. In this stage, participants allowed to try on prototypes and were interviewed and provide feedbacks.

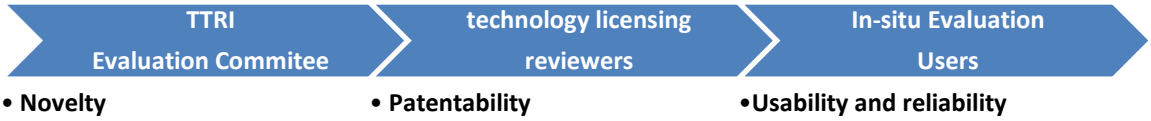


Figure 10: processes of 3 stage evaluations.

4. Results

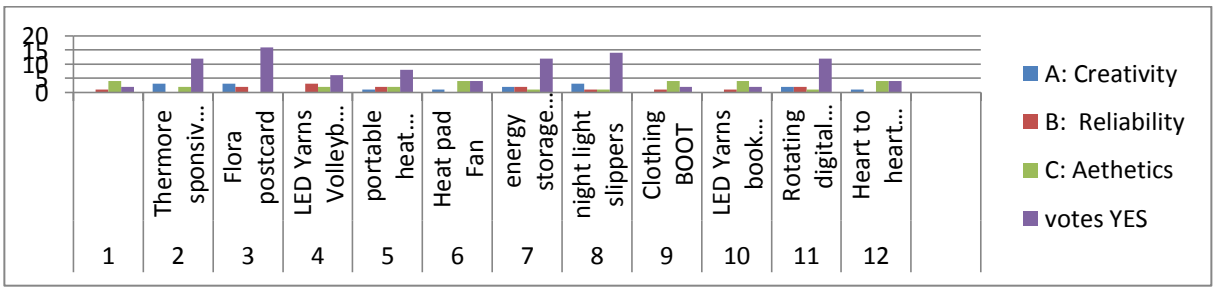


Figure 11: Average amount of rating at Stage 1

At Stage 2, In preparing an in-situ evaluation, we focus on 6 applications of functional textiles, which are 1) PET bottle recycle fiber, 2) Thermoresponsive Luminescent Electrospun Fibers'(IPSE), 3) Digital Print Lamps, 4) LED embedded Yarn', 5)electro-thermal isolation fiber', 6) weaving conductive textile') . At stage 1, 6 prototypes were evaluated and the result has shown as below. Among 6 experience prototypes, although the thermoresponsive Placemats use high-tech equipment of the Institute of Polymer Science and Engineering (IPSE) at the National Taiwan University (NTU) to inject thermoresponsive fiber, the patentability was not recommend by patent attorney due to authorized manufacturers is difficult and commercial value is low. Besides, one of the reviewers suggested the Rotating Digital Printing Lantern is lack of novelty.

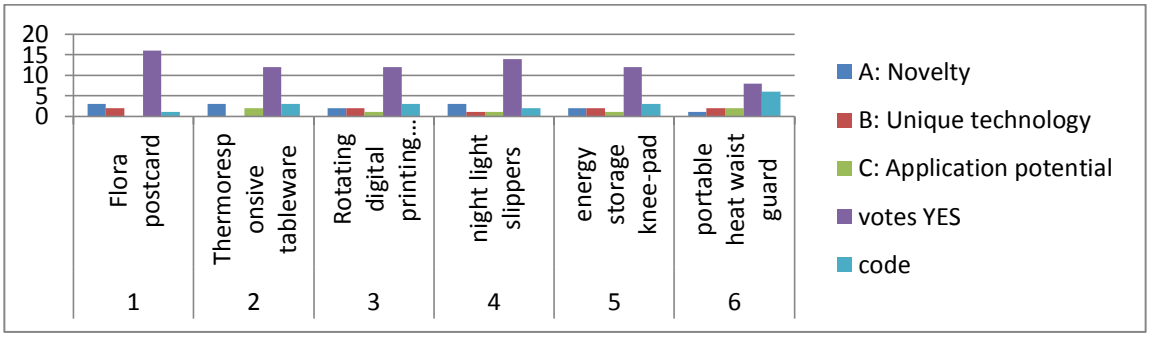


Figure 12: Experience Prototypes and the Average amount of rating at Stage 2

At Stages 3, Flora Postcard (1) and Energy Storage Knee-Pad (5) were rated as most novelty, unique technology and the application potential in daily-life is higher than the others. Night light has the most emotion and aesthetic respond; however the commercial value is low.

5. Conclusions

A challenge in the design of the functional textiles applies in daily life product motivated us to develop prototypes. This paper suggested an approach to applied functional textiles other than fashionable purpose but really serve user with its unique texture. Using this design framework was possible to purposefully design several experience prototypes. Analysis of the data showed that transformation by touching or manipulation supported aesthetics experience. The seeds will sprout to be found out what kind of plant in Flora card after watering, the absence of the invisible graphics of thermoresponsive Placemats, and unrespecting rotating of digital printing lantern. Through the design of the interpersonal behaviors with functional textiles, we learned that “transformation” could serve as behavior notification, supporting a pleasurable emotion. The well-being exploration contributed second group closely linked the textiles to the interaction concepts whether prospective users perceived hint to put back and wear the slippers or exercising to storage the energy power while doing daily activities unintentionally.

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