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The Future of Product Design Utilising Printed Electronics

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Abstract

This paper addresses the teaching of emerging technologies to design students, using 'printed electronics' as an example as it recently became viable to mass manufacture and is ready for use in designs. Printed electronics is introduced as a disruptive technology, and approaches employed in knowledge transfer to industrial/product designers is reviewed. An overview of the technology is provided; the printing processes; material properties; a comparison with conventional electronics; and product examples are identified. Two case studies illustrate approaches for knowledge transfer to student designers. The assessment criteria and design outcomes from the case study projects are reviewed and future/new approaches proposed. The paper concludes that there is a need to develop a thorough knowledge transfer strategy for printed electronics to designers, informed by case studies and extending beyond simply showing examples of existing technology. This is necessary for future proofing both in technological advances and designing for the future.

Key words

printed electronics; product design; design education; communication approaches

1. Introduction

New technologies often bring a range of opportunities within design, however, the communication of these technologies brings its own challenges. In this paper, the relatively new technology of printed electronics will be introduced within the context of product design and methodologies adopted by others is a disruptive technology of particular interest, as electronics technology is all pervasive throughout product design in 2016 and the extent to which designers need to understand such technology has been who have previously presented printed electronics technology to designers will be reviewed. Printed electronics reported in Design Education research and in Industry (Bingham, G., et al., 2015). Within printed electronics, the following areas will be presented and discussed: the printing processes used, materials and properties, comparisons to conventional electronics, and product examples. Some of the earliest printed electronics papers were published in the 1990s (Gilleo, 1990. pp. 229-234); however, it is considered a 'new' technology as it has recently emerged in a range of applications and is at a point now where the ink formulations are reproducible and therefore commercial. This allows companies and the general public to purchase electronic inks and print with them, yet the results from this exposure has been limited in the types of applications from companies and small home based projects. Two previous case studies will be presented and compared in their approaches to presenting this technology to student designers. This comparison and evaluation of the case study projects is crucial in determining the outputs/successes of previous approaches, to then move forward and determine new approaches. The concepts of future/new approaches in presenting printed electronics technology to student designers, aiming to inspire and inform, will be discussed.

2. Printed Electronics

"Printed electronics defines the printing of circuits which include various components, e.g. transistors, diodes, antennas, etc., with conductive ink on the surface of paper, cardboard or plastic, etc. Usually, the ink and surfaces to be printed can largely vary to provide tailored functions" (Coatanéa, et al. 2009, pp. 63-102).

2.1 Printing Processes used for Printed Electronics

There are five different types of printing techniques or processes used for printed electronics, these are: flexographic (like a rubber stamp, with a raised image area), inkjet (where ink droplets are produced from a distance – it doesn't come into contact with the substrate), lithographic (with hydrophobic image areas and hydrophilic non image areas), gravure (an engraved image plate), and screen (which works like a stencil).

To produce printed electronics for industry scale production, in volume, two different processes are used, 'offset/blanket cylinder' for roll-to-roll production for Lithography, Gravure, and Flexography; and a mesh 'rotary cylinder' for Screen. An impression cylinder is used in both cases which pushes the sub

Inkjet does not require any other processes for industry scale production as it works in an entirely different way, by dropping ink droplets onto a substrate, with no plate coming into contact with the substrate. The processes also offer different image resolutions and throughput due to the nature of each process, and the materials that can be used for each process.

For designing and printing electronics, the resolution of each process (Figure 1) is also essential knowledge for choosing which process is best for the job. As discussed by the Organic Electronics Association, also known as the OE-A (OE-A, 2013), the resolution for each of these processes used for printed electronics can differ greatly. The type of product and usual design manufacture choices or scale, such as if it is a one-off, mass or batch production, will also help in decision making when designers consider these options.

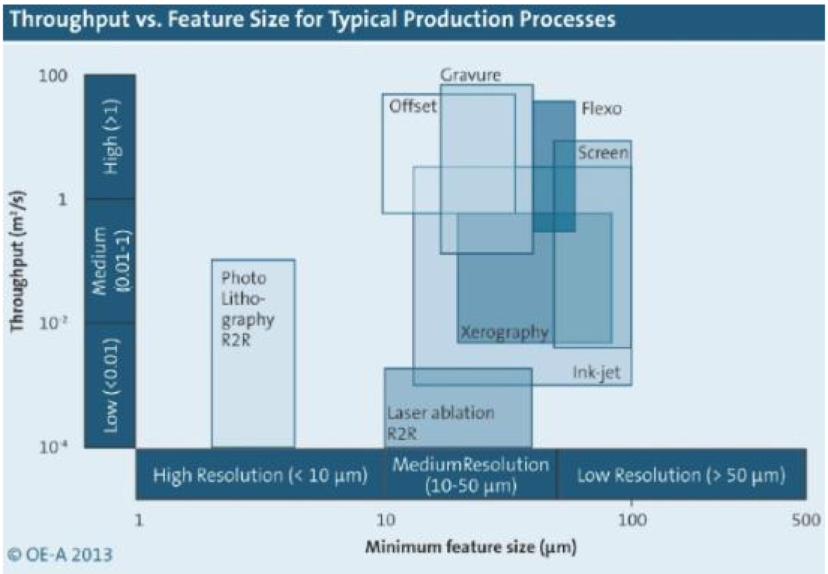

Figure 1. Resolution and throughput for a variety of processes (OE-A, 2013)

3. Comparing Printed Electronics to Conventional Electronics

Looking at a variety of economic and technological factors, discussed also by Gamota (Gamota, 2004, pp.525-529) comparing silicon electronics against printed electronics, and the reasons for choosing printed electronics can be compared and rationalised when choosing types of production and electronics (Table 1).

Table 1. Characteristics of printed electronics versus silicon electronics, and reasons for printed electronics.

	Silicon Technology	Printed Electronics
Economic Differentiation	High cost per unit area	Low-cost per unit area
	High capital in dedicated plant	Low capital flexible plant
	Large batch sizes	Manufacture on demand
Technological Differentiation	Small area products	Large area products
	Rigid substrates	Flexible substrates
	Fragile	Robust
	Fast carrier transport	Slower carrier transport
Reasons for choosing printed electronics: Functionality: Flexible Size: Super large displays (posters) Substrate: Paper film or fabric based devices Cost: Direct integration into other products Weight: Electronic paper		

More advantages for choosing printed electronics are for volume production (low cost and fast), different applications (forms, size, flexible, function) and to save on materials/environmental, minimising metal waste, compared to PCBs (Printed Circuit Boards). However, even when in favour of a particular product being produced by printed electronics over silicon technology, there are still a few typical blockers which may hinder its development, these are: inelastic markets (nobody willing to buy/demand is zero until price has decreased drastically in price e.g. RFID tags), competition from existing technology (comparisons to a silicon version) and also market infrastructure (within the creation of an infrastructure, requirements needed for standardisation) (Gamota, 2004, pp.525-529).

4. Printed Electronics Product Examples

In this section a wide variety of printed electronics product examples are examined, being selected as they demonstrate the technology's diversity and some of the unique applications this technology has been applied in and potential areas of inspiration. Within this section, six different categories are covered: 'Materials' to provide an overview of which materials are used for different components or applications; 'Populating Printed Electronics with Conventional Electronic Components' to show how conventional electronic components can be used with printed electronics with advantages of both technologies and how they can be easily removed for recycling/reusing; 'Dissolvable' to demonstrate advances in research for entire printed electronic circuits to be dissolved in water for potential medical applications; 'Encapsulating and Wearable' to show how this technology can become wearable and washable through encapsulation; 'Skin Mounted – Human/Machine Interface' to show how thin and flexible this technology can be and how it can be attached to the skins surface for use in medical monitoring applications or as a games controller by sensing vocal muscle contractions; and 'Conformable' showing the application a network of sensors inside a skullcap and how this can be used to monitor and display the severity of a blow to the head in real time for safety during sports and fitness activities.

Printed electronics are based on a combination of cost effective and large area production processes, along with new materials, organic and printed electronics open up new areas of application (Cantatore, 2013, p.2). Key advantages of organic electronics are being lightweight, environmentally sustainable, flexible and thin. They can be produced through low cost reel-to-reel processes, allowing the production of a wide range of electrical components.

Organic and printed electronics is also seen as a 'platform technology' as it often based on both inorganic printable materials and also organic semi-conducting and conducting materials; opening up new possibilities for products and applications (Cantatore, 2013, p.3).

4.1 Materials

Looking at producing organic electronics using new, large scale processes (printed electronics), semi-conducting and electronically conductive materials various applications look promising such as low cost RFID (radio-frequency identification), intelligent packaging, flexible solar cells, transponders, disposal diagnostic games or devices, rollable displays and printed batteries along with many more (Cantatore, 2013, p.2).

Organic materials are used in printed electronics for both conductors and semiconductors, for conductors, materials such as PEDOT:PSS, (PEDOT, Baytron P from Bayer AG, doped with polystyrene sulfonic acid PSS) which is a water-based conducting polymer, polyethylenedioxythiophene, (Gamota, 2004, p.25) are used for electrodes, they can be highly transparent. Progresses of PEDOT:PSS conductivity means it is becoming a realistic replacement for Indium tin Oxide (ITO) in some applications (Cantatore, 2013, pp.13-16).

Organic semiconductors materials used are ones such as poly-3-hexyl-thiophene (P3HT) and molecular semiconductor pentacene; these are both p-type materials (Cantatore, 2013, pp.13-16).

Inorganic materials are used purely for conductors such as silver and other metals, as ultra-thin films or filled pastes, are useful if a higher conductivity is needed (Cantatore, 2013, pp.13-16).

4.2 Populating Printed Electronics with Conventional Electronic Components

Populating a printed electrical interconnect circuit with conventional, silicon components can help the current printed electronics keep up to date and competitive against other products until the technology for printed components catches up. It usually consists of conventional electronic components being attached (using conductive glue or paste – like solder) onto a printed electronics circuit board, and can often offer the functionality needed for a product.

In the UK's National Physical Laboratory (NPL) researchers in the 'ReUSE project' (Treacy, 2012) have developed a circuit board that can be disassembled using hot water. The circuit is created from a combination of a printed electronic circuit (2D) and more conventional electrical components (3D). When submerged in hot water (Figure 2), after a few minutes the circuit can be removed, and the components can be gently removed off of the circuit, allowing for 90% recyclable printed circuit assembly (Figure 3).

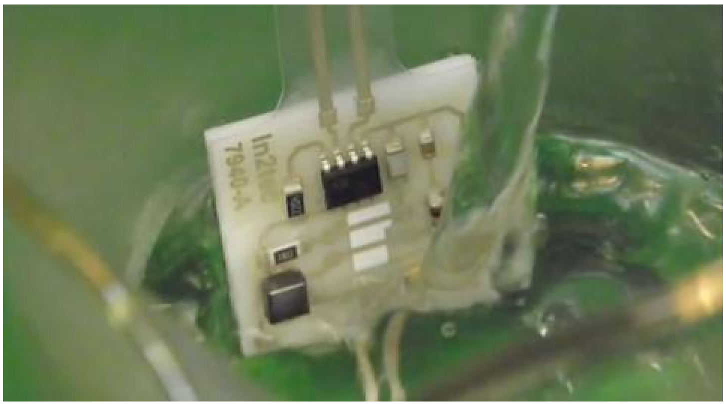

Figure 2. Submerged circuit board in hot water (Treacy, 2012)

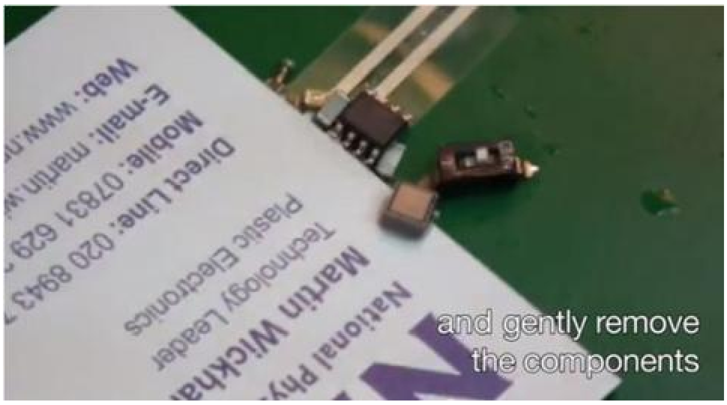

Figure 3. Removing components (Treacy, 2012)

Products such as ‘Printoo’ demonstrate how printed electronics can impact on prototyping, not just the final product, the aim to be modular and mouldable and in turn highly flexible, making this technology available to the public (Figure 4).

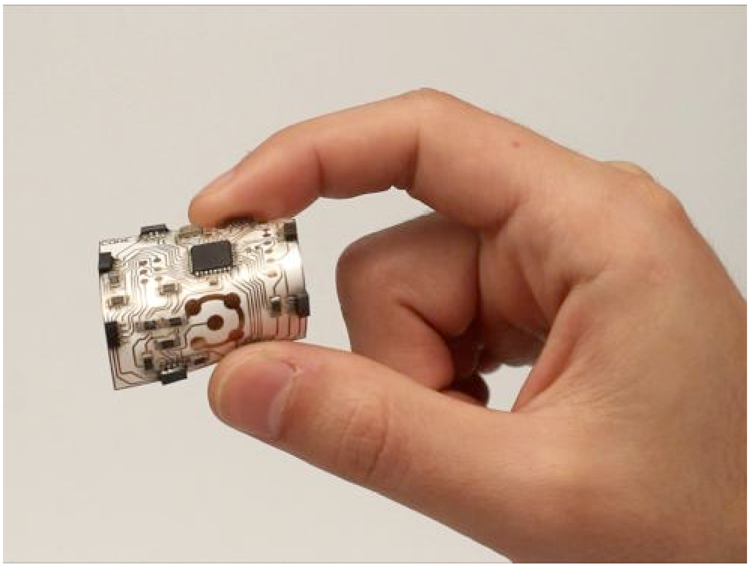

Figure 4. Printoo circuit module (Flaherty, 2014)

An example Printoo often gives for this technology is to be used in a 3D printed watercraft ‘mini ziphius’ (Figure 5), which can be controlled via Bluetooth (Newsloop Tech & Gadgets, 2014).

Ynvisible were successful in funding their Printoo Kickstarter campaign, gaining four times the amount they pledged for (Ynvisible, 2014).

Figure 5 - Printoo 3D printed watercraft ‘mini ziphius’, controlled via Bluetooth (Ynvisible, 2014) screenshot captured from their video for Kickstarter campaign

As it has a modular platform, along with the ability to create apps, to control and connect to Printoo, it opens up potential for educational applications, allowing users to build and control electronics quickly (Lomas, 2014).

4.3 Dissolvable

The work of Hwang et al. (Hwang, et al. 2012. pp. 1640-1644) shows future possibilities in the aim to achieve “systems that physically disappear at prescribed times and at controlled rates” (Hwang, et al. 2012. p. 1640), this is with the creation of a printed electronics circuit that can dissolve in deionized (DI) water or other fluids via chemical reaction (Figure 6).

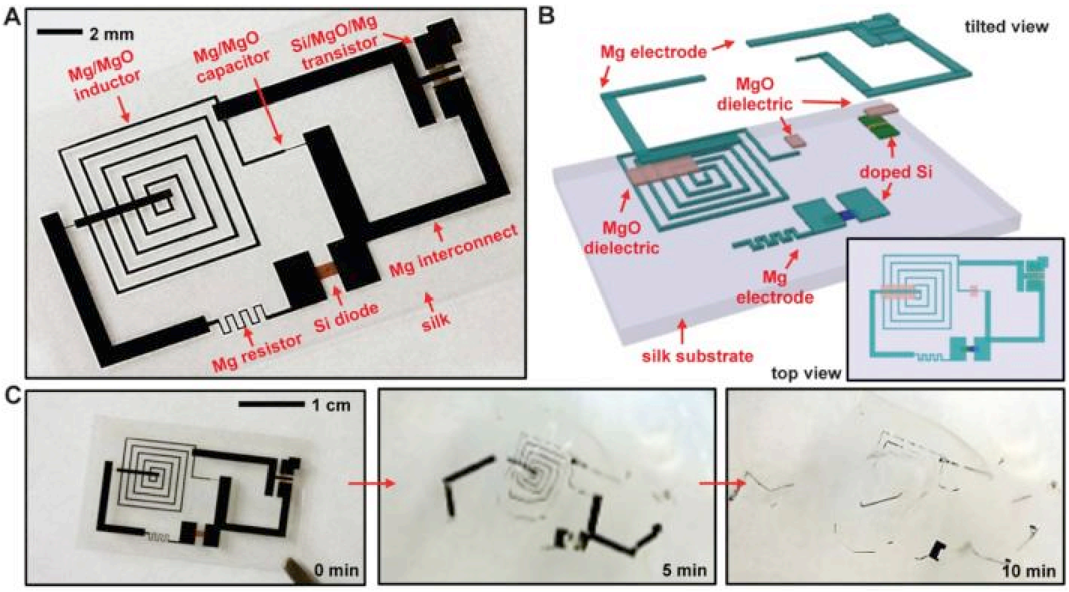

Figure 6. Demonstration platform (A), Exploded view of materials (B), Time sequence of it dissolving in deionized (DI) water (C). (Hwang, et al. 2012. p. 1640)

Printed onto a silk substrate, this demonstrates how in minutes, a circuit can dissolve, examples given are medical applications, and also “portable consumer devices that decompose to minimize the costs and health risks associated with recycling and the management of hazardous waste streams” (Hwang, et al. 2012. p. 1640), if applied in a product, the chosen lifetime before it dissolves could range from days to years. Hwang’s et al. results managed to connect “a key electrical property to models of reactive diffusion, thereby suggesting the capacity to use such analytics in conjunction with established circuit simulators as a comprehensive design approach” (Hwang, et al. 2012. p. 1642). This achievement means that the time scale of the circuit dissolving will be accurate, industrial designers designing products may not be directly involved in this process, but this accuracy and advance in this technology could open up the possibilities for a variety of new applications and products to be designed.

4.4 Encapsulating and Wearable

Materials such as DuPont's encapsulating overprints (DuPont, 2015) enables printed electronics to become wearable, for smart clothing and other wearable electronics, with stretchable, fully functioning materials (Figure 7). DuPont claims their inks can withstand up to 100 wash cycles when incorporated into clothing. DuPont suggests these materials for smart clothing, as within this application they state that it makes it "easier to design, manufacture, wash and wear…these materials can be used in common manufacturing processes to manufacture smart clothing without significant investment" (DuPont, 2015).

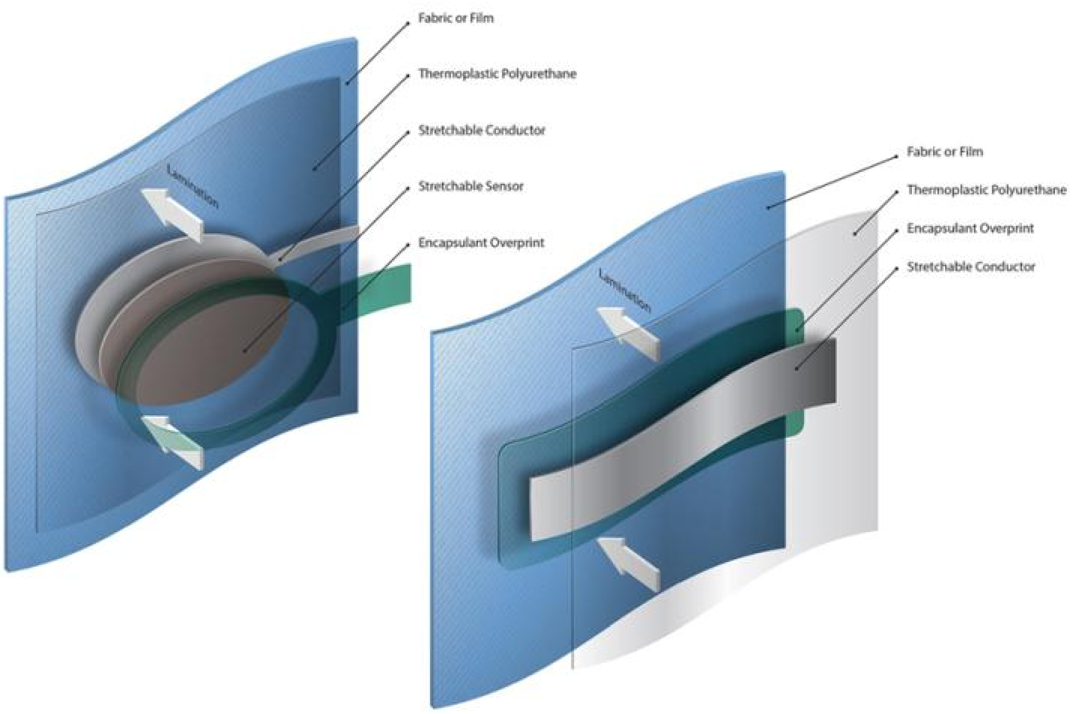

Figure 7. DuPont's wearable electronics (DuPont, 2015)

4.5 Skin Mounted – Human/Machine Interface

The Rogers Research Group (Rogers Research Group., 2015), part of Illinois University, published their work on 'epidermal electronics' in 2011 (Kim, et al. 2011. pp. 838-843). Kim's et al. work turned printed electronics into 'skin-like' membranes that conform to the skins surface, holding the same mechanical invisibility to the user as a temporary transfer tattoo (Figure 8). It is referred to as a 'epidermal electronic system' or 'EES' and it was intended for health monitoring applications by measuring brain, heart and skeletal muscles' electrical activity. The narrow interconnect lines for effective designs were formed using 'filamentary serpentine' or 'FS' shapes for better conformal contact onto the skin.

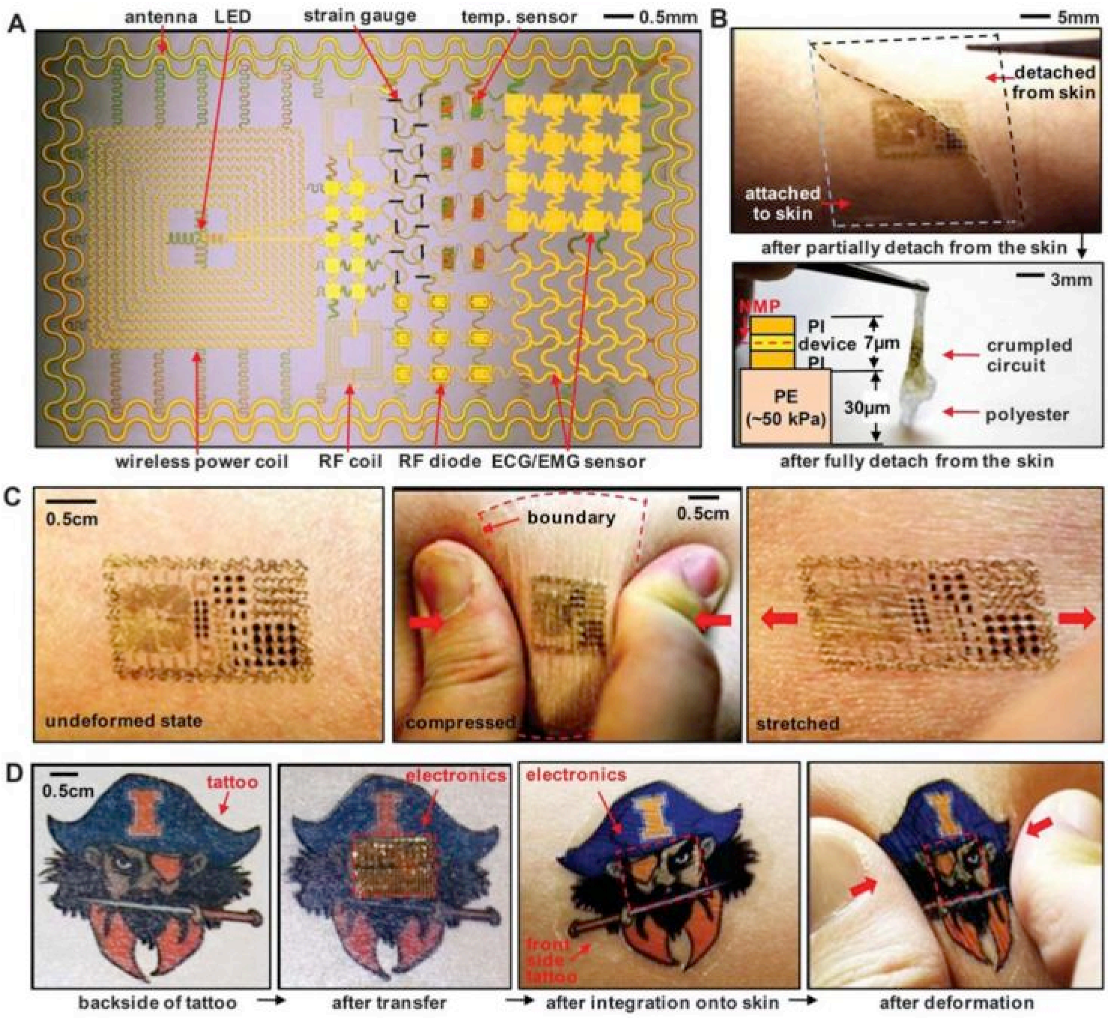

Figure 8. Epidermal Electronics (Kim, et al. 2011. pp. 839)

Adhesion is needed to attach the EES to the skins surface, a suggested application for commercialisation was for health monitoring, as it proved successful in the research, would be an alternative substrate to temporary transfer tattoos, rather than the currently used PVA or polyester. There were no signs of irritation to the skin or degradation of the device when worn for up to 24 hours on the neck, arm, forehead, chin, and cheek (Kim, et al. 2011. pp. 842). It can be used to monitor muscle contraction, it was used on the throat, noninvasively, whilst a person was talking, recording the “vocalization of four words (“up,” “down,” “left,” and “right”) repeated 10 times each…another set of words (“go,” “stop,” and “great”)” (Kim, et al. 2011. pp. 843). These words each gave distinct patterns in signals and were used in the recognition of vocabulary of words, these were then used to enable the “control of a computer strategy game” (Kim, et al. 2011. pp. 843) using the EES as the focus for a human/machine interface (Figure 9). The issues with the EES device were for long-term use; future improvements of the device would need to “accommodate the continuous efflux of dead cells from the surface of the skin and the process of transpiration” (Kim, et al. 2011. pp. 843).

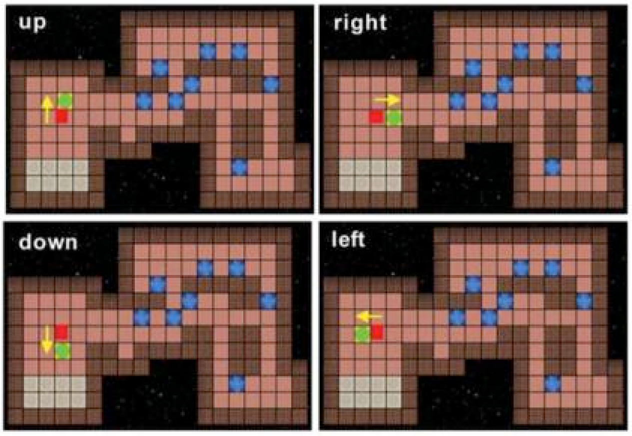

Figure 9 - EES computer game controller, human/machine interface (Kim, et al. 2011. pp. 842)

4.6 Conformable

The research related to epidermal electronic systems (EES) were also transferred from lab research and experiments to fully functioning, commercially available products through the Rogers research group's spin out company called MC10 (MC10 Inc., 2015). Professor John Rogers of the University of Illinois founded MC10 in 2008 to take the "stretchable electronics platform out of the lab and into commercial product development" (MC10 Inc., 2015). In their consumer products under sports they have developed a product with Reebok called 'Checklight' is a head impact indicator to show the severity of a blow to the head, it consists of a skullcap with a network of sensors on the inside that can be worn on its own or under a helmet during sports and fitness activities. Checklight (Reebok International, 2013) continuously measures the impacts to the head and displays a light indicator to show how many hits and how severe the impacts are in real time with a traffic light system visual cue; green shows the product is on and functioning, orange shows a moderate impact, and red shows a severe impact to the head. It is designed as a safety focused, teaching tool to be used by athletes, coaches, athletic trainers and parents. It also won the 2014 best of innovations award (Figure 14) from the International CES innovations design and engineering awards (MC10 Inc., 2014).

Figure 10. Reebok Checklight (MC10 Inc., 2014)

To conclude, these product examples of printed electronics highlight some of the existing, and future potential of this technology. Whilst some of these are still under development in labs, others have become commercially available and are already beginning to change how we design, and how products are designed with electronics, whilst optimising printed electronic technology's benefits that differ from that of conventional electronics. Product examples such as these are very important to acknowledge as they could provide us with future insights into the potential of this technology and could also spark new ideas and inspiration for future designs.

5. Case studies – Printed Electronics Previously Presented to Designers

Two case studies have been selected as they are the only published examples for this type of project: to present printed electronics technology to student designers. They offer different perspectives on the technology, and how others have previously presented it to designers using a driving brief, resulting in technology driven design. This will help to provide and understanding of how others have been successful in communicating the technology, and identify methods to successfully communicate the technology in this research.

Robson quotes Hamkin's (work in 2000) definition of secondary data analysis as being "any re-analysis of data collected by another researcher or organisation" (Robson, 2011, p.358). Whilst all existing literature is secondary data, Robson highlights its benefits in the ability to "capitalize on the efforts of others in collecting the data…allowing you to concentrate on analysis and interpretation" (Robson, 2011, p. 359) which is particularly useful with these two existing case studies/reports specifically on presenting printed electronics technology to designers. Analysing these are very important as observations can contribute towards decisions on how to successfully communicate this technology to designers. Robson provides examples of how others' work could be analysed and interpreted (Figure 11):

- *Re-analysis of case study reports*
- *Additional analyses of case study, and other reports to extend or re-assess the findings of a main report*
- *Reuse of a single data set, either to replicate the original findings, or to address different research questions*
- *Merging several years' data from a regular or repeated survey to achieve a sufficiently large sample to study a subgroup in a population*
- *Using a single data set extended by the addition of data from other sources*
- *Using multiple data sets to provide an overall assessment of findings on a topic*

Figure 11. Analysis and interpretation of others' work (Robson, 2011, p.359)

Yin describes the importance of case study research, and discusses it simply as being "like other methods, it is a way of investigating an empirical topic by following a set of desired procedures"

(Yin, 2014, p.23). Yin over the years (from 1981 to 2014) developed a 'twofold definition of case study' (Figure 12) as a research method (Yin, 2014, pp. 15-17):

1. A case study is an empirical inquiry that

- *Investigates a contemporary phenomenon (the "case") in depth and within its real-world context, especially when*
- *The boundaries between the phenomenon and context may not be clearly evident*

2. A case study inquiry

- *Copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result*
- *Relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result*
- *Benefits from prior development of theoretical propositions to guide data collection and analysis*

Figure 12. Twofold definition of case study (Yin, 2014, pp. 15-17)

This case study research will be used and provide part of a larger evaluation, as described by Yin, this would include "one or more case studies" (Yin, 2014, p.220). The case studies offer an explanation of the relationship between an initiative and its outcomes, "indicating how the initiative actually worked (or not) to produce the relevant outcomes" (Yin, 2014, p.221). Yin provides an example of case studies being used as part of a larger evaluation covering an 'innovative curriculum involving many classrooms' using case studies to "examine the specific teaching and learning processes in this smaller number of classrooms. In this manner, the case studies could shed important light on the way that the innovative curriculum had worked (or not)" (Yin, 2014, p.221).

Studying these two case studies should help to shed light on the way that the knowledge transfer of printed electronics to designers, in these two cases, had worked (or not). The aims of both projects were to produce new designs for commercialisation.

5.1 Case Study 1 – 'Enhancing Creativity and Innovation in Packaging Design with Printed Electronics' (2014)

This project was published online on the 24th September 2014, and was last updated on the 13th October 2014. 'Enhancing Creativity and Innovation in Packaging Design with Printed Electronics' was conducted by Crown Packaging, technology experts from CPI, and Brunel University London. 36 postgraduate design, innovation and branding students participated from Brunel University London (CPI, 2014).

A statement in publication on the thoughts about this technology and product designers was:

> "The integration of electronics with flexible form factors increases the freedom for product designers and will lead to the creation of a number of future interactive packaging

> applications that include lighting, sound, sensing and near field communication in their make- up" (CPI, 2014).

A later publication, on the 21st May 2015 (Packaging Europe, 2015), reporting on the same project provided a much more detailed description of what the project entailed. In the publication was a statement that read "it is predicted that the demand for active and intelligent package will reach $3.5 billion by 2017" (Packaging Europe, 2015).

The total duration of the project seemed to have been approximately 5 months long (Packaging Europe, 2015) according to the stated structure of the project illustrated below (Figure 15):

Structure of the Project:

1. One month introduction
2. Visit to CPI
3. Students were under the guidance of Crown and their mentors for 3 months to develop packaging concepts (deadline)
4. Students created presentation and storyboard for their ideas – presented to Crown and CPI representatives for initial evaluation
   - Students Gained Feedback
     - Students made changes/alterations to their designs
5. Final deadline for submission of concepts
6. Final presentations one month later at Crown's Innovation Centre
   - First half of day – students showed their concepts to Crown's R&D team
   - Crown staff used scorecards to evaluate them (See table ? for details)
   - Second half of day – formal presentations of concepts to Crown's general management who also scored using scorecards (same categories)
   - End of the day – two awards were presented:
     - Best overall idea
     - Best presentation

Figure 13. Structure of the Project – Case Study 1

5.2 Case Study 2 – 'Demonstrating the Power of Large-Area Electronics' (2015)

The project was published online on 2nd July 2015 (Large-Area Electronics, 2015), this project titled 'Demonstrating the Power of Large-Area Electronics' was conducted by the EPSRC Centre for Innovative Manufacturing in Large-Area Electronics (LAE). Technology examples were provided by six industrial partners (Cambridge Display Technology, CIT, FlexEnable, M-SOLV, PragmatIC Printing, Printed Electronics), and also working with the Centre for Process Innovation, part of the High Value Manufacturing Catapult.

48 second-year BA (Hons) Product Design students participated in the competition from Central Saint Martins – University of the Arts London.

The total duration of the project was 3 months long; concepts were presented to the EPSRC Centre and the participating industrial partners at the end of March 2015.

5.3 Criteria Comparison of Both Case Studies

A clear comparison of the criteria of both case studies (Table 2) is important for a more thorough analysis of what was asked of the students and what they were going to be judged on. The table below compares in both of the case studies: 'the brief' set for the students, 'what the students needed to consider', and the 'judging criteria' that would be used on their final designs.

Table 2. Criteria Comparison of Both Case Studies.

	Case Study 1 (Packaging Design focus)	Case Study 2 (Large-Area Electronics focus)
Brief for Students	To work in cross-functional teams to look at how printed electronics could be incorporated into metal packaging to enhance user's experience.	To incorporate numerous function LAE elements in their design ideas, to bring them together in attractive and compelling ways to illustrate functional capability and new modes of use.
What students needed to consider	Consumer point of view: •Design •Functionality	LAE elements: •Sensors •Displays •Energy harvesting •Energy storage •Lighting
	Commercial aspects: •Cost of manufacture •Potential new revenue streams	
Judging Criteria/Scorecards	Originality of their ideas	Design innovation
	The strength of the proposal based on market needs	How well the LAE elements were presented
	The suitability of the designs for actual manufacture	Commercial potential/application
	The financial benefits of the design	
	Overall quality of the team's presentation	

5.4 The Winning Designs and Finalists of Both Case Studies

Case Study 1:

The winning design was a Smart Sunscreen (Figure 15), which is a sunscreen aerosol can that identifies skin-type, sun levels, and calculates the maximum 'safe' time for the user to be in the sun (CPI, 2014). In this case study, there were no published information on any finalists.

Figure 14. Smart Sunscreen (CPI, 2014)

Case Study 2:

The winning design was 'The Waiting Ticket' by Hanako Zhang (Figure 16), a flexible wristband incorporating a display and communications to keep a customer informed of the timing of an appointment (Large-Area Electronics, 2015).

Figure 15. The Waiting Ticket (Large-Area Electronics, 2015)

The three finalists of the project (Large-Area Electronics, 2015) were:

'The Interactive Book' by Kai Lawrence, communicates information through different graphic examples of printed electronics, each of which forms a page of a book, with the technology embedded into the pages, with haptic interaction on each page to allow the user to learn through doing (Figure 17).

'Smart Step' by Qian Han, are smart insoles with built in pressure sensors and gyroscope system, which connects to an app on a phone via Bluetooth. This allows a user to track movement for sports, dance, or game applications (Figure 18).

'Nerve' by Tracy Hernandez, is a portable electronic massager using transcutaneous electrical nerve stimulation (TENS) to provide pain relief through a flexible pad that can mould to the body (Figure 19).

Figure 16 – The Interactive Book (Large-Area Electronics, 2015)

Figure 17. Smart Step (Large-Area Electronics, 2015)

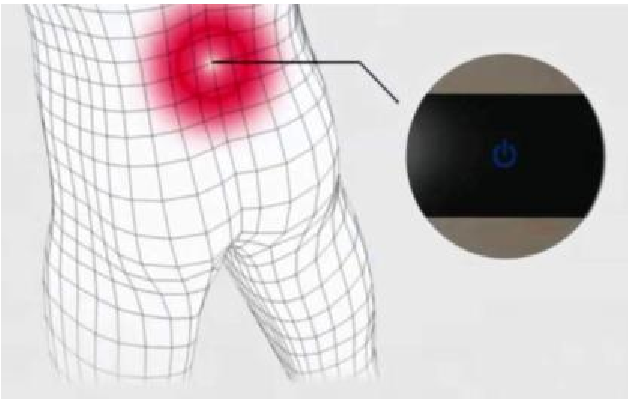

Figure 18. Nerve (Large-Area Electronics, 2015)

5.5 Student Designers' Experience of the Projects

In both of the case study projects, the designers felt that they had learnt a lot about this new technology and also more confident as a designer because of it; however, in both of these projects, the designers relied heavily on the advice of the printed electronics experts.

Case Study 1:

In this project's publications, there were no direct interviews or opinions from the designers, however others expressed their opinions on how the project had been a positive experience for the designers.

Stephen Green, the Programme Director at Brunel University London said "This project has been a great example of the value of Industry-University collaborations: Our students have gained invaluable first-hand experience of designing with emerging technologies. Through Brunel, Crown and CPI have access to a powerful resource for exploring new ideas and bringing these ideas to life to inspire further product and system development" (CPI, 2014).

Dr Cormac Neeson, the Director of External Partnerships at Crown Technology said "Crown was able to tap into the creativity and enthusiasm of the students, while also helping in their development and understanding of printed electronics and packaging manufacture and product design. We had some really great ideas, some of which we are looking to develop further" (CPI, 2014).

Dr Alan McClelland, the Commercial Manager at CPI said that this collaboration "demonstrates the importance of creative thinking and design in identifying where printed electronics can provide real added value for future packaging concepts" (CPI, 2014). "The quality of the students' ideas was excellent, it is common for students to focus solely on light or displays on packaging, but we were looking for design innovation to show us applications where printed electronics could provide sustainable benefits. This was something addressed in the concepts as well" (Packaging Europe, 2015).

One of the statements published "Participants found that the challenge offered them real consumer and industrial experience and combined both practical applications and theoretical learnings" (Packaging Europe, 2015)

In this project, the designers were under close guidance of their mentors and a company for the first three months to develop concepts. To follow were a series of presentations to evaluate the designs, followed by feedback, and the changes/alterations to be made to their designs.

This allowed for the project leaders to strongly influence the designs produce, which may have made the designers feel very constricted with their creativity towards the designs.

Case Study 2:

Hanako Zhang, winner of the competition, felt excited to work with the new technologies "When we were all briefed on this project and took the technology in our hands, I remember we were all amazed not only in its functionality, but also in its lightness and beauty. So it was exciting to think about how this technology can tie together with design to create a new kind of aesthetic" (Large-Area Electronics, 2015). Hanako added that the technology "has endless possibilities to change people's lives by simplifying things: what used to take more space or more time could be minimised drastically – and working with something like that made it a valuable learning experience" (Large-Area Electronics, 2015).

A finalist in the competition, Qian Han reflected "this project opened a new door for me…the [EPSRC Centre staff and industry partners] were very supportive. They helped me to understand how the technology works and what are the available and better [material] choices that I can use for my design. So now I am feeling more confident as a product designer" (Large-Area Electronics, 2015).

In this project, experts advised designers on which materials are "better" materials to use for their designs – this implies that designers may have been influenced/guided in what materials to use. This should really have been for to the designer to decide.

Designers need to be informed well enough about the technology so they shouldn't have to ask or feel that they need to ask, or need reassuring about their designs when implementing this technology.

Whilst working closely with printed electronics experts appeared to produce the desired outcome from a commercial point of view for the two case study projects, a sufficient knowledge transfer of printed electronics to designers is needed. In future projects, particularly in the early stages of design, a printed electronics expert may not be available for providing such close guidance for designers.

A designer will need to be equipped with a basic knowledge of the technology to fully optimise the capabilities of the technology and enhance the design of the product itself in form and function.

After studying these two projects, it is now known that without a sufficient knowledge transfer of printed electronics technology to designers, they will rely too heavily on the expert's advice, which may have a detrimental effect on the design process.

Discussions about successful approaches for presenting printed electronics technology to designers will be identified through interviews with experts who have experience in successfully presenting this technology to designers. The interview outcomes aim towards defining new approaches for presenting the technology to designers to ensure sufficient knowledge transfer.

5.6 Stated 'Future Work' from Case Studies

Both projects had a strong emphasis on commercialisation and innovation of the designs. Beyond the projects, the next steps were to create prototype demonstrators and also the commercialisation of the designs.

Case Study 1 Future work:

"Future work between CPI, Crown Packaging & Brunel University London will focus on the scale up and development of these and other ideas, accelerating the concepts to prototypes and turning them into real products" (CPI, 2014).

Alan McClelland, the Commercial Manager at CPI said "some of this exciting technology is now viable and can be demonstrated in working prototypes, however, the next challenge is developing the manufacturing processes to make these products at high volumes" (CPI, 2014).

Crown are looking to commercialise a number of the designs, putting them on store shelves in the future, also including (Packaging Europe, 2015):

Keep stock of beauty products

Interactive sports packaging

Tracking health

Convenient infant formula

The little drummer

Case Study 2 Future work:

"The EPSRC Centre plans to work with the technology providers and a product design company to make a prototype demonstrator before producing a small number of demonstrators systems. If your organisation is interested in owning a demonstrator, please contact the EPSRC Centre" (Large-Area Electronics, 2015).

6. Conclusion

The examples of printed electronics indicate the state of the art with regards to capability and the case studies demonstrate how the technology can be introduced to and applied by designers. In the two case studies, printed electronics experts worked closely with designers to produce desirable new products/applications for commercialisation. The case studies identify that both the printed electronics experts' advice along with presenting already producible printed electronic elements/examples provides the basis for communicating printed electronics technology to designers. However, this requires considerable time from a printed electronics expert(s) but provides designers with a limited view of the technology.

Whilst knowledge of which parts of the technology can currently be produced is a valuable insight for designing in the present, it does not provide a long-term perspective of the technology. To create designs for the future, designers need to be aware of the state of the art for the technology and be provided with information on areas of the technology which are still in research and development. The latter is necessary so that when these areas have been developed and are ready for production, designers will be in a position to implement and incorporate the technology into their designs.

It is also evident from these projects that a hands-on experiential approach is beneficial in increasing understanding of this technology to enhance design, as it demonstrated its ‘functionality’, ‘lightness’, and ‘beauty’ which inspired the creation of ‘a new kind of aesthetic’ in design (Large-Area Electronics, 2015).

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