# PRINTED ELECTRONICS, PRODUCT DESIGN AND THE EDUCATION OF FUTURE INDUSTRIAL DESIGNERS?

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**ABSTRACT**
The knowledge transfer of printed electronics technology to the designers of products has the potential to make a significant impact. There is a perceived lack of exposure to this emerging technology among industrial designers. It is desirable for student designers to be made aware of the opportunities such technology affords in order to enhance the design of future products. It offers a diverse range of new flexible form factors, no longer constrained by a rigid circuit board. In order to understand this disruptive emerging technology, a knowledge framework is required to support the education of student designers. This paper focuses on three essential areas of knowledge for a framework: approaches to technology readiness; techniques used for printed electronics, and a taxonomy of printed electronics. This combined information with design examples and a technology readiness grading would provide a basis for the development of understanding printed electronics. This paper concludes that a knowledge framework of printed electronics can be achieved. The translation of other fields into a taxonomy then utilised for educational innovations has previously proved successful within the context of Industrial Designers and Engineering Designers understanding the respective language of their disciplines. The overall goal of this research is to create a printed electronics taxonomy that can be used to educate student designers and enhance future product design outcomes.

*Keywords: Printed electronics, product design, industrial designers.*

## 1 INTRODUCTION

Printed electronics technology is a new but growing industry which is beginning to be integrated into product design. In the 2014 edition of the IDTechEx report, Das and Harrop [1]-predicted that “The printed, flexible and organic electronics market will be worth over $70 billion by 2024”. A section of the report identified “an urgent need for creative product design” within the printed electronics field, highlighting the significance of knowledge transfer to designers.

The significance of printed electronics has been recognised by the International Electrotechnical Commission (IEC) who set international standards and conformity assessment for all electrical, electronic and related technologies [2]. The IEC technical committee for printed electronics, called ‘TC 119’, aim to implement the, “Standardization of terminology, materials, processes, equipments, products and health/safety/environment in the field of printed electronics” [2]. However, standards have still not been defined, nor put in place and appear to be work-in-progress, but demonstrates a level of advancement for this technology.

A European Union funded project titled Technology and Design Kit for Printed Electronics (TDK4PE) started in October 2011 and ran until August 2014. The aim of this project was to develop a methodology designed to, “abstract physics to a point where engineers could address physical design with sufficient certainty and great freedom for creativity” [3]. This interest displays a level of commitment to foster creativity within the printed electronics field and support the development of a common language for printed electronics. However, the methodology utilised focused on the way that the technology was designed and manufactured as opposed to strategies to transfer knowledge to designers.

This paper reports on research in which a knowledge framework is being created to increase and support understanding in the use of printed electronics technology by product/industrial designers, including student designers. It presents an opportunity to propose avenues of investigation into this technology with a focus on the specific needs of designers.

The translation of this technology into a resource has the potential to equip designers with accessible fundamental knowledge to facilitate informed decisions about how printed electronics can be used during new product development.

The approach taken focuses on three different areas: 'approaches to technology readiness'; 'printed techniques used for printed electronics'; and 'a taxonomy of printed electronics'. This combined information will create a number of areas for the identified taxonomy of printed electronics, which currently stands as, interconnect, passive components, sensors, displays, power sources, and active components. These areas will be integrated with design examples and a technology readiness grading. This taxonomy will be used to generate tangible methods to increase understanding about the technology. This information, or the methods by which it is communicated, may also be altered for the benefit of student designers in successful understanding of this disruptive emerging technology.

Printed electronics technology has existed and been discussed for years, with some of the earliest printed electronics papers published in the early 1990s discussing the use of polymer bonding to create direct chip interconnect [4]. However, it is considered 'new' technology as it has recently started to emerge in a range of applications, and is at a point now where the ink formulations are reproducible and therefore commercial. This allows companies and also the 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 projects from the public. The extent of this technology within a product design context has not yet been explored, it seems that industrial design students have a perceived lack of exposure to this technology.

## 2 APPROACHES TO TECHNOLOGY READINESS

Identified by Engineering Research Centres [5], the Technology Readiness Level (TRL) system is used in industry to determine how close a product or piece of technology is to being commercially produced, from just a concept TRL 1 to ready for production and commercialisation TRL 9.

Mankins [6] identifies the first idea of articulating the status of a new technology was stated in 1969, with the plan for it to be used in a future space system. Combining the already established practice of the time 'flight readiness review' and the new concept of 'technology readiness review', which assessed the level of the new technologies maturity.

The National Aeronautics and Space Administration (NASA) was the first to invent the TRL system, discussed by Banke, from NASA [7], the first scale was conceived in 1974 by one of NASA's researchers, Stan Sadin, which consisted of seven levels; these were formally defined in 1989. NASA adopted a scale with nine levels in the 1990s, which then went on to gain widespread acceptance across the industry and is still used today. Makins [6] further defines this as being in 1995, when the scale was strengthened with the first definitions of each level, accompanied by examples.

TRLs were then embraced by U.S. Congress' General Accountability Office (GAO) and also adopted by the U.S. US Department of Defence (DoD), along with many other organisations considering the TRL system too. The TRL system is considered proven in being highly effective in communicating the status of new technologies; NASA's TRL system [8] is still currently used.

The Centre for Compact and Efficient Fluid Power (CCEFP) TRL system [9] which has been adapted from NASA's TRL system, differing in the language in the scale in order to create broader meaning and applicable to their terminology and technology. One example of this is in TRL 3, in NASA's system it was "Analytical and experimental critical function and/or characteristic proof-of-concept" [8], and in CCEFP's version, it is "Proof of concept research (bench scale)" [5]. CCEFP are a national science foundation engineering research centre, demonstrating how others have adapted the system to fit their own field.

An issue often noticed typically between TRL 4 and TRL 6 is the 'Valley of Death' which is between pre-competitive research and where industry is interested for commercialisation. To bridge this 'Valley of Death', designers can offer the technology an application; which often inspires industry to invest if it will boost their profile or generate revenue for their company/business, so educating designers about the technology could potentially be necessary for getting it from just a prototype to a fully working product or application which is commercially available.

As discussed by Markham [10], Bruce Merrifield first used the phrase 'Valley of Death' in 1995 when referring to the challenges of transferring agricultural technologies to Third-World countries.

A good visual example of this 'Valley of Death' is further defined by the Centre for Process Innovation (CPI), who help clients to assess the feasibility of their ideas and provide advice on how to move forward, however they define this 'Valley of Death' as between TRL 4 and TRL 7, referred to as 'The Innovation Chain' bridging the gap between academia and industry. In their business model, further definitions of exactly what they offer for universities and businesses combining a "technology push with business pull to drive forward those ideas" [11].

The Technology Strategy Board's (TSBs) [12] TRL system is a good comparison to the others as TSB are non-biased. They also look at the TRL system against funding sources, further highlighting the divide between university research and companies/industry; but looks at it positively as 'the innovation gap' rather than the 'valley of death'.

A composite table was created to easily compare existing up-to-date TRL scales from the National Aeronautics and Space Administration (NASA) [8], the Centre for Compact and Efficient Fluid Power (CCEFP) [5], the Centre for Process Innovation (CPI) [11], and the Technology Strategy Board (TSB) [12], selecting the most relevant parts to be used for a TRL scale to be adopted for this printed electronics research. The wording is critical when selecting the most appropriate for this topic as it needs to be in the right context, for example, NASA's TRL 9 definition would not be appropriate as it refers to this level as being "flight proven" [8]. In this case, this wording is only appropriate to be used within this aerospace TRL scale, as it is too specific to that field. Also in cases where the definition is the same, such as when looking at TRL 1 for both CPI and TSB, both defined as 'Basic idea', the information is used from the source that is least biased to their industry/topic, and also which is most respected/recognised to validate the decision, so in this particular case, TSB was used.

### 2.1 TRL approach adopted for this Printed Electronics Research

Using a combination of the TRL systems, considering the information and layout, a series of images were created to help relate this TRL system directly to printed electronics, which can be seen in the TRL system below (***Figure 1***). It has been created as it gives the research a greater depth of analysis, it also helps for contextualisation and to determine which TRL is related to which stage of printed electronics, and how close the technology/product is to commercialisation. Using this TRL system created for printed electronics, examples can be analysed to determine the findings and also assign the TRLs achieved in each example.

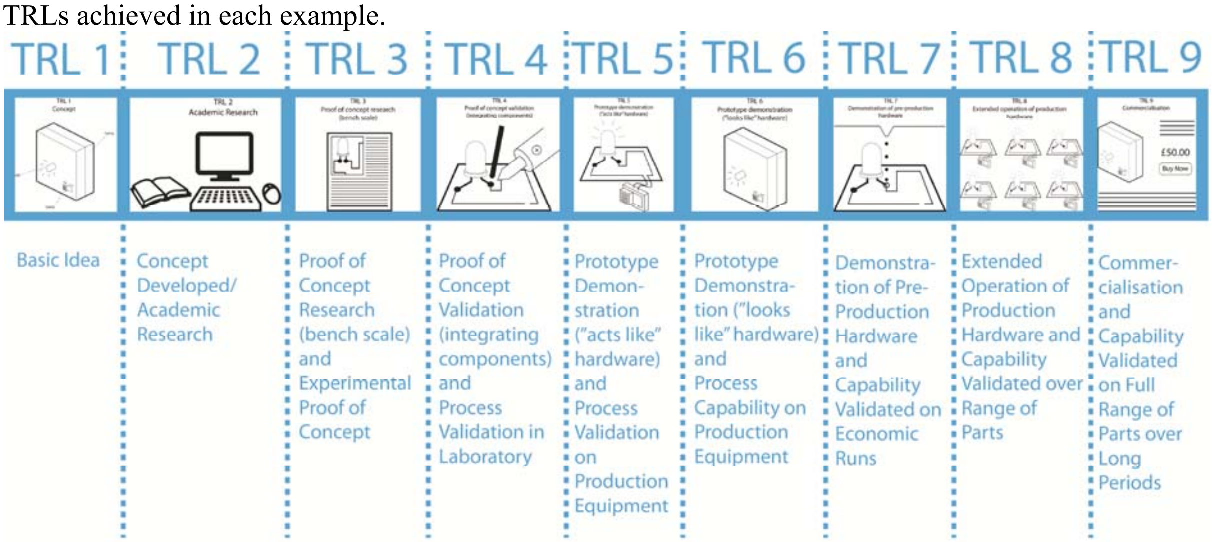


*Figure 1. TRL system for Printed Electronics*

## 3 PRINTED TECHNIQUES USED FOR PRINTED ELECTRONICS

When teaching student industrial designers about this technology, the printing techniques used for printing electronics (***Figure 2***) are important to be aware of, these are screen, gravure, flexographic, lithographic and inkjet printing, knowledge of these production processes in design can help the decision making process when it comes to manufacturing products. Knowing this in turn helps the designers to design as they can then also consider the capabilities and limitations of the production processes, and what affect that may have on the end product.

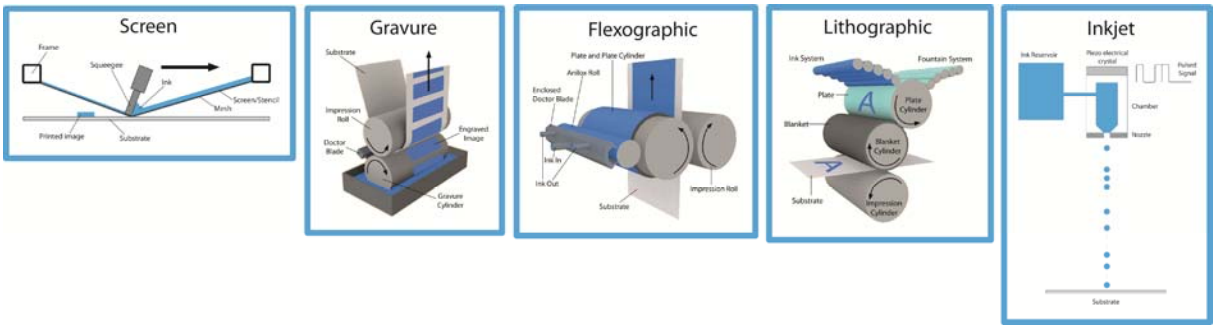


*Figure 2. Printed techniques used for printed electronics*

The process resolution and throughput are more considerations to be taken into account when making decisions, (***Figure 3***) as it is essential knowledge for choosing which process is best for the job. As discussed by the Organic Electronics Association (OE-A) [13], 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.

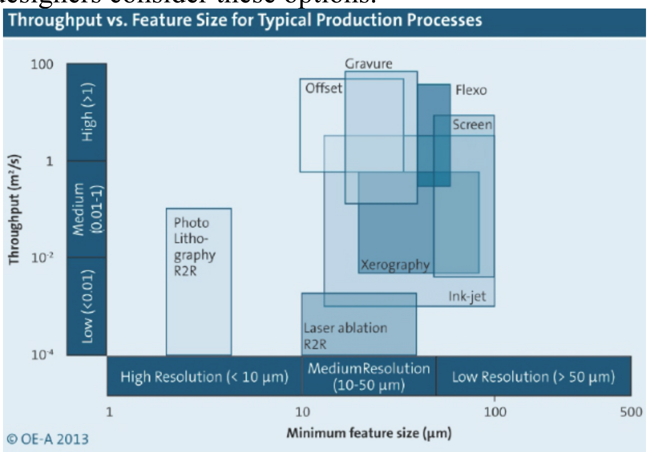


*Figure 3. Resolution and throughput for a variety of processes*

## 4 A TAXONOMY OF PRINTED ELECTRONICS

The translation of other fields into taxonomies for educational innovations for designers has previously been proved successful; such as in coding analysis when exploring complex patterns in the activity of design practitioners [14]. In Oxman's work, taxonomies were used to expand the inter-relationships between design and technology with the developments of fabrication technologies and digital design to be used to "educate designers to function as material practitioners" [15]. Others have translated information into taxonomies to be used as an educational innovation for designers, such as in Ahmed's work [16] on developing an intuitive design knowledge index for engineering designers. Pei's work on the development of a "teaching and learning tool in design education" [17] that builds a mutual language for inter-disciplinary collaboration during 'New Product Development (NPD)' between industrial designers and engineering designers achieved this by creating a taxonomy generated that comprised of "35 forms of sketches, drawings, models and prototypes" [17] when looking to bridge differences in design representations. Pei then built on this research [18] by creating a taxonomy of this information to be used by industrial designers and engineering designers in this NPD stage and then incorporated visual design representations (VDRs) creating a refined taxonomy, each image supported the definition of each taxon.

It seems possible at this point in the research to formulate a taxonomy of printed electronics. This arrives at six key areas based on the global capabilities. These six categories are Interconnect, Passive Components, Sensors, Displays, Power Sources, and Active Components; they are presented in the chronological order of their initial development. The taxonomy helps to determine the gaps in the capabilities. The order of the six areas are displayed in the chronology of evolution, for example, in order to achieve Passive Components, Interconnect must be achieved first. Active Components are

holding up the evolution of printed electronics as they are the most difficult to produce, and only a few have been achieved.
These six areas have been chosen to help the designers learn, for example, sensors are a passive component, but when designing they could be viewed as a stand-alone element to consider or incorporate into a design as it serves a defined tangible function, such as detecting temperature or gas. There are overlaps in the taxonomy, but it is aimed to transfer this topic knowledge across in a way that designers can understand and relate to.
The structure of the taxonomy begins with the six different areas, for example starting with the section ‘Interconnect’, followed by the subsection ‘Conductive Inks’, then the manufacturing processes (e.g. Screen, Gravure, Flexographic, Lithographic and Inkjet) in chronological order of when each was first used in printed electronics (using the earliest published example). Within these manufacturing processes, a range of up-to-date examples has been used in this research as evidence to determine which technology readiness level (TRL) each process has reached (***Figure 4***). Interconnect is quite a simple example to provide as it only has one subsection, and it can be manufactured through all of the printing methods and each are at technology readiness level (TRL) 9. In other sections and subsections the TRL numbers differ, and some subsections are not produced by all of the printing techniques. This information enables the researcher to determine which information is necessary to include or exclude from the information presented to the student industrial designers. This process and TRL assessment along with examples of application provides a structure for this technology when teaching.

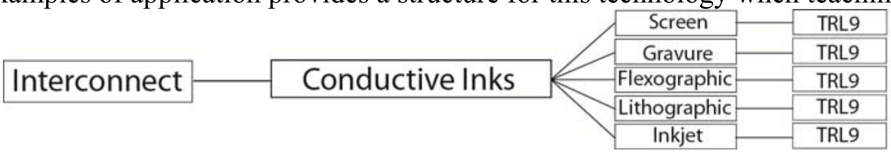


*Figure 4. Taxonomy for Interconnect section*

## 5 DISCUSSION

The work of Varekamp [19] discusses the relationship between industrial designers, and electronics. Varekamp states how industrial designers have a limited technical knowledge when it comes to the electronic domain, however they compensate by having discussions early in the design process with external electronics experts. Varekamp mentions the possibility of discussing “electronics in a “designerly” way” [19] but there are downsides to this current method of communication from designers to electronics experts as the designers use little technical terminology and it also limits the exploration of electronics, and the designer to fully design product behaviour. A need for a practical, information source to be used in design projects, by industrial designers was emphasized by Varekamp, and how industrial designers’ education still lacks the topic of the “feasibility of electronic technologies” [19]. Varekamp concludes with the goal to “empower industrial designers to change from integrating electronics to: designing integrated electronics, its product behaviour and influence on user experience” [19] by using a framework that combines “design methods and tools that facilitate communication with experts that goes further than feasibility” [19].
In devising a taxonomy of printed electronics it unveils any uncertainties within the technological capabilities. Seeing the technology mapped out in this way will hopefully help people to identify what is and is not currently possible in printed electronics. Whilst the information is displayed for ease of understanding and clarification of printed electronics capabilities, it is to be used for analysis to aid teaching, in deciding which information is appropriate to present to student industrial designers, not to be the information presented directly to them. Information presented to students would be in a different form, such as existing product examples and process diagrams to aid learning. However, when the designers have understood the technology, this taxonomy could be an advanced point of reference for them at a later stage, showing them more clearly the feasibility of printed electronics. Similar to the work of Varekamp, this taxonomy would be a feasibility framework, but communication between industrial designers and printed electronics experts would still be necessary, until a mutual language is achieved.

## 6 CONCLUSIONS

The taxonomy of printed electronics, constructed through this research, provides insights into the state of the art of this disruptive technology. These insights can inform the construction of a framework to

transfer knowledge to educators of student designers. With printed electronics ready for manufacture, this could also help alter perceptions of the technology and open up opportunities for industrial designers and the technology through the design of innovative products.
The technology has a sustainable approach to materials, and creates both form and function; this will influence future design greatly, if designers are educated about this technology. The growing range of substrates that can be printed on and used in design, such as glass and fabrics, opens further avenues for designers to explore diverse design, in quality products.

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