Should open-source technology be used in design education?

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Should Open-Source Technology be used in Design Education?

Tom Page, Loughborough University, Loughborough, UK

ABSTRACT

There has been some argument as to the legitimacy of the use of open-source technology (OST) in product design and manufacturing. Much of this has focused on intellectual property rights of the designer in the use of open-source software (OSS) and open-source hardware (OSH). Furthermore, in design education the question as to whether product design and industrial design students should learn to use open-source technology has been widely asked. This research addresses this question and considers commercial and non-commercial applications of open-source technology. The research methods comprised interviews and questionnaire survey with practicing designers and design students. The findings were analysed and discussed in relation to the growth in the application of open-source technology in commercial and educational settings.

Keywords: Design Education, Industrial Design, Open-Source Software, Open-Source Technology, Product Design

1. INTRODUCTION

There has been some argument as to the legitimacy of the use of open-source technology (OST) in industrial and product design education. Much of this debate has centred around intellectual property rights of the designer in using of open-source software (OSS) and open-source hardware (OSH). Furthermore, in design education the question as to whether industrial and product design students should learn to use open-source technology has been widely asked.

The aim of this research was to investigate whether product and industrial design students should learn to use open-source technology as part of their undergraduate studies. This work considers the recent growth in the application of OST in product design and manufacturing and its role within industrial and product design education. The objectives of this research were to:

• Chart the extent to which open-source technologies have emerged over the last 15 years;
• Identify the extent to which product development is enabling users to economically create and manufacture (some of) their own products at home;

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• Identify the extent that open-source technologies affect the accessibility of the skills and tooling required to engage in industrial and product design education in non-commercial environments.

The research methods comprised interviews and questionnaire survey with practicing designers and design students. The findings were analysed and discussed in relation to the growth in the application of open-source technology in commercial and educational settings.

2. OPEN-SOURCE SOFTWARE (OSS) AND OPEN-SOURCE HARDWARE (OSH)

The term “open-source technology” represents of two main categories of technology: open-source software and open-source hardware. Software refers to a “set of instructions executed by a computer” whilst hardware is “the physical device on which software [is executed]” (Muffatto, 2006, p. 24). The majority of software falls within application software or system software. Application software refers to the programs that a user runs on a device such Microsoft Word, iTunes, Internet Explorer, whilst system software refers to the instructions that allow the system to function such as operating systems such as Microsoft windows, Apple OS(X), BIOS, and in turn run application software. Application software is the focus of research and discussion over system software; it holds more relevance to the OS movement and product design and manufacturing. The definition becomes more complex when we include “open-source” to the title. A common definition of open-source (Weber, 2004) comprises of three main focal points: source-code is distributed with the software or made available for an equal cost; the software may be redistributed by anyone- inferring no income/fees to the author; and the software may be modified by anyone, and then redistributed under the same principle.

In essence open-source software products are generally free of charge, and have the files with their code/structure available so that they may be modified and customised (Beaver, 2004). Open-source hardware incurs unavoidable cost in materials and manufacturing and as such, the cost of this must be reimbursed. Free software is a term which many people believe is interchangeable with open-source; however, there are subtle differences as it does not necessarily refer to free-of-charge. The most important difference is that the OSS movement allows the user to modify the code, and can then publish it under a different license to make it private. Free software requires any modification of the source-code to be licensed under the GNU General Public Licence, and therefore retain its free to modify status. In the same principle as open-source software, open-source hardware must have the hardware design available; this might include printed circuit board layouts, mechanical drawings and other such product design and manufacture documentation.

The largest use of OSS is in large multinational corporations, where the larger the company the larger the use of OS seems to be (Walli, Gynn, & Von Rotz, 2005). However, this use is primarily in system software, and so does not hold huge relevance in industrial and product design education. Some users depend on OSS as much of it is free of charge, making it suitable for students and start-up companies particularly when considering the cost of many proprietary alternatives. Other users such as hackers, use open-source as a developing medium to create pioneering features to software (DiBona, Cooper, & Stone, 2006). This global network of hackers working independently in an unstructured way allows for a huge scope of development which could prove tasking for even the largest of companies to carry out and could revolutionize product design and manufacture (Weber, 2004).
Product design and manufacture is the ideation, design, development, manufacture and assembly of physical products and is conducted (unsurprisingly) predominantly by product designers and engineers. Product design itself has many disciplines: industrial, furniture, interaction and fashion (plus more), however there are others who engage in product design and manufacturing. The shift in product design and manufacturing facilities becoming more accessible to larger populations via cheaper design methods and tools is blurring the boundaries of what demands an actual product designer with artists, and those merely interested in creating interactive objects. (Page, 2014).

The prevalence of OST is very much skewed toward OSS, largely due to the different times in which OST and OSH have emerged and grown in use and popularity. Presently, the most common applications of OSS are in computer and cellular/mobile phone operating systems, particularly, in the use of Linux and Android. The other main application is in simplified operating systems for homemade electronic devices, such as those that may be found on www.sourceforge.net. Regarding the users of OSTs, sources agree that approximately 98% are male (Deek & McHugh, 2007) or that the implicit consensus is that open-source is a male-dominated environment (Agerfalk & Boldyreff, 2010). It is also regarded that the majority of current users are I.T. professionals or students (Deek and McHugh, 2007; Goldman and Gabriel, 2005) - whilst this is likely to be true, it is suspected that more recent evidence would indicate more home users (Lakhani, 2002).

With respect to the development of OSTs, OSH has been developed significantly in recent years (Rubow, 2008) and OSS may be poised for rapid growth in the future (Lerner, 2010). There is a clear link between OSH and OSS - one cannot develop without the other - and so such evidence goes hand-in-hand. This view is widely regarded in industry that the past few years have seen unprecedented growth of OSS (Lerner, 2010). However, Lerner does state that the movement has faced a number of challenges and is not without its problems, which has limited its growth in application.

Hibbetts (2013) claims that the desire to improve the world through open-source technologies is the driving force behind its rising popularity and awareness. The rise of open-source hardware companies is due to a number of cultural and technological trends, in turn creating designers who don’t just want to buy products, but have a hand in developing them (DiChristopher, 2013). These opinions should not be seen as contradictory, but as trends that drive the growth of OSTs together - aided by the rise in OSH packages becoming more widely available in consumer stores as in the case with Raspberry Pi.

Cicero (2013) elaborates on OSTs, in the emergence of several communities around specific human issues such as construction, transportation, sustainability, fabrication, furniture, and materials. This identifies a few of the possible applications for OSTs, and how they could affect daily life. He discusses the role of the product designer, stating: the designer is increasingly becoming the one that designs the process that will allow the user herself to become a final product designer (Cicero, 2013). On the other hand, LaBarre (2010) discusses open-source workshops available to teach people how to create their own products using OSTs. Research agrees that the role of the designer is set to shift, with the potential for people to make/modify their own designs at home.

The 2013 Future of Open-source Survey Results conducted from 2011 to 2013 indicated that open-source is being adopted heavily in fields including finance, energy, automotive, aerospace, government, medical, media and retail (Duck. 2013). This is an insight into how designers may end up using open-source, despite being based on 58% of respondents being non-vendors and 42% vendors. The use of OSS in industry will undoubtedly trickle down to the public for home use.

Giseburt (2012) comments on MakerBot’s statement that they no longer believe that they can have a sustainable business with OSH. Contrastingly, MakerBot® co-founder, Zach Hoeken Smith, describes this as the ‘ultimate betrayal’; believing that desktop 3D printers stemmed from
the RepRap project should remain open-source (Giseburt, 2012). Affordable 3D printers have been purchased and used by designers, and enabled them to manufacture custom objects with a few clicks. Bickel and Alexa (2013) summarise the widespread opinion that 3D printing will have a substantial effect on product development. It is expected that 3D printers will enable custom manufacturing shops to print out products more quickly; affecting user retail habits. Aside from 3D printing, evidence suggests OSTs allow for consumer development of existing products (Thompson, 2013), and is often a fraction of the cost of their proprietary counterparts (Rosenblum, 2012). OSS is however, not straightforward to use (Thompson, 2013), which could render them obsolete to many non-commercial users if this does not change.

3. RESEARCH METHODOLOGY

3.1. Research Methods Used

A questionnaire was completed by 182 participants that addressed all three research questions with the essential aim to help predict future trends for OSTs and industrial and product design. Interviews were conducted with varied demographics in an open-question, informal format to maintain that suitable outcomes and experiences were included in their answers. Interviews targeted research questions two and three which were suited to qualitative methods (Allison et al., 1996; Flick, 2007). Consideration into bias, inconsistency and misunderstanding was taken into account to maintain viable results. Unstructured interview questions allow a depth of knowledge and understanding to be perceived which may lie out of the realm of what can be achieved through structured techniques (Dillon et al., 2003; Denzin & Lincoln, 2011; Bickman, 1998) and so were chosen for this application.

3.1.1. Participant Selection

Participants were chosen based on persons who have a skillset similar to that which a product designer may possess (i.e. design or manufacture experience). Sample numbers were generated based on the rule that “a single study in a specific setting cannot [produce truth]” (Willis, 2007) and in obtaining material until reasonable comparisons could be made.

1. Organize data into units (sentences, paragraphs, etc.)
2. Associate similar units and categorize
3. Determine links/associations/relationships between the categories
4. Compare and contrast categorized evidence

Data units are generated according to relationships among sentences/paragraphs, which is largely subjective to the researcher, so the same researcher was used for consistency and validity. Categories were be compared to isolate key findings and further categorized, allowing for contradicting data to be easily contrasted. The categories were:

- **Incentives:** Motivation the participant has mentioned to become involved with open-source or product design and manufacturing activities.
- **Deterrents:** Anything mentioned that can be considered a reason not to engage in open-source or product design and manufacturing.
3.2. Research Questions

3.2.1. Question one

To what extent have open-source technologies emerged into a more mainstream agenda in the last 15 years? This question is meaningful as it may be answered (to considerable extent) with measured data, e.g. statistical analysis- indicating that the use of secondary and quantitative data is appropriate. The ability to obtain empirical results and ascertain the magnitude of the variation are characteristics of these research methods. Results that originate from sources with more time and less geographical or economic constraints in place than that for this study; and are therefore likely to provide increased accuracy, sampling and validity.

3.2.2. Question two

Is product development heading in a suitable direction to allow users to economically create and manufacture (some of) their own products at home? This question is an indirectly-meaningful question - an investigation not answerable by enquiry alone (Allison et al., 1996). Its answer is not a simple Boolean answer, and so it is important to take into account the opinions of participants for detailed answers. This identifies qualitative research as suitable over a quantitative approach. Primary and secondary research is suitable, whilst design students will be utilised due to their expertise and accessibility; however, the relevance of secondary sources such as internet articles must not be dismissed; their avant-garde status and expert authors can provide meaningful insights, and even influence the opinions of those involved with the primary research.

3.2.3. Question three

To what extent are open-source technologies affecting the accessibility of the skills and tooling required to engage in Product Design and Manufacture in a non-commercial environment? This is indirectly-meaningful - correlational research question wherein the emphasis is to discover a relationship between the two (or more) variables. The outcomes of this question are subjective and opinionated and as such require detail in order to gain meaningful data from their analyses. Qualitative research is used to obtain an answer as large quantities are not required, and the interpretation of social experiences, circumstances and perspectives of the participant is important. Salient criteria and accessibility to in-depth primary research are available (Lewis & Ritchie, 2003); thus primary research is the appropriate approach. Surveys/questionnaires are deemed non-factual (Bickman, 1998). Despite this, they have
been used with closed questions approach (Allison et al., 1996) to address objectives in these situations:

- Used to gain insights into participant OST use and context, and gauge relevant opinions. 3 surveys of 20 people of varying age groups conducted in simple random sampling technique (Allison et al., 1996);
- Online questionnaire to design students, to gauge their application of design skills outside of study to investigate independent design characteristics, with analysis to correlate independent design to OST use;
- Online questionnaire similar to above, aimed at a diverse audience (from forums, friends, family etc.) with a sample of 100 people for ease of analysis and credibility for a theoretical approach (Allison et al., 1996).

4. FINDINGS

Identification of eighteen incentives and six deterrents indicates strongly that OSTs are viewed as a sensible option compared to proprietary software- yet with the number of actions and evidence accounting for only thirteen instances each, it may be seen that despite their views on open-source the participants do not engage in it as much as expected. Whilst there is a clear focus on the benefits of OSTs, the number of negative associations is small in comparison. This showed evidence that many view OSTs as a good idea. The method of investigation: internet forums, was used as a qualitative method. Feedback from eleven participants provided suggestions and examples of uses of OSTs, whilst valuable opinions helped draw insights such as the resistance to adopt OSS in certain commercial environments.

4.1. Quantitative Data Findings

4.1.1. Product Design Participation Survey – Product and Industrial Design Students

This was aimed at obtaining nominal data to address an objective (Saunders et al., 2011) with an appropriate positivist approach (Willis, 2007). The results (as expected) show a 100% selection for industrial/product design. 95% of participants voted they are experienced in other disciplines, with 36% of correspondents also feeling they are experienced in graphic design, and each person on average voting for two disciplines.

Answers to the second question indicate minor deviation in the first four answers (career, lifestyle, and passion) of only 18%. 53 responses show an average vote of 2.4 times, indicating that the average participant considers design to be more than a career, and that it is built into their personal life in the form of a passion or lifestyle in industrial or graphic design -Question one. Two participants voted design a “chore”, indicating that the mean average participant likes their choice of study- from this result we can suggest the likelihood of participants taking part in design activities (and thus engaging with OS) on an independent basis is relatively high.

Question three proves this theory to a certain extent, with 72% of participants admitting to taking part in design activities outside those demanded by their study/career. Shows that a substantial amount of design students: 1) seem to enjoy designing, and 2) put effort into design on a non-commercial and personal level.
4.1.2. Product Design and Development in Non-Commercial Environments - Public

It is important to compare the results above to feedback from the general public in a similar positivist approach to determine if the attitude is apparent in non-designers. Only 13% of participants admitted to having a career involving any design whilst 17% and 8% possess manufacturing skills or have tried to make a product respectively, providing validation to question one and showing that some participants have past experience with design or manufacture. The key information here is that 67% of participant would like to manufacture their own products if the means were suitable - an important statistic considering the minor product design and manufacturing experience prevalent in the participants. 19% of the participants had motives other than saving time or customisation for engaging in OS product design and manufacturing- showing that the general public are keen to embrace product design and manufacturing in the home.

4.1.3. Age Range Questionnaire

The final questionnaire was replicated and dispersed to three different age categories (18-25/26-35/36+) to allow comparison and determine if the sample population has experienced growth or decline in the use of OSTs. The first Question obtained 100/50/15% of participants having used OSTs, in ascending age order. This dramatic correlation is likely to be from the result of OSTs being used in academic curriculum as 80% of 18-25 year olds had used them during study yet clearly shows their increase in use. There is an overall increase in the use of OSTs consistent throughout the results, apart from the 18-25 age-range which experiences a drop in use in commercial and personal environments possibly due to their short duration in a commercial/non-academic environment, as may be seen in Figure 1.

Figure 1. Have you used open-source hardware or software in commercial or personal use?
Question 2 asks participants if they thought that the use of OSTs has grown, with only one user in the whole study thinking it has decreased, whilst only eight participants voted that its use had stayed the same. This distinctive correlation provides ample evidence in the sample audience of the emergence of OSTs, both in real world use and perception as may be seen in Figure 2.

Results to question 3, show bias towards users using OSTs stating ‘about the same’ as they used to. However, 18 users state that they are using OSTs less than previously, compared to the 17 who use it the same amount. This figure is due largely to the vote from the 18-25 age-range, and from this result, it seems that this is more evidence for the increase in use of OSTs in academic curriculum (as these users may be likely to stop using it after their studies), and if we discount this age-range, the overall number of people who picked “the same amount” is more than those who use it less, whilst the upper age ranges indicate a higher proportion of people who think it has grown as may be seen in Figure 3.

5. DISCUSSION

The survey of design students showed a strong link between those with experience in industrial and product design and those partaking in product design and manufacturing outside of their commercial environment, reinforcing the theory possession of skills in product design and manufacturing being likely to utilise their skills outside of its necessity just in a career. A second survey for members of the public who may not have a career linked with product design and manufacturing (87% had no link) identified that if suitable methods were available then they would engage in product design and manufacturing in a home environment here 67% agreed. With

*Figure 2. Do you feel that the open-source software/hardware movement has gained popularity over time? (more than one answer applicable)*
less than one in ten respondents admitted to already making their own products (on occasion), it is a clear indication of the desired shift of product design and manufacturing into the home.

Several participants were interviewed who have a skillset related to either design or manufacture. Whilst none were as designers, the opinion that “[if you have] the skills, then you may as well use them” and admitted to using them in their personal life to produce things for themselves or family/friends. The growth of OSTs has led to increased numbers becoming actively involved with the OS community (Sowe et al., 2007) and more time and expertise being applied to the creation and development of OSTs- this is not without significant effect on the home user and proprietary software developers. OSS is allowing for commercial and non-commercial users to develop on CAD software such as LibreCAD, Blender or FreeCAD. This means that if the hardware is available, then manufacture using OSH could shift from a professional environment where proprietary CAD systems are used, to an amateur setting such as local communities or the users home where they could download and produce a product themselves. Despite open-source CAD being available, proprietary CAD is still widely regarded as superior to open-source versions, and open-source plug-ins are being utilised throughout industry to increase efficiency and cut costs.

In regards to product design and manufacturing, OSH is revolutionizing product design and manufacturing in the home. For ease of discussion, products will be defined into three categories:

- **Functional Prototypes:** Do not look like a finished product but carry out the function as intended.
- **Aesthetic Prototypes:** Look almost as a perfect finished product, but may do not function as intended.
- **Complete Products:** A combination of functional and aesthetic prototypes. It performs the function as intended whilst resembling the desired design.
Different OSH applications lend themselves to suit different types of products e.g. Arduino provides users with relatively little experience to create functional prototypes of relatively complex microcontroller programs, but lacks in its aesthetic design. Taking Arduino one step further is the Raspberry Pi, which adds functionality, power and compatibility to allow for an even broader scope of products (such as controlling household appliances to voice activated coffee machines). A step toward the Internet of Things (IoT). Functional prototypes are aided by huge online resources compiling projects which can simply be downloaded and replicated, giving the user the capability of “cloning” someone else’s project rather than buying a “proper” product, often saving money in the process.

The leading technology from the OS movement for aesthetic prototypes is clearly the 3D printing machines that form the RepRap movement- allowing the designs of 3D printers to be completely open-source, and furthermore allow many of the parts required to build a printer to be printed on another RepRap machine. The age of 3D printing is relatively new to consumers but well established commercially- helping to produce products including Boeing propulsion systems and orthodontics (Hopkinson & Dickens, 2001). One important relationship between OSH and OSS is the ability to design and manufacture a product using only OS methods. A product could be created on an OS computer system (e.g. Linux), using OS CAD (e.g. Blender) and printed on an OS machine (e.g. RepRap-Mendel), allowing for complete customisation and modification of any of the parts, programs or processes along the way.

An important aspect of the relationship between OSS and OSH is the cost factor. OSTs usually bring with them decreased costs compared to proprietary software; IBM recently stated a 23% reduction in unit cost and 90% reduction in entry cost for their products due to the combination of 3D printing, OSTs and intelligent robotics (IBM, 2013). Feller et al (2007) states that the main benefits of OS in product design and manufacturing are efficiency, quality and flexibility- In essence cheaper products, made faster, better, and with more potential. This is solid evidence of the magnitude in which OSTs may affect product design and manufacturing.

With the prominent demand for product design and manufacturing facilities in the home, users are clearly anticipating the arrival of home manufacture methods, which must be justified. Industry shows that the use of OSTs and RP methods is bringing great savings in commercial environments (IBM, 2013) (Walli et al., 2005), so it is logical for the same principal to apply to non-commercial environments. The benefits that OSTs can bring to non-commercial users in the context of product design and manufacturing are vast, but perhaps the biggest advantage and primary driving force for the emergence of the technologies is cost saving for the user. Household RP is being enforced by the OS and RepRap movement; saving the consumer money from not buying the physical product (although the plastic itself can be costly) and considering travel, time spent, and the cost of retail (wages, consumables, training, etc.).

The future may see stores shift from selling as many products in store, to selling licenses for them, allowing consumers to make them after purchasing the rights. Whilst being a negative for many companies, the environmental implications could save billions of pounds each year though decreased transport, packaging, stores etc. This could, in turn put many jobs at risk (although others would be made in other areas) from couriers, to retail workers, and the product designer. Two possible routes could dictate the impact of the effect on designers: users download and produce products; or users download, customise and produce products.

Route 1 would leave the role of the designer largely unaffected, however route 2 could leave regard for the product designer diminished, as their skills may not hold as much weight in industry as they currently do with more people possessing the skills. The role may evolve into creating platforms with the goals of user customisation, or focus more on sustainability rather than concentrating on an aesthetic. Job opportunities could arise in “micro-factories” in each town.
to provide residents with a local factory rather than every user having their own, or as “customisation companies” who can perform the process for those unable to use the OS CAD software. This possible lack of knowledge could leave some people “in the dark ages”, particularly with older generations who may struggle to adapt. The change would take many years to implement but whilst only 48% of questionnaire participants found shopping a chore there are likely to be people who would still require the retail experience. Those with a good understanding may still encounter problems- one major downfall of OSTs. Whilst proprietary software has dedicated support (an important asset in a commercial environment), OS help remains an online help community of self-appointed experts- this can yield helpful answers, but it not as convenient or structured as picking up the phone.

Customisation and development of the OS products is a vital aspect. If manufacturing facilities became commonplace in households, then the number of people with the ability to modify and develop the code will rise. This would possibly turn everyday users into a “global developments team” to improve the designs- resulting in rapid development of not just the product, but of the manufacturing methods themselves, especially when there is the ability for a product to replicate itself a limitless amount of times. The ability to create completely customised products provides an almost novelty-appeal, but there is already a huge market for aesthetic customisation, and when consumers are able to perform it affordably themselves, the aesthetics of products may soon change completely. 57% of correspondents in a questionnaire indicated that they would find product customisation appealing.

Differences between OS and proprietary software could create difficulty if a student has grown up accustomed to OSS, however as many design packages function in a similar way, skills can usually be transferred between them to ensure quick adaptation. Whilst in its current stages, product design and manufacturing in a non-commercial environment is limited and only viable in certain circumstances, this is not likely to be the case for long. Continuous developments in manufacturing methods and an ever expanding community of OS developers (Sowe et al., 2007) means that the rate at which advancements in home manufacture are occurring is likely to increase.

The “trickle down” phenomenon that occurs with most technologies will eventually result in affordable, small footprint machinery that can create products to match the quality of today’s industrial spec machinery. Tremendous benefits include a reduction in outsourced manufacturing facilities although it is probable that high volume products will still be created using traditional methods with significantly increased sustainable factors, and dramatically slashed waiting times for products, as well as no more “out of stock” products.

In the true spirit of open-source, home design and manufacturing may well allow for the modification and improvement of products by the user themselves. Instead of putting up with a design flaw, the user could simply replace the part or tailor the design to their needs, and share it with others. This could well develop into consumers who take on the task of creating their own products from scratch, and then marketing the design to others to make revenue for themselves. A potential drawback however is the number of copyright and registered design infringements; the users more capable in CAD could easily copy designs, and then go on to distribute them in an illegal manner. This level is cybercrime would have to result in internet security policies being severely revamped in order to prevent cyber-theft of designs, and yet would probably never be completely fool-proof.

Competitive brands price points could easily be levelled significantly due to the realisation from consumers that they should be able to print a similar product for a similar price, and may not take into account the level of development etc. that went into the design. The question “what will happen to brand image if competing products can be produced at home for equal cost (the cost of materials)?” must be asked. This could well open up the opportunity for the less affluent
to indulge in products they could not previously afford, or create their own extremely high quality items to supplement their hobbies and daily lives in replacement of common brands, once an OS template of a device is produced. However, in the same heartbeat, it opens the envelope of development for companies to produce never before seen products (such as Koenigsegg’s recent 3D printed titanium exhaust (Bengtson, 2014)) with higher quality and larger machines than available to consumers.

6. CONCLUSION

The emerging agenda of OS has been quantified and proved based on research into user habits and company reports in evidence concurrent with the opinion of Rubow (2008) and Lerner (2010) as a result predominantly of the cost savings and increased personal gain it can bring. With this emerging agenda growth into non-commercial area’s as well as public sectors has been proven, and in turn increased awareness of how OSTs may affect their lifestyle in a positive manner, as suggested by Hibbetts (2013). There is a strong connection with the OS movement and product design and manufacturing in the home environment, which has seen significant growth and media exposure in recent years. The OS movements effect on product design and manufacturing is significant, especially when considering the cost of OS alternative to home manufacturing methods, and the ease of being able to replicate premium products with relatively simple packages. It is noted that an increase in product design and manufacturing in the home environment may have significant repercussions on the retail industry, and in particular the manufacture of batch manufactured products; resulting in a shift in the sectors of employment- declines in some areas such as retail staff, but increases in areas such as personalisation companies.

This increase however, will almost certainly boost the level of understanding of basic electronics and product design and manufacturing in younger generations whilst encouraging extracurricular activity in the form of creating prototypes etc., giving increased job prospects, personal satisfaction, and a generation more suitably equipped to carry out the ever-more complicated task of research and discovery (particularly in technological circumstances. Huge variation on products may occur as users begin to customise existing products and tailor OS designs their specific needs, which may pose hurdles for brands who could struggle to enforce a unique selling point in their products. These hurdles could significantly diminish the value of many brands- where products could be replicated to look like another product, or technology could be cloned and modified to suit the user.

In light of the findings, it is predicted that the shift of product design and manufacturing will be a slow process, with an early emphasis on novelty aspects such as product customisation- whilst the long term incentive could develop a generation more adequately equipped for industry and suitably skilled to tackle the ever-more complicated technical challenges presenting themselves in product innovation. It is not expected for this shift to remain 100% open-source, however, a distinct proportion of OS developers is likely to have a significant effect on the overall direction of the technologies and incentives for users to become part of the open-source community.

The predominant limitations of this work relate to the emerging and largely unrecorded nature of the relationship between OS and product design and manufacturing. A lack of substantial research material has limited insights and created a somewhat blunt area of discussion, whilst more resources could have resulted in a much larger research sample to obtain an increase in insights and more room for debate. As OS and product design and manufacturing is in very early stages, there are few people who are actually partaking in the practices. This results in a narrow basis on which to approach the discussion, but on the contrary allowed for expanded and extensive research into related areas.
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Tom Page’s background is in electro-optics development and production and worked for Ferranti Defence Systems Ltd. in Edinburgh. In 1990, he took up a two-year fixed-term research assistantship at the Engineering Design Research Centre in Glasgow. Upon completion of this role, he taught Computer-Aided Engineering at the University of Hertfordshire in Hatfield. Since moving to Loughborough University in 2003, Tom has taught electronic product design, interaction design, design and manufacturing technology and physical computing. His research interests are in engineering design, value management, technology education and electronic product design. Tom’s work has been widely published in the form of journal papers, book contributions, refereed proceedings, refereed conference papers and technical papers. He has supervised research students, examined PhDs and MPhils and has acted on the reviewing panel of a number of key journals and conferences.
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