Aug 11th, 12:00 AM

The inherent value of design research for industry: An impact case study using low-cost 3D printing for high-value commercial products

Blair Kuys
Swinburne University of Technology, Australia

Mark Strachan
Swinburne University of Technology, Australia

Follow this and additional works at: <https://dl.designresearchsociety.org/drs-conference-papers>

Citation

Kuys, B., and Strachan, M. (2020) The inherent value of design research for industry: An impact case study using low-cost 3D printing for high-value commercial products, in Boess, S., Cheung, M. and Cain, R. (eds.), *Synergy - DRS International Conference 2020*, 11-14 August, Held online. <https://doi.org/10.21606/drs.2020.204>

This Research Paper is brought to you for free and open access by the Conference Proceedings at DRS Digital Library. It has been accepted for inclusion in DRS Biennial Conference Series by an authorized administrator of DRS Digital Library. For more information, please contact DL@designresearchsociety.org.

The inherent value of design research for industry: An impact case study using low-cost 3D printing for high-value commercial products

Blair KUYS^{a*}, Mark STRACHAN^a

^a Swinburne University of Technology, Australia

* Corresponding author e-mail: bkuys@swin.edu.au

doi: <https://doi.org/10.21606/drs.2020.204>

Abstract: Often published literature in design research explores theoretical content to advance the way we look at a design discipline but in Australia, it rarely bridges the gap between scholarly work done within a university and design work done for industry. There is an overwhelming sense of importance put towards industry-university engagement in Australia to improve funding mechanisms for research within universities, but also to ensure the research being done has impact for industry. This paper details a successful impact case study, which utilised the professional skills of a design team within a university to successfully tackle a challenging commercial project. By operating within a research framework, the gap between research theory, research practice and the generation of high-value outcomes has been bridged with demonstrable impact.

Keywords: industry-university engagement; low-cost 3d printing; research-led practice; industrial design

1. Introduction

This paper refers to a successful product development team within an Australian university that established a program based on 'academic research-led industrial design practice'. Over the past five years (2015–2019), the team has attracted significant commercial interest, achieving a 300 per cent annual project growth and earning more than \$AUD4.5 million in industry-linked research income. The team's fast-growing industry base could be characterised as 'Small to Medium Enterprise's (SMEs) with big ideas' – the Australian business sector arguably most in need of professional design support. This diverse industry base includes, for example, suppliers of veterinary smart-device services, polycarbonate glazing systems, elite athlete injury recovery solutions, kitchenware, and Australia's first fire-rated skylight. For this paper, one successful example of a project is shown in detail to illustrate the approach taken to conduct research within a university context to generate

This work is licensed under a
Creative Commons Attribution-NonCommercial 4.0 International License.

profitable commercial outcomes for the company. The impact case study within this paper explains the design process adopted by a product development research team within a university to develop a range of commercial track-mounted downlights, which utilised low-cost 3D printing as the commercial outcome.

The Australian SME sector often struggles to gain access to professional product design services, particularly a service that targets genuine innovation (IBISWorld Industry Report OD5443, 2018). The university product development research program has presented a clear economic advantage to this important group by providing a product design service that is comprehensive, targets innovation and is accessible. The design strategy challenges pre-existing design boundaries and draws broadly on the university's intra-faculty knowledge resources. In this regard, the team's design service targets product innovation — much needed in the Australian SME sector — rather than the incremental design upgrades often realised by conventional commercial design.

Roos and Kennedy (2014) in their book “Global perspectives on achieving success in high and low-cost operating environments”, show there is substantial evidence for design-led innovation as an enabler for the success of SMEs within high-growth environments. A chapter within their book by Bucolo and Wrigley (Chapter 9, 2014), show that businesses that may have been exposed to the concept of design previously at a product level are now seeking to better understand its value through implementation at a strategic level offering.

From an economic impact perspective, there is a general perception that design only delivers economic value for the design industry. However, there is proof that design has a high economic impact in non-design-led industries and how mistaken this assumption is (Micheli, 2014).

In a report from Micheli, 2014, he describes three key statistics showing estimated business growth for the UK when engaging with design as follows:

- Design increases turnover: For every £1 invested in design, businesses can expect over £20 in increased revenues
- Design is linked to profit: For every £1 invested in design, businesses can expect over £4 increase in net operating profit
- Design boosts exports: For every £1 invested in design, businesses can expect a return of over £5 in increased exports (Micheli, 2014)

2. Method

Developing commercial products through design practice has been around for centuries. Using design practice as a method to conduct design research and generate research funding to a university is however relatively new. Koskinen et al. (2011) note “design practice provides methods” (p. 23) and in particular when designing with specific cliental — as demonstrated in the case study described in this paper — research methods such as prototyping or general experiments with the material is a valuable way of gaining knowledge.

The 1990's and 2000's saw the growth of 'generative' research methods that put design practice at the core of the research process (Koskinen et al., 2011, p. 23). However, these methods did not always translate into a commercially viable product outcome. Dorst (2008) argues that design research should refocus its attention and enrich academic design research by working on a deep and systematic understanding of the 'design object', the 'designer' and the 'design context'. This statement is used in conjunction with the research aim to help legitimise the case study by promoting the designer, the design context and most importantly the physical manifestations of research-led practice in scholarly design research; with a direct focus on a new contribution to knowledge that is accessible to industry.

In the simplified version of the traditional supply chain, designers are the precursor to production. The roles and responsibilities between design and production are well established and clearly delineated. Petrick (2013) states that in the 3D printing world (a primary focus of this paper), these roles have become blurred and the notion of who is a designer is called into question, as anyone with the ability to use CAD tools can create 'designed' products to be printed. This is true, however, not everyone can design products that have the extant commercial value that people will pay money for. There is a distinct difference between a 3D printed product and a 3D printed commercial product. As various 3D printers require expertise in file preparation, the CAD designer becomes an important part of the design process. The following research impact case study details the changed role of the designer; having to obtain the traditional skills of an industrial designer such as sketching and prototyping, while taking on modern skills in CAD/CAM that are constantly evolving with the rapid growth in additive manufacturing technologies. By necessity, the modern industrial designer needs to acquire both traditional skills for the initial imagination of a product, as well as modern technical skills to translate a clever/smart concept into a physical commercial outcome. The project took 11-months in total; from the initial project meeting through to the actual product launch. Initially, the team was divided into groups – one investigating the 3D printing technology and the design of the lights; and the other, investigating the engineering aspects of the 3D printing material and the development of a suitable heatsink. This was the fundamental research that led the design process described in detail within the following section.

3. Research Impact Case Study

The following case study describes research conducted within a university context that leads to a range of commercial products for the company. Significant research at the beginning of the project was required to frame a direction both the company and the research team agreed on. This is termed 'research-led design practice', where the research is used to direct the design process. It is noted that R&D departments within the industrial sector could also do this, however, in an Australian context, a large majority of companies are SME's where time, funding and capabilities are not always apparent to undergo the 'front-end' research required for successful product development.

This is where a university with personnel skilled in both rigorous research and professional practice can assist to alleviate the pressures of industry to work together on commercial product development.

At the beginning, it was as simple as a SME approaching the university wanting to improve their product range but did not know how to undertake the innovation process to accomplish this. The company concerned is classified as 'small' in relation to a SME, employing around 10 permanent staff and predominantly focused on commercial lighting based on imported componentry and localised assembly. The company had rarely engaged with design before and approached the university for assistance after visiting the university and being introduced to the research team. Initial conversations provided a reality check by highlighting the cost of introducing new products and the associated capital investment involved in the tooling set-up costs for injection moulded plastic parts. From a new product development perspective this is well understood by the research team as a large majority of products designed by this team require injection moulding. The company was shocked by the typical costs involved and reluctant to invest in tooling for a new product range – particularly one that didn't have a proven market. The discussions moved from injection moulding to the disruptive alternatives of additive manufacturing where product can be produced on demand and where there are many efficiency gains including eliminating the need to hold large inventories of components (Ghobadian et al., 2018). From this, the project was then framed around using 3D printing as the potential process for a new range of lighting. Consequently, the project brief was broad and unconstrained presenting more flexibility and the potential for infinite design outcomes within a given physical envelope. Nevertheless, this comes with a significant level of risk as in the early stages of the project the potential final outcomes were not realised. 3D printing is a fast, agile and cheaper method for testing new designs and can easily multiply the product range, however, there was very little precedence of low-cost 3D printers being used for large scale commercial outcomes.

Based in an industrial area of Melbourne, Australia, the company is a lighting manufacturer specialising in energy-efficient commercial lighting. Prior to 2015, the company focussed on simple geometry folded-metal and imported injection-moulded plastic luminaires – predominantly from China. The company CEO along with the research team workshoped and conceptualised a significant shift from this line: a LED track-lighting system featuring 3D-printed plastic housings and advanced electronics. While the conceptualised range presented a huge market advantage, two hurdles stood in its way: 3D printing as a commercial production mode was largely unproven, and the advanced electronics demanded particularly high levels of cooling. These two critical areas that needed development formed the design research criteria from the beginning of the project and are detailed in the design process below:

4. Design Process

4.1 Research

Research concentrated on 3D printers and plastic materials with an emphasis on the capabilities and capacity of low-cost additive 3D printers. Comparative trials and full thermal analysis of the cooling requirements were undertaken in conjunction with the research and development of the heatsink. Figure 1 shows an example of research conducted on low-cost Fuse Deposition Modelling (FDM) 3D printers. A total of 19 low-cost FDM 3D printers were reviewed and trialled primarily to establish an understanding of the quality, reliability, cost and speed of printing. In addition, five reviews were also undertaken of low-cost Stereolithography Apparatus (SLA) 3D printers to determine the most suitable 3D print method for this project.

IMAGE	MODEL	PRODUCTS SIZE (W D H)	BUILD VOLUME (W D H)	SUPPORTED MATERIALS	MAX RESOLUTION	APPROX COST
MakerBot Replicator 2, G5	528 x 441 x 410 mm	252 x 199 x 150 mm Not heated	PLA	0.1 mm	\$5,450.00
MakerBot Replicator z18	493 x 565 x 854 mm	305 x 305 x 457 mm Not heated	PLA	0.1 mm	\$11,500.00
MakerBot Replicator 2X	490 x 320 x 531 mm	246 x 152 x 155 mm Heated	PLA & ABS	0.1 mm	\$4,568.00
CreatBot DE Series	NOT GIVEN	400 x 300 x 300 mm Heated	PLA, ABS, PVA, HIPS, Nylon, Laywood, Laybrick	0.4 mm	\$7000.00
UP BOX	485 x 520 x 495 mm	255 x 205 x 205 mm Heated	ABS & PLA	0.1 to 0.4 mm	\$3,000.00

Figure 1 An example of research conducted on low-cost FDM 3D printers.

For this project, access to a wide range of 3D printers supported by the university was invaluable for the front-end research to determine the most effective 3D printing methods for this application. This is another area worth highlighting where a university can play an important role in R&D by providing a large equipment capability that most SME's would not usually have access to. From a design perspective, the project was one of the most unique projects the team have worked on. The idea of using low-cost 3D printers for commercial production appeared to be both implausible and challenging. Such challenges as understanding the limitations with 3D printing and the engineering characteristics of the printed outcome; comparing and identifying the best materials to meet the technical and thermal specifications of the LED source, and; the design of a heatsink that not only functions according to the LED specifications, but can also be utilised across all of the designs were the biggest challenges.

Minimising the printing time was crucial as this method of production is presently much slower than other processes such as injection moulding. This is where the research into efficient production using low-cost 3D printing was vital for the commercial success of the project. Extensive research was carried out on currently available FDM machines while also anticipating new capabilities from established suppliers. A key focus was the printing process itself, with a detailed analysis of the fusing method as the polymer material is bonded together layer by layer on the build platform. Details such as overhangs cannot be printed in 'thin-air' and require support material made up of a lattice scaffolding to allow complex geometries to be printed. This, however, requires more material and slows down the print time for each part. Minimising the printed support material was a high priority so as not to jeopardise the final design by optimising the print quality and minimising the amount of post-print finishing required (removal of the lattice). This necessitated the careful configuration of the product on the print bed to reduce overhangs, minimise the lattice scaffold, and ultimately speed-up the print time.

Another key component of the 'front-end' research was reverse engineering existing track downlights to understand the componentry required in the new products. Reverse engineering is a method of disassembling existing products to better understand their construction and manufacture. There are a number of approaches to re-engineering (Chikofsky and Cross, 1990) (Eilam, 2005) (Kuys et al., 2009) but for the purpose of this project, the primary focus was an analytical process of observation and documentation used to ensure the newly developed products would function correctly and ensure the heat generated from the LED could dissipate throughout the heatsink.

Figure 2 Two of many photos showing the reverse engineering of existing track downlights used to better understand the internal componentry.

4.2 Concept Development and Refinement

The design process during the concept development stage was predicated on exploring organic forms and the development of shapes that could not be reproduced using conventional manufacturing techniques. All of the 'front-end' research for the project had to be adapted to the creative minds of the design team to come up with distinctive designs that both distinguished themselves in comparison to what was currently on the market

and competing at a similar price point. A direct quote from a member of the design team speaking of the design challenges is as follows:

“I ... had to think counteractively. We nearly always design parts which do not have undercuts (injection moulding), can be machined or extruded without even thinking about it. It's become such a part of our mental process that to break that mould within our own thinking was a struggle.”

Figure 3 *Early concept sketches trying to ‘break’ the mind-set of designing for injection moulding. Free-flowing organic shapes were promoted and prototypes were used to review with the company.*

Figure 4 *An example of one concept pushing the boundaries of organic 3D CAD modelling and exploiting the capabilities of 3D printing over injection moulding.*

After the design team pushed past their natural tendency to design componentry by complying to established constraints for injection moulding, they generated 10 concepts for presentation. The concepts were reviewed, scored and evaluated in terms of time of print, amount of material used, aesthetics, market potential and ease of assembly. The company committed to take five to production. Once these concepts were selected, this then presented another design challenge – refining the highly creative selected concepts to an appropriate level that would be optimised for printing on target FDM low-cost 3D printers, while keeping their original characteristics. The orientation of the product on the print bed

not only affected the speed of print, but more importantly it affected the quality of print. This is because FDM printing is done in layers and when a curvaceous surface is orientated incorrectly on the print bed it results in an unacceptably rough surface that is clearly visible (see Figure 5). Thin wall sections invariably failed on some prints and support material in some cavities was very difficult to remove. An extensive series of test prints was completed to better understand the limitations of the low-cost 3D printers. While this was replicated to some extent in the earlier stages of the research, it was now being done for a specific design and build context. This maturing understanding was vital in achieving the grade of the 3D printing to ensure a desirable quality of product.

Figure 5 An example of a poor-quality 3D print finish occurring from the layering process on curvaceous surfaces. This is avoided by reorienting the product on the print bed.

The team recognised the need to standardise the testing procedures and create sample 3D prints as a basis to ensure consistent and fair comparisons across all low-end 3D printers. CAD sample cubes and spheres were created with various features such as different wall thicknesses, extruded and embossed details and curvaceous surfaces to better determine some design constraints. These CAD shapes were then 3D printed and formed design guidelines during the refinement stage of all selected concepts. Rigor was required to ensure comparable and reproducible test results in similar environmental conditions. The tests proved to be a valuable exercise in identifying and setting the print orientation for final products to minimise support material, speed-up print times and maximise the surface quality of the prints (see Figures 6, 7, 8 and 9).

Figure 6 The CAD development of sample cubes used to better understand low-cost 3D printing capabilities.

Figure 7 3D printed sample cubes showing varying wall-thicknesses and intricate details.

Figure 8 The CAD development of sample spheres used to better understand low-cost 3D printing capabilities with a focus on curvaceous forms.

Figure 9 3D printed sample spheres showing varying wall-thicknesses and intricate details.

While research was being conducted on 3D printing capabilities to help inform the design refinement, the engineering team were developing a unique heatsink specific to accommodate the LED light source and associated electronics. This is where product design engineers are a valuable asset to a product development research team by understanding

the design process supported by engineering rigor. This allows fluid discussion between the industrial designers and product design engineers to minimise the chances of the innovative features being 'engineered-out' of the final products. An example of this is seen within the development of the heatsink which consisted of curved fins at the end of each linear section. Here, the effective dispersal of the heat without affecting the surrounding polymer housing is critical. Figure 10 shows Finite Element Analysis (FEA) of a standard heatsink to understand the distribution of heat throughout the total surface area and to dissipate heat more effectively. Figure 11 shows CAD refinement that ensured design features were not eliminated. Figure 12 shows an example of the research and development to manufacture a proof-of-concept heatsink for testing, and Figure 13 shows the final heatsink prototype led by the industrial designers and refined by the product design engineers.

Figure 10 FEA conducted on a standard heatsink to understand the distribution of heat throughout the total surface area.

Figure 11 CAD refinement of the heatsink showing the advanced design details.

CNC MACHINING

Using Swinburne University's state of the art DMG MORI 5 axis CNC machine centre, we were to prototype multiple heat sink's for the purpose of testing.

HEAT SINK POST CNC MACHINING

Cutting the machined heat sink off the billet post machining, using a BROBO cold saw.

HEAT SINK POST CNC MACHINING

Separated heat sink.

ALTERNATIVE HEAT SINK DESIGN PROTOTYPE

Although the main hole required to join the two halves of the heat sink together were machined and tapped using the CNC machine centre, some holes required manual tapping.

Figure 12 Production of the aluminium heatsink before committing to a full extrusion system.

Figure 13 The first aluminium machined heatsink used as a proof-of-concept for validating the 3D printed lights.

While the engineering team were refining the heat-sink, the industrial design team were advancing the visual concepts. The ability to create photo-realistic imagery was important for the company to better understand what the final products would look like. These concepts were then printed and evaluated between the product development team and the company on a weekly basis.

Figure 14 3D rendering showing the final product along with the assembly process.

Figure 15 A 3D printed example showing the complex geometries possible with a low-cost 3D printer.

The development also benefitted from regular engagement with the company throughout the project. The company could readily assess and evaluate progress by engaging directly with the tangible realities through all the critical stages of the development, which led to a design outcome that was not a surprise to the company.

4.3 Design Outcome

The end result was an entire new range of high-end, production ready, light features designed by the university-based research team that benefitted from regular involvement

and feedback from the company. The company's track-lighting range, comprising five unique designs shows how research can inform decisions concerning the design process; and by default, informing practice of 'research-led industrial design practice'. This example shows how design teams can think more strategically about identifying opportunities for companies that are forced to diversify/innovate their product portfolio due to rapidly changing economic environments. This is typical for SME's who do not have much experience in innovation processes and engaging with designers. Many SME's have limited resources which means any innovation collaboration needs to build on existing organisational capabilities. A direct quote from the company helps validate the impact this research has had for his company:

"Without the [university] team this range simply wouldn't have occurred. We are very excited about the product range, its 3D printing production advantages and its great export potential."

In summary the final five 3D printed track downlights are made from ABS, a plastic common for 3D printing and costs on average \$AUD70 per spool of material (800 grams of material). Depending on the design, the research team were able to print between 4–10 lights per spool of material as shown in Table 1.

Table 1. Manufacturing comparison of material usage, print time and amount of prints per spool for the 5 lights chosen to go into production.

Light Design
Amount of material used	76 grams	137 grams	104 grams	185 grams	182 grams
Print time	11:20 hours	23 hours	15 hours	20 hours	29 hours
Light housings per spool	10	5	7	4	4

While clearly more expensive than the raw cost of an injection moulded part, it is the capital investment required at the front end of the manufacturing process that is avoided in this situation. Comparable costs for injection moulded parts could be 10–20 cents per part in raw material, however, the tooling set-up for each light would be around \$AUD30,000–50,000 up-front investment. While this investment would be amortised across the production run, there is no guarantee the final product will be successful. Crucially, it would avoid a large

investment in tooling for mass-production with a risk of an unpopular design languishing on the shelf – with 3D printing it is ‘print to order’. And that is exactly what the company is doing. When an order is received, printing can occur immediately, but moreover the key benefit is having 3D printers running overnight. As shown in Table 1, the longest print time for one light is 29-hours. By utilising the 3D printers overnight, a large proportion of the print time occurs when the company is closed – once again maximising efficiencies and helping SMEs stay responsive to global markets.

Another benefit of directly using 3D printing for commercial outcomes is the ability to create unique designs that are impossible to produce by any other manufacturing process. 3D printing allows complex geometries to be created and unlike injection moulding, undercuts within the products are not a problem. The layering process of 3D printing allows for multiple walls and intricate details on alternating planes, whereas with injection moulding all designs must conform to a two (or multiple)-part mould in order for the injection moulded part to be released. While injection moulding can have dual cores and sliders to allow more complex geometries, it adds significantly to the tool costs creating even higher risks that if the product is not successful, the return on investment will rapidly diminish especially where low volumes of production are concerned. Even with these advancements in tooling for injection moulded parts, the geometries created for the 3D printer’s equivalents are so complex, they are physically impossible to produce with injection moulding, or any other manufacturing process available. This presents a truly unique offering by using clever design and expert CAD modelling, with an advanced understanding of 3D printing to create products that are exclusive to the company and cannot be replicated by any other means. This strategy reduces risk and the anxiety associated with being committed to a limited range of injection moulded products that involves considerable upfront investment and the subsequent costly storage of multiple component parts (Clarke & Mia, 2004). While the complex geometries can be potentially copied to replicate the designs, there is no real advantage to whoever is copying the design. This is because minimal labour is involved and the cost of 3D printing and materials is similar no matter where you are in the world.

Further flexibility and competitive advantage can be gained through the use of colour. The colours available in the current range of Zortrax 3D printers (preferred printer for this project) currently consists of blue, sky-blue, android green, green, orange, cool-grey, pure white, pure black, red, warm grey and yellow. However, the company has worked with the material supplier to have batches of unique colours made to their own specification on mass so, hypothetically, they can print the lights in any colour they want or to suit the bespoke needs of customers. This range of products has the ‘smarts’ within the designs and not the manufacturing. The five initial designs created for this project are used to introduce the product range; however, the research team created another five follow-up designs ready to expand the range when required. This highlights the value of design in creating a family of products that can be readily introduced into the market by the company when they identify or recognise an opportunity. This advantage means the company can be first in the marketplace with new and unique product ahead of any conventional competitors.

This underlines the potential of this responsive agile approach that can provide Australian manufacturers with significant competitive advantages. This is all achieved while expensive capital investments in tooling is eliminated and production inventories are kept to a minimum.

Figure 16 The final products developed for the Australian SME – 3D printed track downlights.

Figure 17 Left: The final 3D printed light at the production facility – showing an impressive surface finish for a low-cost 3D printed part due to the significant research done on 3D printing. Right: The final aluminium extruded heatsink. Designed to be consistent across all designs and docked to length as required.

Figure 18. A detail photograph of the final 3D printed product with an anodised heatsink.

Figure 19. The final product installed and operating.

5. Discussion

Published literature on 3D printing is often dedicated to the specifics of 3D printing technologies such as speed, quality of print, materials and improvements in the scaffolding (support material) (Bak, 2003). In particular, it is dominated by literature that focuses on 3D printing in the medical industry with applications such as bone tissue engineering and bone substitute implants, however, these are mainly focused on high-end titanium metal 3D

printers (Bogue, 2013). There is minimal research on how low-cost (AUD\$3,000–\$6,000) 3D printers can be used to advance company innovation by using this low-cost manufacturing for commercial outcomes. In some cases, the published literature actually discounts this. In a statement from Wohlers Associates in an article by Bak (2003), Wohlers states, “Rapid manufacturing is the direct production of finished goods from a rapid prototyping device.” This definition suggests that true rapid manufacturing systems are those that employ additive processes to deliver finished goods directly from digital data, eliminating all tooling. Such systems, Wohlers says, do not currently exist, although he acknowledges that conventional rapid prototyping systems are being successfully applied to produce low-volume end-use parts. The challenge, he notes, is to merge rapid prototyping capabilities with the high-volume throughput traditionally associated with manufacturing applications. This impact case study acknowledges the issue of high-volume production but, by contrast, illustrates how rapid prototyping can be used in a different way to create commercially viable products. Rather than use rapid prototyping for mass-produced parts, it is used for complex parts that cannot be replicated by any other manufacturing process. It also illustrates how a small company can avoid the high start-up costs of production and help ‘test’ the market before committing to large scale injection moulding production.

The article from Bak (2003) is dated and in a field that has significantly advanced in the past 16 years, it shows the importance of this paper by providing a real-world commercial industry project using low-cost 3D printing to advance company innovation. More importantly it shows the results of a profitable outcome using sophisticated design and a thorough understanding of 3D printing to ensure commercial viability. An advantage of 3D printing is the rapid advancement in technology. The costs of 3D printers are continually going down while at the same time the quality and speed are both going up. An example of this is the HP Jet Fusion 3D printer (introduced in 2017), which utilises a new powder printing technology. While currently expensive (AUD\$400,000), this is arguably the biggest innovation in 3D printing in the past 10-years advancing beyond SLA, Selective Laser Sintering (SLS) and FDM, due to significantly faster print times, quality, and material options.

In the dated article from Bak (2003), Wohlers Associates states: “For Rapid Prototyping to better penetrate new markets, a number of changes must occur. Machines must become less expensive to buy and easier to use and maintain. System prices and the overall cost of ownership must drop further and materials must improve. Furthermore, new machines and applications must develop to support the production of finished manufactured parts, versus models and prototypes.” It can be argued that with this project, a great deal of the concerns mentioned in 2003 have been addressed. 3D printing machines are much more affordable than 10 years ago. The quality has improved significantly and the cost of material is cheaper, however, it is the application of this technology for projects of commercial merit that is still lacking. 3D printers are only as good as the CAD operator and the design team who understand how to design end-products specifically for 3D printing.

Projects such as this are beneficial to both the university with an ever-growing expectation for industry income, as well as the company to help expand their product range with minimal

investment. In the context of Australian manufacturing, which is suffering from the decline of the automotive sector, innovation needs to focus on products with maximum profit and minimal investment. While not possible for all products, in the lighting industry this is ideal. Rarely do we look directly at lights when installed. They are either too high, mounted in the ceiling or when they are on they are too bright to look directly at. This is what sparked the idea to develop low-cost 3D printing methods for the commercial finish of the exterior housing of track-lighting – a product that is high-value in the lighting industry; a product that requires significant design resolution to stand out from the competitive products; and a product that doesn't necessarily require a perfect 'injection-moulded' exterior finish. This helps businesses be agile and responsive. By working closely with a university, the company have access to state-of-the art equipment which in this case was a wide-range of 3D printers, as well as in-depth research capabilities. There was significant research and development undertaken for this project which this paper cannot do justice, however the aim of this paper is to promote a research-led industrial design project done within the framework of a university. It aims to inform other research-intensive organisations to adapt to new forms of research output (non-traditional research output or NTRO) and promote the impact the research can produce.

The impact of this form of research-led design engagement highlights how SMEs can be helped with the development of new products. It can generate greater reward for those organisations that want to innovate but do not have a specific product direction. In this case, the research-led industrial design team within the university understood the difficulties faced by an SME to invest in new designs, leading them to consider low-cost 3D printing to propose some new products. In 3D printing the design team could foresee a fast, agile and cheaper method for testing new designs and multiplying the range. Indeed, such research-led design and the adoption of such additive manufacturing technologies could be considered the zenith of the JIT 'Just-in-time' management philosophy. A situation where a company's competitiveness is substantially strengthened by minimising waste, improving product quality and maximising production efficiency (Ghobadian et al., 2018).

6. Conclusion

The research and development team involved in this project was led by a professor of design with advanced knowledge in industry-university engagement and new product development. For this project, he was supported by members of his research team consisting of three industrial designers and two product design engineers. Like most product development it's rarely done in isolation and is most successful when done in teams. This can be said for industry engaged research where the research lead is taken by the research active academic, while having a supporting network of commercial designers to ensure the research translates into an outcome that satisfies the company. Using the research to influence the design team has created a unique value proposition within the university because the company is exposed to thorough academic research, has the use of university equipment and receives an outcome with true commercial potential.

The comprehensive nature of these services, particularly the on-campus prototyping and testing, has proven hugely attractive to industry. Most importantly, the research team has been able to realise the fast timelines and responsiveness demanded within a commercial consulting environment. This is something that university teams and the systems within a university need to adapt to. Examples such as procurement of equipment, purchasing of goods and ethics reviews where applicable all need to work faster. Before forming this research group, certain processes within the university took longer to execute than many of the projects themselves. The fast-nature of such commercial ventures require industry-university engagements to be agile and adaptive, and not be inhibited by cumbersome university systems that do not work in the company's favour.

For the project presented in this paper it is not suggested that 3D printing will replace injection moulding especially where high-volume production is concerned. This paper presents a case for developing and introducing new products for a SME that has not previously engaged with design or research services. The approach taken has minimal up-front investment and directly results in reducing risk. The biggest issue for new product development for most companies (especially SMEs) is the risk associated with upfront investment and exposure to an unpredictable market. Usually new products incur large up-front expense when taking a conceptual idea through to a manufactured product. The research program reduced this risk by producing a comprehensive collection of both traditional and non-traditional research output to inform the commercial design outcome. Traditional peer-reviewed academic publications have focussed on the analysis of the working practices and processes. In this domain, scholarly design theory is tested, and the very nature, limitations and potential of research-led industrial design is explored. The program's non-traditional research output manifests in the form of each project's final product or service; an artefact that embodies new design knowledge developed over the course of the research-led design process.

The company these products were designed for now employs a full-time member of staff dedicated to the 3D printing aspects of the business and they currently have over 30 low-cost 3D printers – with a business model to support at least 100 3D printers as the first product range matures. The printers are now running 24 hours a day which is the beauty of 3D printing. When an order comes in the 3D printer starts printing – it runs overnight and the next morning the light housing is removed from the FDM print bed, support material cleaned off, the product assembled, packaged and ready to send to the company. The following quote from the company CEO highlights the importance of this project to their business:

“We expect the number of lights being printed to build up to a couple of thousand a month at least.”

The relationship between the product development team within the university and the lighting company continues and a second project using low-cost 3D printing for a commercial range of pendant lights has just been completed. This shows confidence in the company's willingness to further engage with the university and build from the knowledge created in

the first project to further advance the product offerings – Australian designed and Australian made products competing in the global marketplace.

7. References

- Bak, D. (2003). Rapid prototyping or rapid production? 3D printing processes move industry towards the latter. *Assembly Automation*, Vol. 23 Issue: 4, pp.340–345.
- Bogue, R. (2013) 3D printing: the dawn of a new era in manufacturing? *Assembly Automation*, Vol. 33 Issue: 4, pp.307–311.
- Chikofsky, E., Cross, J. (1990). Reverse Engineering and Design Recovery: A Taxonomy. *IEEE Software*. V 7, Issue 1. P13–17. DOI: 10.1109/52.43044.
- Clarke, B., & Mia, L. (2004). JIT Manufacturing Systems: Use and Application in Australia. *International Journal of Operations & Production Management*.
- Dorst, K. (2011). The core of ‘design thinking’ and its application. *Design Studies*. 32 (6), Pages 521–532.
- Eilam, E. (2005). *Reversing: Secrets of Reverse Engineering*. Wiley Publishing Inc. ISBN: 10: 0-7645-7481-7.
- Ghobadian, A., Talavera, I., Bhattacharya, A., Kumar, V., Garza-Reyes, J. A., & O’Regan, N. (2018). Examining legitimatisation of additive manufacturing in the interplay between innovation, lean manufacturing and sustainability. *International Journal of Production Economics*. <http://doi.org/10.1016/j.ijpe.2018.06.001>.
- IBIS World Industry Report OD5443 (2018). Industrial Design Services in Australia. December 2018.
- Koskinen, I., Zimmerman, J., Binder, T., Redstrom, J. and Wensveen, S. (2011). *Design Research Through Practice. From the lab, field, and showroom*. ISBN: 978-0-12-385502-2. Elsevier.
- Kuys, B., Anderson, L., Jackson, S. and Melles, G. (2009). Reverse engineering: a formative method of research. *International Association of Societies of Design Research (IASDR)*. Seoul, South Korea.
- Micheli, P. (2014). *Leading Business by Design. Why and how business leaders invest in design*. Warwick Business School and Design Council. UK. January 2014.
- Mueller-Vollmer, K. and Messling, M. (2017). Wilhelm von Humboldt, *The Stanford Encyclopedia of Philosophy* (Spring 2017 Edition), Edward N. Zalta (ed.).
- Petrack, I. J. and Simpson, T. W. (2013). 3D Printing Disrupts Manufacturing: How Economies of One Create New Rules of Competition, *Research-Technology Management*, 56:6, 12–16.
- Roos, G., Kennedy, N. (2014). *Global perspectives on achieving success in high and low cost operating environments*. ISSN: 2327-3429; eISSN: 2327-3437. 2014. Wohlers Associates (2017) (www.wohlersassociates.com). Accessed 02/11/17.

About the Authors:

Professor Blair Kuys is the current director of Swinburne University’s Centre for Design Innovation. He has extensive experience in product development and a strong track-record in industry-university engagement. Over the past 6-years he has signed over 30 industry-university research projects to the value of \$AUD6.2M.

Mark Strachan is a passionate designer and educator committed to interdisciplinary, collaborative design and strategic development. His expertise draws upon over 35 years in industry, academia and consultancy where he has extensive experience in systems, services and product design & development.