Design research units and small to medium enterprises (SMEs): an approach for advancing technology and competitive strength in Australia

Introduction

Small to medium enterprises (SMEs) are a particular kind of business with specific sets of material and financial constraints. These constraints become explicit when SMEs attempt to innovate and adapt to new technological situations. Often SMEs are not resourced in a way that enables them to adequately explore the possibilities of a new technology through research and development. While SMEs are ideally positioned to exploit niche markets due to their flexibility, unlike larger corporations they operate from a low capital base and are unable to accommodate the levels of risk and high costs associated with R&D (Rammer, Czarnitzki and Spielkamp, 2009). In this sense it is advantageous for SMEs to look outside the organisation to share risk and fully explore the possibilities of new technologies in order to innovate. The peculiar combination of academic research and design practice common to design research units (Dorst 2016) is one way SMEs can share risk. This is particularly relevant in the case of emerging technologies, such as Additive Manufacturing (AM), where product ecologies are characterized by a high degree of contingency. In other words, the particular way a given technology interacts with an institution is yet to crystalize into a stable form with particular sets of meanings and practices for the institution and its customers. Due to a high level of expertise and relative immunity from risks, academic design practitioners and university research units are ideally positioned to assist SMEs to comprehensively explore the systemic and semantic possibilities of new technologies before they give form to a particular product ecology.

This article presents partnering with universities as a viable possibility for SMEs that wish to invest in typically cost prohibitive R&D. The research does not aim at a comprehensive, global overview of comparable case studies, nor does it set out refined strategy, applicable across a diverse range of scenarios. The intent is to provide a suggestive introduction, and do some initial sorting of relevant bodies of work to ready the terrain for subsequent case studies of a more detailed, outcomes focused nature. The focus of the article is Australia, with some limited benchmarking against comparable work in the UK and New Zealand. The specific case study plays the role of bringing into certain limitations into relief and inviting an impressionist consideration of different models and hinting at rough criteria to guide future efforts.

SMEs and the challenge of R&D

The predominant aspect for SME’s to ensure that their product base remains competitive in the medium to long term is innovation. As noted by Katila and Ahuja, ‘the ability to create new products is an important component of firm innovative capabilities’ (2002, 1183). The key driver behind successful innovation is the generation of new knowledge through R&D outcomes (Rammer, Czarnitzki and Spielkamp, 2009). Therefore the development of strategies that drive R&D in directions that generate appropriate outcomes is crucial to ensuring innovation success. Furthermore R&D strategy needs to be appropriate for each SME and their desired outcomes. A strategy is ideally developed to leverage existing expertise and resources specific to a company, while generating new meaning which both complements and transcends such expertise (Verganti, 2009). It is therefore important that methodologies are developed, tested and fine-tuned to help SME’s find the most appropriate R&D strategy for them, to ensure the highest possible levels of success.

SMEs face significant challenges in financing R&D. It is a widely held view that R&D activities are in general difficult to finance due to R&D investment being associated with high costs, risk and protracted return on investment (Hall, 2002). This means any enterprise will have to balance the expected benefits from successful R&D and the costs and probability of failure when engaging in R&D (Rammer, Czarnitzki and Spielkamp, 2009). This is the case for enterprises of any size. The difficulties for SMEs are particularly pronounced. Large enterprises operate from a larger capital base than SMEs and generally have several investment strategies in operation at the same time, R&D being only one component of an entire investment portfolio. Thus if an R&D project fails, the loss of that particular investment has less of an impact overall. In contrast SMEs typically operate from a much smaller capital base and are therefore more vulnerable to the loss of investments. This is especially the case if an R&D strategy involves purchasing new technology, equipment and the know-how to operate it. In cases such as this, the high up-front costs for the purchase of new equipment, and the high ongoing costs for the employment of trained individuals to operate the equipment poses a considerable risk.

One way for SMEs to reduce the burden of risk is to partner with organisations that can supply relevant research and/or technical capabilities. Martin (2009) describes the need for companies to embrace exploration to remain competitive, highlighting that while there may be high risk, there is also, high reward. Research on the nature of risk in design identifies three factors in managing risk including investing in pre-launch homework, orientating new products to customer requirements and utilising cross-functional, multi-skilled teams that avoid pre-determined structures (Jerrard and Barnes, 2006). Partnering with an external research organisation facilitates the pre-launch verification of strategic objectives, provides cross-functional, multi-skilled teams and, if the right research partner is engaged, can deliver new product innovations.

Government support of industry and research collaboration

The Australian Government has released the Industry Innovation and Competitiveness Agenda (2014). The report outlines an action plan as part of the government’s Economic Action Strategy and highlights a number of disturbing statistics regarding innovation in Australian manufacturing. Notably, that ‘according to the Global Innovation Index, we are 81st out of 143 countries on how effectively we get returns from research, ideas and institutions’. And that ‘Australia ranks last out of 33 countries listed by the OECD on the proportion of businesses who collaborate with research institutions’. The report identifies five Industry Growth Centers, one being Advanced Manufacturing to manage and support connections between industry and research in order to improve our performance in those engagements. Additionally, the report identifies Australian small businesses as likely to be innovation leaders as they have the ability to be flexible, able to exploit niche markets and embrace new technologies. There are over 2 million small businesses in Australia (Department of Industry, Innovation, Science, Research and Tertiary Education, 2012) that include manufacturing SME's. There are a large number of SME's in

Australia and a high proportion of companies in low to medium technology industries, that the government would seek to provide support and incentives for engaging with university research.

Government intervention to improve the competitiveness of SME's has been conducted previously in other regions. A study of the performance of a Korean Government program to improve the innovative capabilities of Korean SME's provides useful insights. The SME Technology Roadmapping Program was conducted between 2008 - 2011. The research reports on a survey conducted after the completion of the program (Jun, Seo and Son, 2013) to evaluate the program success and propose improvements for future programs. The paper by members of the Department of Industrial Information Analysis, Korea Institute of Science and Technology Information, provides noteworthy points for consideration in the development of a local strategy.

a. The SME Technology Roadmapping Program was developed in response to the recognition of a need to support SME's in Research and Development and that existing Roadmapping Programs were geared to larger organisations. The features of the program are:

- A market-orientated focus rather than focusing on technological trends.
- Mid-term (3-5yrs.) rather than short-term (2-3yrs.) or long-term focus (5-10yrs.)
- Intra-company functions and organisations can participate in the development of the roadmap.
- External specialists are also invited.

b. SME Technology Roadmaps are focused in scope in that they are developed for single companies and belong to the category of product-technology roadmaps. They are company-led rather than industry-led.

c. The objectives of the program were expanded to include not only new technologies and products but also strengthening the capabilities of relevant personnel.

The program was successful but the survey identified that short-term (2-3yrs.) roadmaps would be more practically useful for SME's and noted limited funding available to SME's is a factor. The concern here is that when the time and cost of the program increased the expected sales increased but program satisfaction is reduced. So, for higher satisfaction, shorter-term roadmaps need to be implemented, acknowledging that profits may not be as lucrative. The key of the study was to identify how to encourage program satisfaction and loyalty. These findings suggest that projects should be developed within the program that provide implementable outcomes for the short-term (2-3yrs.), that technology investigations respond to the SME's market needs and that opportunities for personnel within the company have the opportunity to engage with the project and strengthen their capabilities (Jun, Seo and Son, 2013).

Another example of Government support for connecting companies with external research is that of the Knowledge Transfer Partnerships (KTPs) programmes in the UK (Hofer et al., 2010). Partly funded by the Government, the program requires that the businesses involved have identified an innovation opportunity of strategic significance that will help them gain competitive advantage. A qualified graduate, known as a KTP Associate is appointed to work with that company, jointly supervised by the company and the University to apply research knowledge and expertise in the development of the opportunity into tangible outcomes such as new products and processes. The appointment may last up to three years and during their time with the company the Associate is responsible for managing the project and facilitating knowledge transfer between the university and the company under the supervision of company staff. In recent years, the program has focused on small to medium enterprises. There have been a number of successful KTP program partnerships in the manufacturing sector and it has been noted that the advantage of the program is that it is of benefit to all partners involved (Hofer et al., 2010).

The KTP Program highlights the importance of knowledge transfer and the importance of working with the strategic vision of the industry partner to productively innovate change. The two-three year term is consistent with the findings from the Korean SME Roadmapping Program as well as the importance of providing company personnel to engage with the project collaboratively.

Established and emerging: the potentials of Additive Manufacturing

AM systems use thin, horizontal cross sections from computer-aided design (CAD) models, 3D-scanning systems, medical scanners, and video games to produce parts in about every shape imaginable (Wohlers, 2013). It has been described as a key force in ‘the new industrial revolution’ (Berman, 2012), whereby technological advances serve an increasingly fine grained market segmentation with increasingly high expectations regarding customisation and speed of manufacture. The language of revolutions emphasizes the significant change in design and manufacture that AM potentially affords and the demands placed on institutions and individuals to adapt to its generative force. However, such language risks neglecting the characteristically diverse and contingent social, symbolic and material infrastructure into which a new must fit.

One of the key potentialities of AM is its role in facilitating a shift from producing prototypes to end use parts. Such a change will be felt differently in different companies depending on their organisational culture and previous technological capabilities. For example, Mellor et al (2014) discuss a case where a rapid prototyping (RP) firm shift to rapid manufacture (RM) through the use of AM. The CEO of the company used for the case study highlighted a key change from an RP environment where speed of production is key, to an RM environment where ‘cost and quality control become critical for success’ (p.199). In this instance the subtle difference motivated a change in the structure and culture of the organisation to support the transition from one type of service delivery to another.

AM is seen as playing a key role in various strategies to combat the migration of manufacturing to cheap labour markets. Petrovic et al., (2011) presents various examples of AM integration by European SME’s. The case study covers projects for construction of injection mould tooling, biomedical implants and lightweight structures. In the construction of injection mould tools, improving heat transfer and reducing cooling times can shorten cycle times and improve productivity by up to 33% (Petrovic et al., 2011). Cooling channels are pathways inside the tool that allow coolant to pass through the tool removing heat. Pathways that closely follow the part cavity provide effective cooling. Conventional technology is challenged by the often complex nature of cavity design, whereas AM is able to easily construct paths that follow complex cavity designs.

In the biomedical sector new generation implants and materials are being developed for customized health products that incorporate different technical requirements such as materials destined for jaw implants that replicate the mechanical and thermal properties of natural bone. Additional possibilities are the ability to configure internal geometries that offer designers the opportunity to create internal lightweight structures, thus reducing weight while maintaining strength as seen in lattice structures used in human bone implants which allow the bone to grow into the implant. The Selective Space Structure (SSS) project investigated this through the development of lightweight structures that analysed and proposed solutions for internal configuration of parts (Petrovic et al., 2011). Increased strength to weight ratios and improved transmission of movement solutions have been used in both the biomedical and aerospace sectors (Petrovic et al., 2011).

Studies have shown that AM can be a cost effective option for the small to medium sized production quantities typical of SMEs. The Atzeni et al., (2010) case study compares an AM part with a conventionally manufactured part from a cost perspective. The study involved a small electrical component with dimensions of approximately 15 x 19 x 28mm, enabling a large quantity of the parts to be produced at any one time, that is, more than 2500 parts per AM build. A comprehensive costing analysis revealed the break-even point, or, the moment when AM becomes more expensive than conventional manufacturing doesn’t occur until thousands of parts have been produced (Atzeni et al., 2010). This is assuming that AM parts do not require post-processing and the entire volume of the AM machine is used.

While AM is well-established and effecting significant advances in high performance and medical sectors it remains an emerging technology for SMEs. Well financed SMEs operating in high performance and medical sectors tend to have relatively low production volumes and high performance criteria uncompromised by cost. These companies are responding to the suitability of AM technology according to their unique operating parameters. SMEs operating outside these sectors face a different set of contingencies. The question of how to best integrate AM into existing organisational structures is characteristically uncertain, particularly with regard to how the technology interacts with established and potential values of a company. SMEs can capitalize on the flexibility afforded by their relatively dynamic organisational structures if they can accommodate such uncertainty and, for a given duration, remain open to the new meanings it might engender. In this sense, it is imperative for SMEs to work proactively to establish a resilient product ecology into which AM can fit without it dictating the way a company sees itself and the sets of meanings associated with the brand—this particularly so because innovation in AM technology is fast moving. SMEs that have a robust sense of identity and a strategy specific to their capabilities are more likely to give form to a new technology rather than limit themselves to being a service provider for that technology.

A change in manufacturing technology is ideally complemented by a concurrent change understanding the compositional possibilities of products. In the case of AM, this might mean seeing previously discrete components of a product as a single entity or capitalizing on the relative freedom from previous geometric constraints the technology affords. Understanding the broader, systemic implications this has more the manufacturing process is of course crucial. This in turn may have further subtle though profound influences on the way SMEs operate and self conceive.

Design research units, SMEs and a culture of innovation

There are a number of different forms of external research support available to manufacturing SME's that can help them gain competitive advantage. Design research units may offer a particular kind of support to SME's, not only assisting in the implementation of strategic and technological change, but in the creation of new meanings peculiar to the penumbra of potentialities that may remain inexplicit when transitioning to a new product ecology. This will include propositions articulating how SMEs can best exploit the particular affordances to do with a given technology and to understand subtle though important changes in the design process which they effect. In the case of AM, this might include potentials relating to geometric complexity, parts consolidation and product customisation (Maiden et al, 2009). Understanding these features in isolation, from a mechanical perspective, requires a specific level of knowhow. However, it is just as important to understand the relationship between a given feature and the sets of yet to be explicated possibilities it enfolds and compellingly communicate this to obtain relevant insights.

The question of how the principles of manufacture will achieve a specific value is a situation defined by contingency. In this sense AM is an ill-defined problem (Dorst, 2011), where in addition to finding a solution (technology as *deus ex machina*) the collective (designer, company, etc.) in question is often well served by evolving the terms of the problem into which a solution might fit. In the case of AM this means deliberating on the relationship between the possibilities afforded by the technology and the exact nature of the vision, style, aesthetic or identity, the technology will be employed to serve.

The responsibility of the research unit should be to adopt an experimental mind-set and, based on understandings of the SME's operation and the capability of the technology, experiment to identify opportunities for the application of that technology. Experimentation is a step in the learning cycle that can be effectively performed by the research unit to facilitate a shift for the SME from the administration of existing business to the creation of new business that it needs to be working towards in order to remain competitive. Successful design interventions with SME's will involve a number of constraints and boundaries that can be beneficial, if embraced and approached in the right way. These might involve understanding and utilising the SME's current manufacturing competency, balancing consumer needs and profitability (Clarke and George, 2005), achieving short-term outcomes, and the constraints associated with the technology itself. Defining the relationship between a specific SME and a given technology in terms of generative constraints ideally provides the design research unit with a basis for experimentation that captures feasibility, viability and desirability (Brown, 2009).

Essentializing the capacities of design and designers remains a fraught task (Dorst, 2016). Nonetheless it is unproblematic to suggest that designers tend to possess some kind of advanced discriminatory capacity when it comes to proposing and distinguishing between possibilities of form and meaning. Articulating exactly how this capacity manifests as it interacts with the possibilities of a new technology is a difficult task. This is particularly so in the case of technologies like AM which can often reduce the aspect of making that involves the bodily movements and tools which seem far more conducive to reflective richness. It is difficult to impute an organic rhythm of the kind famously celebrated by John Ruskin and more recently theorists like Richard Sennett (2008) and anthropologists of technology such as Tim Ingold (2011) to the complicated, multistage, multimedia process characteristic of designing with digital technologies such as AM. Designing often involves diverse and asynchronous inputs that are more difficult to reconcile as part of the same process. The indirect connections between the mind, body and technology in the case of AM makes virtuosic contribution of designers more difficult to make explicit. Unpacking this hidden contribution in a compelling and subtle manner is crucial to facilitating design knowledge development within institutions and the kind of design led client inputs suited to collaborations between design research units and industry (Cawood, Lewis, and Raulik, 2004).

Based on the peculiarities of their profession, academic design practitioners are tasked with regularly translating these capacities into unique sets of documents, including curricula and research proposals, and pedagogical contexts where knowledge is disseminated in action. Furthermore, design research units offer SMEs an outside perspective which can be conducive to innovation. As noted by Dorst in the most recent in a series of papers attempting to make a case for the combination of partitioner know-how and academic knowledge:

> In an ideal scenario the strength of such an academic approach would be that through the comparative distance from practice, overview and access to theories and practices from other fields, an academic design research community could come up with fundamentally new practices for design that would not be easy to conceive by design practitioners as they respond to these forces on a more day-to-day, practical basis. (Dorst, 2016)

In this view, academic design is explicitly about the ends to which new technologies might be put that are foreclosed by sets of constraints typical in commercial design practice. This isn't to say that academic design is an autonomous sphere. Rather, it tests what might conventionally be regarded as commercial imperatives according to a different teleology, where outcomes are received into a situation with are relatively high tolerance for failure and openness to possibility—temporary immunity from the consequences of failure is arguably one of the key, generalizable educational characteristics of universities, for students and academics. Design research units offer SMEs a unique, relatively low risk, access to these conditions.

Case study: Digifacture

The Digifacture Project (2010) is an example of the way design research experimentation can support SME's in innovation. It represents an initial or pilot phase of what might be developed into a more established relationship between a design research unit and an SME. The project brought together seven professional designers and design academics to work with Sydney based SME manufacturing service provider, Advanced Manufacturing Services (AMS). The function of the project was to investigate through a form of practice-led action research, new ways of advancing the application of AM through the development of innovative designs. Kevin Cullen, the Director of AMS stated that the Digifacture project produced ‘flair in design and the ability to think outside the square to maximize the potential of Laser Sintering Technology’ (Pandolfo and Walden 2010, 6). The project sought to understand the nature of practice and process for operational benefit to AMS to assist the company identify opportunities to gain competitive advantage.

Three examples from the project indicate the kind of expertise design research practitioners bring to the manufacturing process. The Eyewear design using selective laser sintering (SLS) was an example of a disciplined investigation into the new territory for product design opened up by AM. Eyewear is an ideal product to test with AM technology such as SLS for a number of reasons. It is an example of a ‘relatively small product with [potentially] high value added personalisation features that are difficult to manufacture with conventional technology’ (Maidin, et al., 2009, 317). Eyewear tends to be a relatively flat 3D object so it is easy to print and it features component parts that might be consolidated through the use of the technology.

[Insert figure 1: Eyewear, MTB Crank Arm, Spk Bowl, *Digifacture* 2010.]

The purpose of the project was to investigate how such a product would need to be designed so it could be effectively made and distributed through a 3D printing bureau such as Shapeways (Walden et al., 2015). The key hypothesis tested by the designer was whether the frames could be printed with front frames and side temples combined, so no further assembly needed other than fitting the lenses. To test the theory it was necessary to physically 3D print a hinge mechanism to see if the hinges would function. The designer’s high level domain specific knowledge (Popovic, 2004) allowed them to quickly and confidently isolate the hinge as the key element to get right in eyewear. The designer printed five different prototype hinges and through testing discovered none of the hinges performed satisfactorily. As a result a new, elasticised hinge mechanism was designed and incorporated into the final product.

This is an example of the kind of crucial design research required to begin exploring the possibilities and limitations of AM. The designer identified an ideal product to test, the key aspect of the product which might be improvable through the printing technology, the literal and metaphorical ‘hinge’ on which that possible improvement depended and a set of suitable iterations to ensure adequate testing. Such a process involves the representation of iteration in terms of learning cycles and reflective practice, which provide a structured and deliberate means of incorporating the experimentation required for creative, workable solutions to be found. It is the kind of multistage learning and experimentation process that SMEs are often unable to perform.

[Insert figure 2: Stefan Lie, Aviators 3D print material tests, *Digifacture* 2010.]

Individual designs are connected to what might be described as a meshwork of variously implicit and explicit formal and semiotic references. Appreciating the force of these referents in the design process can lead to more compelling outputs. In the case of using a new technology like AM, familiarity with this great archive of forms and meanings will ideally allow a designer to take an expansive and nuanced approach to the creative process. This is evident in the Spk Bowl, which was designed as part of the Digifacture project. The designer explored the formal possibilities afforded by AM with a deliberate approach to the formal and semiotic elements of the design. The exterior of the bowl is covered in coloured spikes, creating a contrast between the forgiving interior, which supports and protects its contents, and accentuating the prohibitory element of the exterior, in a manner comparable to natural forms such as urchins and certain fruits. While the elaborate decorative element displays the technical virtuosity of AM, the application of the technology is highly restrained and addresses specific conceptual imperatives. The designer demonstrates an understanding of the specific tension between the intricate, synthetic element afforded by AM and the ancient, relatively simple, though enduringly useful form of the bowl.

Another design for the project focused on the bicycle components industry, using direct metal laser sintering to produce a mountain bike crank arm (MTB Crank Arm). The capacity of AM to create high performance, metal end usable parts, with strong, lightweight structures is widely exploited by well financed SMEs in the aeronautics industry. The designer in this instance sought to apply the same technology in a context where enterprises are less likely to be well financed and performance criteria are typically less stringent.

The designer of MTB Crank Arm deployed an interwoven combination of tacit knowledge, from a long personal history involved with mountain bikes, and design knowledge, from experience as a design practitioner and researcher (Kuys, 2014). Crank arms are a composite of a stainless steel interior and an aluminium coating or shell. The designer’s knowledge of the affordances of AM and the specifics of the prototypical crank design put them in a position to see the potential of producing a crank arm made entirely of stainless steel. The designer worked closely with the industry partner, emphasizing and facilitating iterations through CAD model variations. In this sense the ‘designer’s ability to represent design intent in a given CAD system’ (Maidin et al., 2009: 316) played a key role in exploiting the creative possibilities afforded by the new technology. Furthermore, the design process was conducted experientially in terms the industry partner could understand, allowing regular contributions and close involvement. This approach has the twin benefits of potentially creating a new manufacturing output and as well as a culture where the insights obtained from such outputs can be useful for innovation, whether or not the output meets the criteria required for mass manufacture.

The Digifacture project was successful in proposing new strategic directions for AMS. The design concepts published have been used to demonstrate key advantages of the technology, expand the potential consumer base for the company and clarify communication with AMS customers. The project also supported new knowledge development through the identification of potentially new forms of design practice beneficial for developing products using AM. Prior to this collaboration the extent to which AMS would utilize its AM technology was for tooling inserts and dental components, today the company now engages with multiple sectors including; aviation, medical, footwear, lighting, automotive, robotics and jewellery. Whereas none of the outcomes from the research project have gone beyond being used as publicity material on the company’s website, a distinct shift in the company’s approach, understanding and potential of the AM technology is now evident.

The total cost of the project amounted to roughly $27, 0000, not including the in-kind time of design academics, who were compensated by the non-traditional research outcomes associated with the project and a track record of successful industry engagement. This is a significantly smaller investment than the typical costs associated with R&D in AM, a clear indication of how practice led research projects can have the potential to facilitate mutually beneficial outcomes for industry, who benefit from lower costs, and design academics, who obtain a purposeful context for working towards research outcomes and further industry collaborations.

The outcomes of Digifacture might not meet imperatives articulated in the discourse of the concrete and the immediately measurable. However, they do gesture towards a field of possibilities that may be evolved if nourished with appropriate time and resourcing. Academic design practitioners are typically skilled at tacking between form and concept so that the repository of knowledge retained from failed prototypes can be put to use in a dynamic fashion. Despite no short-term implementable outcomes resulting from the above projects, each contributes to a matrix of practical and conceptual knowledge that hash increasingly expansive applications within and outside the university context.

[Insert figure 3: Eyewear, MTB Crank Arm, Spk Bowl, *Digifacture* 2010.]

Limitations, opportunities and conclusion

The limitations such a case study offers are manifold: it is a single case study and as such does not offer the kind of measurable results that are lacking in the various arguments made for the value of design to manufacturing (Cawood, Lewis, and Raulik, 2004). AMS is a service manufacturer, not a company established in the market as a manufacturer of a dedicated product type. As an example of a manufacturing SME, it belongs to a particular sub-set that many manufacturing SME's do not fit. Strategically, the project did not produce the short-term implementable outcomes deemed to be more important in SME research support programs (Jun, Seo and Son, 2013; Ranasinghe et al., 2014). Further, given that AM is already core to AMS' production system, the project does not address the integration of AM into existing, more conventional manufacturing firms. A more strategic approach would be necessary to ensure successful collaborations between research units and SME's that would seek to implement AM for the first time.

A number of recent precedents for design led industry collaborations have produced demonstrably successful outcomes. One such model is the industry embedded studio PhD as seen Robbie Napper's work with Volgren, Australia's largest bus bodywork manufacturer. Napper's work is a different example of how design research and industry can come together in way that is mutually beneficial (2012). Napper describes the industry embedded studio PhD as meeting two linked requirements, which have been emphasized in the present article: that a company can work on 'long term strategic issues without sacrificing daily operations' while undertaking 'higher risk research than might otherwise be commercially viable by mitigating those risks in a cost-effective partnership' (2012). Napper describes the industry embedded PhD as a response to a complex problem where, 'simple solutions such as blanket standardisation of the product range were deemed commercially unviable' (2012: 99). In this case the specific problem was the tension between the unique specifications demanded by bus operators and the high cost associated with producing customized designs. The research training partnership described by Napper allowed Volgren a ‘large degree of independence from commercial activities’, which in turn allowed ‘the research to accurately determine the root cause of the problem’, namely that ‘bus operators, not the manufacturer, were designing the vehicles with no consideration of manufacturing’ (2012: 99). As Napper points out, while Volgren could have approached such a problem themselves, as they had done in the past, it did not allow them to identify the root cause of the problem.

Another relevant model for facilitating cross-pollination between academia and industry are the design lab type models which are particularly popular in the healthcare sector. Examples include the Design for Health and Wellbeing (DHW) Lab, a collaboration between Auckland District Health Board (Auckland DHB) and Auckland University of Technology’s Faculty of Design and Creative Technologies; the Lab4Living and the Art and Design and Health and Social Care Research Centres at Sheffield Hallam University; The Helen Hamlyn Centre for Design and the Royal College of Arts, London; Cornell University’s Health and Design Innovations Lab; and the Innovation and Design Lab at the University of Santa Cruz (Reay et al., 2016). Design labs are superficially modelled on the idea of a scientific laboratory whereby a certain space is abstracted from the world so a community of researchers can study nature according to operations of increasingly intensified scrutiny. In addition to their design rather than scientific outputs, design labs typically differ from science labs in the deliberate openness to ‘the blending of many different forms of knowledge’ and constitutive participation from a range of stakeholders (Reay et al., 2016: 2). Reay et al., point out the centrality of design methods, such as rapid prototyping, not only to help ‘demonstrate the viability of their solutions, but also helps *facilitate* collaboration’ (2016: 3). In this sense they cleave to the user centeredness and multi stakeholder involvement which is part of the broader design ethos and vital for facilitating knowledge development within an organisation (Cawood, Lewis, and Raulik, 2004; Barge-Gil, Jesús Nieto and Santamaría, 2011). Sometimes labs maybe contained within universities, sometimes, as in the case of the DHW Lab, they operate like a ‘Trojan Horse’ (MacDonald, 2013), entering a given institutional context and once inside spreading knowledge from within.

The industry embedded PhD and the design lab are two established models AM focused projects such as Digifacture might benefit from adopting and adapting in the future. The Digifacture Project is an example of a type of design research project the primary benefits of which are largely limited to the endurance of design as a media object or through technologies of exhibition and demonstration that can be used in various ways to promote a given brand, technology or ethos. While limited in certain respects, this is far from an unimportant aspect of research. As persuasively argued by Claude Rosental in his account of demos in the science and technology industry, such displays ‘are a key element in the process that *bind* the making and the marketing of science and technology’ (2005, 348). According to Rosental, the practice of exhibition ‘is becoming more and more common in many scientific arenas’ and is even used a ‘solution to the complex problem of how to make scientific and technological results public’ (347-348). Digifacture is an example of a design led approach that makes public the results of a research effort and the possibilities afforded by a given technology. Such projects have a future use to disseminate research into a given technology and actively design the publics that form around such technological investigations. Future iterations might either make a more targeted, explicit use of these capacities, or, following other models used in university and industry collaborations, make a more systematic and sustained effort to embed and measure research efforts within a specific commercial operation.

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