FROM USERS TO OUTSIDERS: SHIFTING THE SPHERE OF INDEPENDENT INNOVATION FROM OWN PRACTICE TO EXTERNAL FIELDS

THEME: RELATIONS

TAVS JØRGENSEN

PLYMOUTH UNIVERSITY

TAVS.JORGENSEN@PLYMOUTH.AC.UK

ABSTRACT

This paper concerns doctorial research that investigates how new manufacturing concepts can be developed by individual designers facilitated by an increased diffusion of digital fabrication tools and knowledge resources. The paper reports on a practice-based research study aimed at exploring innovation with a technical focus on the underutilised Reconfigurable Pin Tooling (RPT) concept.

The study feature two strands of enquiry; one concerning innovation with glass forming *within* the researcher's own creative practice, while another strand investigate how the same tools and development approaches can deliver innovation in the furniture industry – a field *outside* the researcher's practice. Both investigations seek to provide new insights into the innovation process delivered by independent designers, and how a shift can be made from undertaking innovation within their own personal practice to delivering innovation in external sectors or industries.

INTRODUCTION

Innovation in fabrication technologies have through the various industrial revolutions and technological sectors been delivered from a number of sources including: 'individuals, outsiders, users, corporate undertakings, spill overs, and process needs' (Smith, 2005, pp. 85–96). In this research the focus is on the innovation contribution from *individuals, users* and *outsiders,* and in particular, how new digital fabrication technologies have the capacity to deliver the *power* for individual design practitioners to innovate.

Overall, there is acknowledgment by several scholars (Pursell, 1994; Smith, 2005) that external actors have a strong potential for providing a significant contributions to the innovation process, particularly in the early phases of a typical innovation process as described by Smith (2005). However, the conditions and opportunities for individuals to contribute to the innovation process have varied significantly over time. Many authors Leadbeater & Miller (2004, p.51); Von Hippel (2005, p.21) and McLuhan & Fiore (1967) – all highlight the important role that independent inventors/innovators played in the first industrial revolution. While Freeman and Soete (1997) describes how the domain of invention and innovation gradually shifted from individual, craft-trained practitioners to becoming an increasingly specialised activity based on scientific knowledge, with Pursell

(1994) also highlighting how increased science based inventions impacted on which actors were able to undertake innovation.

In summery, the opportunities for individuals to participate in innovation appear to be dependent on the maturity and diffusion of a particular technology or sector. The hypothesis of this research is that new opportunities for the individual innovator is currently expanding due to a particular set of conditions and contexts.

TECHNOLOGICAL CONTEXT OF STUDY

This research is particularly situated within the recent developments in digital fabrication. Innovation in technologies in this field was until the mid to late 2000s the preserve of a few specialist companies such as Stratasys and 3D Systems. However, during the last decade the maturing and diffusion of digital fabrication technologies has meant that this sector has undergone a process of moving from a relatively specialist area to becoming much more ubiquitous.

Initiatives such as FabLabs, the Maker Movement and the RepRap project have all helped to serve as catalysts to expand the opportunities for individual innovators to actively contribute to the development of new digitally driven fabrication concepts. Furthermore, online networks and forums have enabled the dissemination of a multitude of independent innovator projects and provided inspiration and motivation for others to undertake their own explorations.

Also contributing to the expansion of innovation opportunities has been the convergence of ideas and development tools from other technology driven sectors such as computer science. Of particular significance in this regard are networked innovation models, which are the basis for open source software developments (Raymond, 1999). In particular the open source RepRap project (Jones et al., 2011) had a dramatic impact on expanding the innovation opportunities in the digital fabrication sector.

To reiterate, the argument presented through this study is that developments in digital fabrication have enabled an increased access to affordable and powerful development tools. This research enquiry sets out to investigate how this environment with an increased access to tools and knowledge resources can enable individual practitioners to establish new fabrication systems not only within their own practices but also enable innovation in sectors beyond their own field.

RECONFIGURABLE PIN TOOLING

The technical focus of the practice based enquiries in this study was centred on the underutilised fabrication concept of Reconfigurable Pin Tooling (RPT).

The RPT fabrication principle could best be described as a principle based on a *bed of nails*. It is a concept that is also known from a popular toy sold under brand names such as ‘PinArt’ (Fleming, 1985). However, the principle of using an array of pins as a flexible tooling method capable of produce an infinite variety of shapes has been explored by inventors and researchers for at least 150 years (Munro and Walczyk 2007). Despite the attractive properties of such a tool, the technical challenges associated with the construction and operation of RPT based system have meant that the concept have seen little commercial utilisation (Munro and Walczyk 2007, pp.551–552).

While the core principle of RPT clearly precedes digital fabrication, Munro and Walczyk (2007) argues that the onset of Computer Numerically Controlled (CNC) technology has resulted in a significant increase in the exploration of RPT. In the wider field of digital fabrication RPT could be best be classed as a *formative* rather than *additive* or *reductive* fabrication principle, with CNC technology typically used to actuate the pins of a RPT system into positions which is then locked into a rigid surface to shape various mediums.

PRACTICAL RESEARCH ENQUIRES

The practice element of this study features two strands of enquiry. The initial enquiry concerned the development of a RPT system for the production of glass bowls within the researcher's own creative practice. Although the overall context for this study was firmly focused on the digital fabrication sector, in this particular practice strand digital technologies severed as the *development tools* rather than the *outcome* of an innovation process and the results of this practice strand was an analogue operated tooling system.

The other practice strand in this study was guided by interaction with a local furniture company, MARK Product, and resulted in the development of a CNC operated RPT system for shaping upholstery foam. In this practice strand digital fabrication provided *both* the development tools as well as the outcome of the innovation process.

In combination, the two practice strands served to investigate tools, factors, and approaches that are involved when independent designers engage in innovation in the context of digital fabrication. The two practice strands are discussed in further detail following subsections.

INNOVATION WITHIN OWN CREATIVE PRACTICE

As previously highlighted, this enquiry explored the process of delivering innovation within a personal creative practice. In this scenario researcher's took a position which could be described a 'lead user' innovator (Von Hippel, 2005, 1986) – as the researcher used his knowledge as an advanced *user* of digital fabrication tools to develop a glass moulding system within his own creative practice.

This practice strand was initiated by preliminary explorations which established a successful (but basic) proof-of-concept that showed a stainless steel RPT system could be use within a high temprature kiln to shape sheet glass through process known as 'slumping' (Cummings, 2001).

Figure 1: Preliminary exploration of the RPT system for glass thermoforming, photos: T. Jørgensen, 2010.

Following this preliminary proof-of-concept further development was carried out by numerous prototyping cycles utilising digital design and fabrication tools in the innovation process.

In particular the parametric modelling environment *Grasshopper* (which is part of the Rhino 3D modelling software suite) was used extensively in this work. Grasshopper's visual scripting interface enabled the researcher to create customised parametric scripts to facilitate quick iterations of RPT prototypes. Mechanical elements designed through this process were initially fabricated through the use of inkjet printers, paper modelling and small-scale laser cutters. The notion of using such low cost and accessible digital fabrication technologies in combination with visual programming tools was noted as particular enabling for the independent practitioner to innovate.

While the initial proof-of-concept explored a RPT system in a *square* formant, further investigations focused on exploring RPT systems based on a *round* matrix format, which in the context of other RPT research is entirely novel.

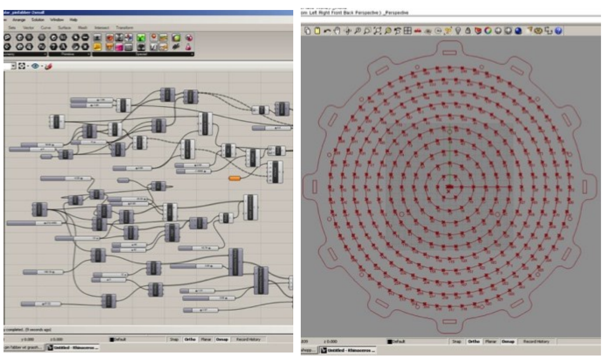

Figure 2: Parametric Grasshopper definition developed by the researcher to create the files for the round glass RPT system.

Another significant enabling factor in the development process in this enquiry strand was the interaction with local suppliers and sub contractors. A particular significant aspect of this factor was the availability of local firms offering affordable and highly accurate metal laser cutting services. This meant that the files created by the researcher could be very easily be used to create bespoke parts for realising working prototypes fabricated in durable materials with very high levels of accuracy. Through the use of personal digital design tools and local digital fabrications services, the researcher was able to carry out quick iterations of fully functioning tooling prototypes, which were tested and used within the researcher creative practice. This process of development can be characterised as a reflexive process based on cycles of construction, test and evaluation loosely structured with an action research methodology.

Through this development process a number issues, which had been identified by other researchers as very challenging aspects of the RPT concept, was resolved through the creation of some original technical solutions.

Figure 3: RPT system with glass bowl (upside down) still resting on the pins following the slumping process, photo: T. Jørgensen, 2012.

One of the key challenges of the RPT concept is the need for a quick, but also effective, pin locking mechanism. In this particular application (glass forming) this issue was made more challenging as the tooling system had to endure temperatures of 680-760ºC required by the glass forming process. But despite these challenges a very effective and novel pin locking system was establish through this practice strand.

Other original aspects established during this research included a new *selected pin positioning* approach where pins were placed in particular selected holes, rather than using pins in the entire matrix of holes. In the context of other RPT research this approach is also entirely novel.

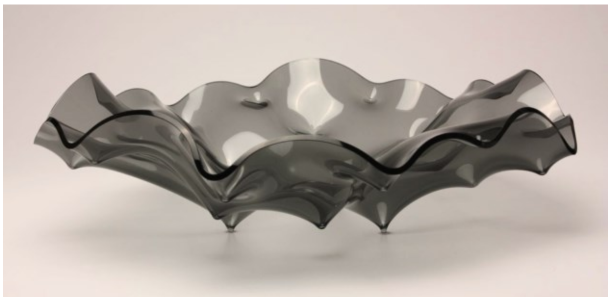

Figure 4: Pin Bowls with characteristic indentation from the pins as integral part of the aesthetics, photo: T. Jørgensen, 2012.

The final result of the development process was the creation of a successful and very flexible glass forming system, which the researcher used to create several bodies of creative works (glass bowls). The creative explorations also generated new knowledge in terms of combining the RPT concept with the glass slumping process with two novel approaches being established. An initial approach was based on creating glass bowls upside down with three central pins creating tripod feet. A subsequent approach was a further development of the 'aperture slumping' approach (Cummings, 2001) using the pins to create a variety of circular orbits, through which a glass disk is formed into a domed bowl form by a combination of heat and gravitational force.

Another key aspect of the creative exploration of the RPT glass tooling system was to utilise the evidence of this partcular production method as an integral part of the aesthetic of the pieces. This was achieved in both bodies of creative works by leaving the impression of the pins as a core artistic feature.

Figure 5: *Blue Orbit Bowl* (2014) by the author, utilising the RPT in combination with a further development of the aperture slumping approach, photo: T. Jørgensen, 2013.

Output from this enquiry have been shown widely at leading international exhibition venues including the Saachi Gallery (London) the Pushkin Museum (Moscow) and Siggraph (Los Angeles). Furthermore, numerous pieces have been sold with some acquired by public collection including by the Crafts Council England.

The widespread critical acclaim of the prices created with the RPT tool provides evidence of a successful innovation process having been achieved in this research enquiry.

Figure 6: *Pin Bowl* exhibited at Milwaukee Art Museum, photo: T. Jørgensen, 2011.

INNOVATION IN EXTERNAL FIELDS OR SECTORS

In this practice strand the researcher sought to investigate a different innovation position from that of the *user innovator*. More specifically, this research strand the researcher aimed to undertake tool development in the furniture sector – a field separate from his own practice. Consequently the role of the researcher in this enquiry could be described as shifting to an '*outsider innovator'* position (Smith, 2005).

The idea of using the RPT concept as a method of shaping upholstery foam emerged through preliminarily discussions with a small furniture design company, MARK Product. The concept of shaping upholstery in this way was inspired by a particular manufacturing process used for creating the characteristic textured surface in acoustic insulation foam. In this process the foam is processed through a set of textured rollers that compresses the foam and as the foam emerges from the rollers a band knife cuts through the centre of the foam. As the foam is still in compression while being cut the foam is shaped by the texture on the rollers and as the foam springs back from this compression a three-dimensional textured surface is revealed.

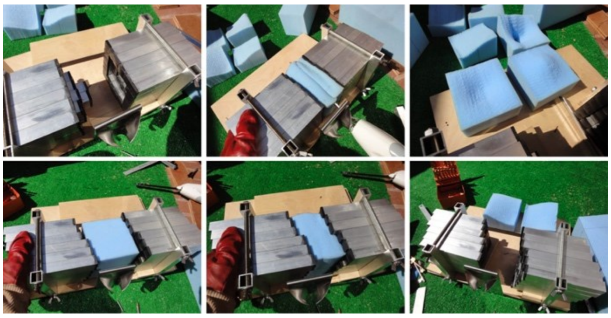

Figure 7: Exploring the RPT concept through early stage prototyping photos: T. Jørgensen, 2012.

Unlike the glass forming system the aim for a RPT foam shaping concept was to create a genuine digital fabrication system where the pins would be set via CNC technology. The challenges of developing a RPT system integrated with a bespoke CNC setting system were potentially far greater than establishing the analogue operated RPT system for glass forming. Furthermore, many of the challenges in this enquiry required very different technical solutions from the glass system, for example an entirely different pin locking system had to be developed.

Despite the differences in the technical requirements of the two fabrication concepts, the development methodologies and prototyping tools (a mixture of analogue and digital), where largely the same with both RPT systems. Suppliers and subcontractors for prototyping material were also shared among both of the practice strands.

Just like the development of the glass system, parametric scripts created in Grasshopper environment, was used to design the physical parts for the foam system but furthermore Grasshopper definitions were also used to create a customised CNC setting software.

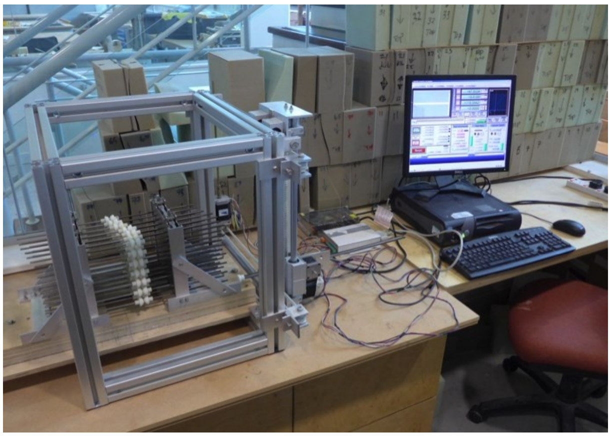

Figure 8: The Complete Foam RPT system with CNC enabled pin setting feature, photo: T. Jørgensen, 2014.

Mirroring the glass RPT investigation, this practice strand also established a successful and versatile tooling system and a novel fabrication concept for shaping upholstery foam into complex curved forms could be presented as a result of this research.

To test the capacity of the foam RPT system a series of empirical tests was undertaken. This was done in order to establish the potential of the system to be employed in a commercial context and therefore complete the innovation sequence with a final *diffusion* stage.

To test the system's capacity for accurately translate digital design input into physical form a series of five different test shapes were used. Each of the five shapes were reproduced three times to test the *consistency* of the production.

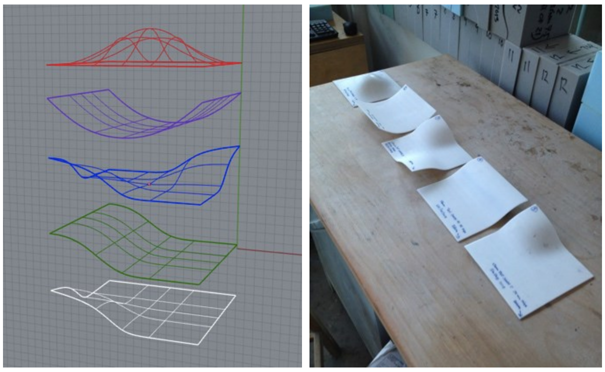

Figure 9: Test shapes designed in Rhino and 3D printed forms to aid visual inspection, photo: T. Jørgensen, 2013.

For these tests the CNC part of the fabrication system was equipped with a bespoke created touch probe that enabled the shapes to accurately measured, in effect facilitating the system to test it's own output.

Figure 10: Foam shapes produced for empirical testing of the tooling system's performance, photo: T. Jørgensen, 2014.

The tests provided evidence of the system's capacity of achieving good levels of *accuracy* when translating digital design input into foam shapes with less than 5% average deviation. An even better performance was recorded in terms of *consistency*, with around 2% average deviation noted when shapes were repeated with the same pin setting.

The results, both in terms of the system's performance concerning *accuracy* and *consistency,* indicate a good potential for further commercial exploitation.

Subsequent interviews with the directors of MARK Product provided further evidence for the commercial potential of the system, with the company seeing good potential in this novel fabrication concept. This combined data provides evidence for the independent practitioner’s capacity to contribute with innovation in sectors separate from their own, thereby preforming the role of the *outsider* (Smith, 2005) in the innovation scenario.

IDENTIFYING KEY FACILITATING FACTORS IN SCENARIOS WITH INDEPENDENT INNOVATORS

This core aim of this research was to investigate the key facilitating factors that enable independent practitioners to innovate.

The hypothesis at the outset of this investigation was that an increased access to development tools and knowledge resources (such as online forums) that constituted the primary facilitating factors in this innovation scenario. However, as the study progressed and all the data from the practice activities were gathered, the researcher concluded that the results provided a more nuanced picture.

There were clear indications that other factors also impacted significantly on the development process and helped to facilitate innovation in this specific context. In response to the findings, the results are summarized into the following facilitating factors:

- Access to tools.
- Access to knowledge resources and peer support.
- Access to suppliers and local environment for innovation.
- Prototyping approaches.
- Material knowledge.

The following subsections will address these factors in additional detail.

ACCESS TO TOOLS

This factor, as a significant enabling aspect, was explored throughout the two practice strands with the researcher finding the access to cheap and powerful digital design tools a clear enabling factor in the innovation process. A particularly important aspect in this respect is that digital design tools can facilitate a fast prototyping sequence by utilising both personal as well as external digital fabrication resources. An example of this was the use of low cost inkjet printers, small laser cutters and 3D printers – particularly in the initial stages of the innovation process. The portability of the design data meant that design files from the initial explorative prototyping stages could very easily be submitted to external companies for fabrication in durable materials using high-grade digital fabrication equipment, such as powerful CNC metal laser cutters.

A key aspect of this factor is also the relative ease-of-use many of these development tools present. For example, without the visual scripting interface of the Grasshopper software the foam RPT system would probably not have been established without significant assistance from specialist programmers. The study indicates that the increased ease-of-use of many design and programming software means that the independent innovator can engage in aspects of developmental work which they had previously been excluded from due to the specialist skills required. While the particular digital design and development programs used in this study (Rhino 3D, Grasshopper and MACH 3) are affordable, but not free, many other powerful and entirely free digital design software exists for independent innovators to use.

In conclusion, the study has confirmed the assumption that access to affordable, powerful and easy-to-use digital design tools is a highly significant facilitating factor for independent designers to innovate.

ACCESS TO KNOWLEDGE RESOURCES AND PEER SUPPORT

This study provides a more nuanced evidence for the impact of this factor in the innovation process.

Based on both general media reports and also academic literature (Gershenfeld, 2005; Raymond, 1999; Von Hippel, 2005) the researcher expected to find that a key factor in the growth of independent innovation could be attributed to peer group support, particularly via online communities. However, through the practice strands of this study the researcher did not find a particular value in the interaction with peers through online communities or forums. However, it should be noted that some online knowledge resources (accessed without direct peer interaction) did provide some useful knowledge (in particular tutorials to build up the researcher's skills with Grasshopper scripting). Furthermore another (minor) impact from online sources was the postings of other projects concerning digital fabrication, but these served mostly as sources of motivation rather than actual resources of technical information.

In contrast, interaction through physical, face-to-face situations with peers was found to be of significant of value. A CNC building workshop, organised by the researcher, provided a particularly significant impact in the development of the foam RPT system.

It is relevant to highlight that the observations in regard to online resources could be specific to this particular enquiry and technical focus, and other projects concerning different fabrication concepts might find online support resources to be of more significant value.

ACCESS TO SUPPLIERS AND THE LOCAL ENVIRONMENT FOR INNOVATION

At the outset of this study the value of good supplier and subcontractor networks were assumed as one of the key facilitating factors for the independent innovation, but the extend of this factor was not fully understood. However, through the practice enquiries it was realised just how critical the access to a network of suppliers and subcontractors was to these particular innovation scenarios. The use of local laser cutting firms has already been highlighted as a particular critical aspect in both of the innovation scenarios, but the impact the innovation environment was found to extend much wider beyond this aspect.

In particular, it was presumed that the notion of 'flexible specialisation' Kumar (1995) and also Lazonick in Fagerberg et al., (2006, pp.35–37) could used as a model to rekindle local and regional manufacturing through the use of digital fabrication tools. While the importance of the local environment seems evident in this study, the researcher believes that the original notion of flexible specialisation have some different characteristics from the one that was identified in this study. More specifically in addition to the notion of sourcing services from a local (physical) network of specialist companies, the individual innovator can now also use the Internet to create an additional network of specialist subcontractors and service suppliers. Consequently, a more current model of flexible specialisation could therefore be presented as two spheres of network; a local one based on interaction with companies with a physical presence (bricks and mortar) and a remote one, consisting of companies where only web interaction is undertaken.

In relation to this study, an example of this structure can be presented as the local suppliers of the stainless steel components and aluminium profiles as representing the local sphere of flexible specialisation. As an example of the remote network, companies that supply the specialist CNC parts could be highlighted. The building of a digital fabrication system based on CNC technology still remain a fairly specialised activity and consequently very few of the parts can be sourced locally. Most CNC parts are generally only available via online suppliers, but these internet based companies are plentiful and there are very good options for the sourcing of parts to support almost any level of technical engagement with CNC technology. This network of suppliers was a critical facilitating factor in the development of the foam RPT system.

The spheres of suppliers utilised in the practice aspects of this study could be further separated into two subcategories; one being the suppliers of the technical parts for the development of fabrication systems, with the other being the category of suppliers of the materials that the fabrication systems are intended to manipulate. In it worth noting that in the latter category, the position was almost reversed from that concerning the suppliers of specialist CNC parts. In this category certain materials were found to be only available from local suppliers, with the supply of sheet glass providing a good example of such a situation. Another aspect, which is worth highlighting, is that the researcher found the personal interaction with such suppliers provided access to highly valuable knowledge and insights concerning the characteristics of the materials, Additionally, such interaction was also a useful source for industry insights. The researcher considers that such knowledge would have been very difficult to retrieve from online sources.

In conclusion, it seems evident from this study that a network of online as well as local, (physical) suppliers provides an environment, which enable the independent innovator to operate increasingly effectively. The two *spheres* of suppliers presented here can be seen as providing the independent innovator with a support network that can be described as a new, hybrid, type of flexible specialisation.

PROTOTYPING APPROACHES AND DEVELOPMENT METHODOLOGIES

In the practice strands of this study the researcher tried to adopt developmental approaches that are characteristic of the subcultures that are currently associated with independent innovation activities, such as the Maker Movement and Hacker communities. Such approaches are typified by development through practical prototyping rather than theoretical pre-planning. The value of practical prototyping is also referenced by authors such as Schrage (1999), who, in particular, advocates the value of experimentation and 'improvised' exploration in wide range of innovation scenarios.

The researcher found, in his explorations, that a development approach based on very active prototyping had distinctive advantages – particularly in regards to the speed of development. It is also argued that such an approach can be identified as having led to the creation of specific technical solutions within the RPT systems; solutions which most likely would not have been achieved had development approach based on theoretical planning been employed.

MATERIAL KNOWLEDGE

Several parts of this research include findings that highlight the significant role that the moulding medium played in the innovation process by informing and directing the development with the two fabrication concepts. In both of the practice strands the material characteristics of the moulding medium (glass and upholstery foam) had a fundamental impact the construction and use of the production systems.

While it could justifiably be argued that the material characteristics of the fabrication medium are relevant in all tooling and moulding processes, the required material characteristics in the practice elements of this study are very specific. With the glass RPT investigation, only the precise properties of molten sheet glass (heated to a very particular temperature) would work with this tooling system. Equally, the foam RPT system is entirely dependent on the specific material characteristic of furniture foam being both elastic and compressible. In order to fully explore both of the tooling applications, the researcher had to gain extensive experience with the moulding mediums and make adaptions to the RPT systems in response to the developing knowledge of the material characteristics of these mediums.

In summery, the findings of this study provide evidence that intimate knowledge of materials is critical important in innovation scenarios involving the production of physical artefacts.

CONCLUSION

The finding of this study confirms the hypothesis that the *access* to innovation tools is one of key facilitators for the independent practitioner to innovate. But the findings of this study also indicate that a number of other factors and aspects also contributed to the innovation scenarios in the practice elements of this study. As a concluding argument the researcher proposes that this collection of innovation enabling factors could best be represented as an *Innovation Tool-Set*, with an illustration of this model presented in the figure below.

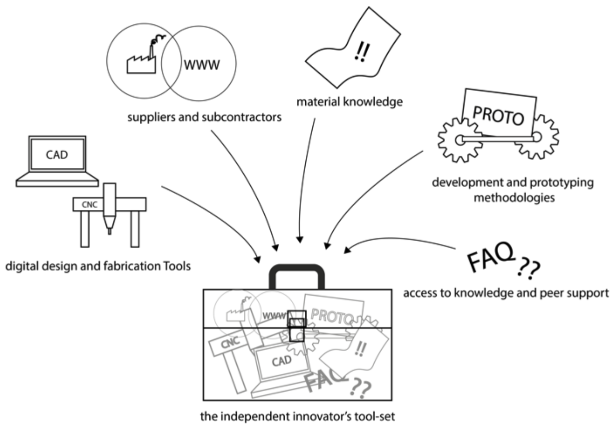

Figure 11: Enabling factors for innovation - compiled into the notion of an innovation tool-set.

While the exact composition of the *tool-set* in this model clearly can vary from one individual innovator to another, the researcher proposes the overall structure of this tool-set model reflects the *general* characteristics of this study's current context (the independent innovator in the operating with digital fabrication).

It could be argued that it is the *material knowledge* factor that presents the most obvious potential for variations in this model, and clearly the two practice strands of this study concern entirely different moulding mediums with very different characteristics. To further clarify the *material knowledge* aspect in this model, this factor is to be understood as an enhanced level of 'tacit knowledge' (Bolt, 2007) or 'material thinking' (Carter, 2004). The researcher considers that while very *specific* material knowledge can be useful in an innovation scenario, in terms of the tool-set model proposed here the material aspect should be seen as a more *general,* enhanced material understanding rooted in tacit knowledge developed from practical experiences.

SHIFTING INNOVATION POSITIONS AND SPHERES

It is important to note that the two practice strands represent two different innovation *spheres* and innovator *positions*.

In the glass RPT investigation the researcher explored how new tools could be developed by the *user* and this scenario can therefore be seen as illustrating how innovation can be delivered within an *own* practice or sector. In the foam RPT investigation the researcher developed an upholstery foam shaping system in consultation with a local furniture company. In this practice strand the researcher used broadly the *same* innovation tool-set that he employed in the glass investigation. While the technical solutions and moulding medium differs in the two practice strands, the more significant difference in the two practices strands is rooted in the innovator position in the two scenarios. The researcher can be seen moving from operating within his own practice to delivering innovation in an external sector or field. The role of the researcher could therefore be described as shifting into an *outsider innovator* position. A diagram illustrating such a *shift* in the innovation *spheres,* as well as the innovator *positions* is illustrated in the model below.

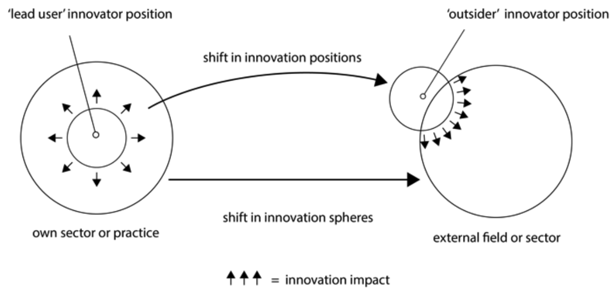

Figure 12: Illustrating the shift in innovation spheres and innovator positions.

As a concluding insight the researcher argues that it is the combination of factors in the innovator tool-set previously described, which enable the independent practitioner to make the specific *shift* from a *user* innovator position to operate effectively other sectors in the role as the *outsider* innovator.

The researcher argues that this model could be used to encourage and foster future independent innovators operating beyond their own practice sphere.

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