# HARNESSING THE POWER OF EXPERIMENTATION THROUGH DESIGN THINKING AND AGILE METHODS

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## ABSTRACT

Design thinking and agile thinking are approaches that have great value in product innovation management. While they may be widely discussed in practice, it is unclear to what extent they are understood and how they are applied. To answer these questions, qualitative research was conducted with design engineers involved in product innovation. Interviews focused on the type of iterative development used and the extent to which experimentation, with a variety of media, contributes to design and innovation. The research examines experimentation through creation of low-fidelity models. These include mechanisms modelled using construction toys, or scale models created from materials found in a workshop, to test and explore ideas. We use the concept of boundary objects to explain the way that these low-fidelity models facilitate communication between individuals who possess differing sets of knowledge. A variety of experimentation techniques are identified, from hand drawn sketches to simple models, which contrast with computer drawings and simulations. A distinction is revealed between those who trust their own intuition and creativity compared with those who rely on objective measures and trust computer models. A question over the extent to which design involves analysis and synthesis is demonstrated in this distinction. The contributions of this research are as follows. Firstly, it reveals the ways in which technologies – old and new – enrich the armoury of the designer, by facilitating the exploration and communication of ideas. Secondly, it provides insights into the role of experimentation in innovation by examining the use of low-fidelity prototypes. And finally, it draws comparisons between design and agile methods, finding opportunities for cross-fertilisation and suggesting how managers may wish to support designers in innovation projects through agile methods and by encouraging experimentation.

**Keywords:** Design thinking, Agile, Experimentation, Boundary Objects

## INTRODUCTION

Innovation projects, particularly in their early stages, are challenging due to uncertainty. Technological complexity, competitors' strategies and customers' preferences are all difficult to predict in advance and create uncertainty (Sommer and Loch, 2004). In response, managers are regularly advised to adopt methods such as design thinking (Bolland and Collopy, 2004; Brown, 2008; Martin, 2009) and more recently agile thinking (Rigby et al., 2016). Both approaches have become widely used by companies and investors seeking to reduce risk and improve the probability of successful innovation. Yet the ease with which such concepts can become merely buzzwords (Johannson-Skoldberg et al., 2013) risks reducing the value, successful adoption and ultimately the credibility of these approaches. While many companies may use the terms, it is not clear whether they understand them or apply them as intended.

At their core, both design and agile thinking can be characterised by similar or complementary behaviours and approaches to problem solving. For example, both emphasise the experience of users and encourage development of solutions based on users' often implicit needs. Design thinking is most widely understood as following the ethnographic approach to user research and regular use of prototypes implemented by IDEO (Hargadon and Sutton, 1997, 2000; Brown, 2008) or the managerial approach used by Alessi (Verganti, 2009). Design thinking has become commonly referenced in product innovation, although frequently becomes a buzzword or a rigid and unhelpful approach. Meanwhile agile methods have become almost ubiquitous in software development, similarly focusing on understanding users and their requirements from an experiential perspective, with tools such as user stories and personas (Beltagui et al., 2016). Agile methods are contrasted to the so-called waterfall approach, although curiously, the origins of this term are from a paper suggesting testing and iteration between stages in a software project reduce the cost of rework later (Royce, 1970). In other words, the paper that coined the term waterfall advocated an agile approach, so agile arguably predates waterfall.

Modern agile methods focus on delivering a minimum viable product after every period of work, known as a sprint or timebox. These may be mockups or prototypes that are valuable to the customer, in order to communicate or demonstrate, or should be working prototypes that are potentially shippable. In product innovation, similar approaches have been sought for creating low fidelity prototypes (Rudd, 1996; Sauer and Sonderegger, 2009). For example, Google glass, a wearable technology product embedded into a pair of eye-glasses, was developed using prototypes built from coat hangers and other available low-fidelity tools. As Thomas Edison is reported to have said, innovation requires a pile of junk to test ideas with (Hargadon and Sutton, 2000). While low-fidelity prototypes are common in agile methods and software development in general, their use in product innovation, as a means of developing, testing and communicating can be better understood. The purpose of this research, therefore, is to understand the extent to which such agile approaches are used in product innovation. We follow the tradition of documenting effective practices to generate theoretical insights (e.g. Hargadon and Sutton, 1997) and interrogating accepted principles to understand their central elements (e.g. Dorst, 2011). The purpose of this study is to investigate the overlaps between the two approaches of design thinking and agile with a focus on what lessons can be learned through cross-pollination. Through in-depth interviews with design engineers and project managers, the complementarities between the approaches are uncovered, generating insights for product, service and process innovation.

## LITERATURE REVIEW

### Agile

The origins of the agile software development movement can be traced to Takeuchi and Nonaka's (1986) seminal article on innovation in the Japanese automotive sector. In this context, innovation projects resemble rugby – a series of collective scrums and individual sprints – as opposed to the more common but less efficient relay race. This makes it logical that agile methods used by software teams should be applicable for contexts such as engineering product design (Rigby et al., 2016).

Agile methodologies encompass "ability for quick adaptation to changing requirements" (Kettunen, 2009, p. 408) and empower teams working closely with customers to create high-value and cost-effective outcomes through frequent short iterations. Both the close connection with customers and the dependence on an iterative development cycle align these methodologies closely with design thinking (Brown and Martin, 2015; Verganti, 2009). The key aspects of the agile approach are collective effort, overlapping phases and iterative experimentation. These are also regarded as key aspects of design(erly) thinking (Johansson-Sköldberg et al., 2013).

### Design Thinking

Design thinking has become increasingly prevalent in the management literature. Bollond and Collopy (2004) argue that managers should be schooled in the thinking techniques commonly employed by designers. They build on Herbert Simon's (1969) argument that all artificial sciences (e.g., engineering, medicine and economics) should be treated as design sciences. This means they are concerned with changing a present situation to a more desired one, as opposed to discovering the nature of the present situation, as natural sciences do. It also leads to the proposal that those involved in the artificial sciences, should be trained to think like designers. Lawson (1994) was able to demonstrate that designers and scientists use different approaches to solve problems. He found that scientists were more likely to analyse available information, to understand the rules and wait for the ideal solution to present itself. Meanwhile, designers proposed solutions and examined the results in a trial and error process– they were focused on finding a working solution quickly and then refining it. Schön (1991) described the idea of reflective practice, which lies at the heart of design theory. He observed reflective practitioners who act not as detached observers making disinterested decisions as the result of analysis. Rather they behave as though they are involved in a conversation with the problem. They act and reflect on the changes an action has made before selecting the next course of action. This approach resonates with Archer's (1965) insistence that design is not merely analysis but requires the creativity, interpretation and decision making that only a human brain can provide.

Liedtka and Ogilvie (2011) also focus on the prevalence of two distinct mindsets, fixed and growth. The former demands certainty and the avoidance of risk, resulting in the desire to place big bets slowly, the latter is open to experimentation and making small bets quickly. One of the key differences between these two mindsets is their view of customers. While both types of mindsets are required (Martin, 2009) to make businesses truly successful, the latter approach to management has been found to be more successful for growth (Liedtka and Ogilvie, 2011). In this mindset views customers as people rather than as data. In design thinking the customer or user is seen as central (Brown, 2008) and the focus is on understanding unfulfilled and/or unrecognized customer needs and propose solutions.

**Experimentation**

Successful innovation search is a crucial first step in the development of new products, services or processes. Faced with escalating expectations for innovation, intense risks and moving targets, firms increasingly adopt strategies based on experimentation. The goal underlying such methods is to obtain early feedback about new ideas with a minimum of up-front investment. Gillier and Lenfle (2018) summarize the main categories of experimentation-based methods ranging from algorithmic search – where the problem to be solved is known at the outset and remains stable, to adaptive search, which allows for re-specification of the problem, to random search in which the problem emerges as experimentation proceeds and to expandable search – where the problem expands as experimentation proceeds. Of these, algorithmic search is the most traditional method and draws on longstanding models such as Newell's (1959) General Problem Solver model. Meanwhile, a decade later Simon's (1969; 1973) work on scientific discovery and design highlighted the difference between well-structured problems and ill-structured problems, referred to as *wicked problems*. This work espoused an experimental approach to problem solving consisting of two main steps, the formulation of the problem and the search for a solution. A foundational assumption of Simon's work is that the problem can be formulated up front, thus providing clear direction for solution search. This is in line with Thomke and Fujimoto's (2000) recommendations for front-loading problem definition and problem solution, i.e. defining and solving problems early in the new product development process, even if only temporarily or partially.

When faced with demands for "innovation at the speed of information" (Eppinger, 2001, p.149) developers naturally migrate towards more experimental approaches. However, experimentation is not without its pitfalls and getting stuck in infinite loops of iteration and indecision can ultimately end in failure. This has led to the formalization of various methodologies to manage the experimentation process and shepherd it to fruition. Among the most popular and most widely used of these methods are the agile movement and design thinking.

Designers tend to follow a process of experimentation that revolves around iteration, trial and error and prototyping (Thomke, 1998). The role of the designer in this instance is to help elicit requirements through the use of prototypes – which may well be "low-fidelity" prototypes (Gerber and Carroll, 2012) – to reveal unknown-unknowns (Jensen et al., 2017). Early prototypes represent a low risk opportunity to fail and to learn through failure. They also allow for regular delivery of functionality in the same way that agile projects require delivery of working software code after each sprint. This approach is well suited to projects involving complexity and uncertainty, where experimentation helps to overcome initial ambiguity (Pich et al., 2002; Candi et al., 2013). Thus an agile project management approach, allied to a design thinking approach to problem solving, may show promise as an approach to innovation management.

Juxtaposed against the notion of the effectiveness of experimentation (Thomke, 1998), a somewhat contradictory stance is argued by Verganti (2009) who argues that too much reliance on customer input is likely to lead to insular thinking and incremental innovation. Indeed, a strong reliance on seeking input from and listening to (potential) customers might work against the kind of knowledge and technology brokering (Hargadon and Sutton, 1997 and 2000) that can lead to breakthrough innovation.

Indeed, the key to successful innovation may be more about flexibility than about following customers. In fact, firms tend to react to high levels of turbulence with attempts at flexibility (Eisenhardt and Tabrizi, 1995). Candi et al. (2013) propose an important distinction between flexible project planning and flexible project specifications or definitions. They find that only the latter – being flexible about the definition of problems – is related with performance outcomes. In fact, they find flexible project planning to be negatively related with performance. This highlights the importance of being deliberate about innovation methods while also maintaining flexibility about problem definitions. Thus, simply raising the flag of agile or design thinking is not likely to lead to success, but rather the deliberate implementation of these strategies around problem definitions that are expected to be in constant flux.

**Boundary Objects**

Boundary objects (Star & Griesemer, 1989) are artefacts that facilitate communication between individuals who possess different types of knowledge. They help to overcome knowledge boundaries by being flexible enough to enable multiple interpretations and hence facilitate communication. The concept originally emerged from a study of multidisciplinary teams working in Zoology museum. While levels of expertise and types of understanding varied between academics, scientists and enthusiasts, the use of objects such as maps and field research notes helped these disparate individuals communicate and share knowledge. Carlile (2002) applied this concept to a study of automotive product development. He identified the use of technical drawings as a means of overcoming boundaries between design and engineering personnel. These drawings enable interpretations to differ while offering a basis for shared understanding and communication, or "a shared syntax or language for individuals to represent their knowledge" (Carlile (2002, p. 451).

Boundary objects may be stable representations of expert knowledge, but but they can also be open, enabling conversations to be started (Nandakhumar et al., 2013). A related example is Schön's (1983) idea of reflective practice, whereby an actor's knowledge is developed through a process of interaction with objects. Schön (2017) describes an architecture student's conversation with her tutor in which a drawing is used to exchange knowledge between the individuals. More than simply communicating, the drawing allows both to share their ideas and overcome boundaries in their knowledge. Yet the drawing allows ideas to evolve – by acting, reflecting and then taking the next step, the design the is shaped by the situation. Moultrie (2015) used the concept to explore how designers and scientists communicate when bringing new technologies to market. The boundary objects in his study were *sketch models*, in other words simple, low-fidelity physical models that communicate ideas and allow exchange of knowledge across the boundaries of the groups involved.

## METHODOLOGY

Research was carried out in an engineering design office, in which a wide range of design skills are applied to client projects. Interviews were conducted with engineers and project managers involved in early-stage innovation projects. This was seen as an ideal context to examine the complementarities and possible combinations of agile and design thinking methods. Interviews focused on two key topics. First, the nature of design work, with regard to how users are engaged and how iterative project phases are managed. And second, the use and value of low-fidelity prototypes or sketch models (Moultrie, 2015). The interviews, combined with participant observation of design teams in action are used to elaborate the findings.

**Table 1 – list of interviews (job titles have been generalised in the interests of anonymity)**

| | | |
|---|---|---|
| 1 | A | Design Engineer |
| 2 | B | Engineer |
| 3 | C | Design Engineer |
| 4 | D | Design Engineer |
| 5 | E | Engineer |
| 6 | F | Engineer |
| 7 | G | Project Manager |
| 8 | H | Engineer |
| 9 | I | Design Engineer |
| 10 | J | Design Engineer |
| 11 | K | Project Manager |
| 12 | L | Project Manager |
| 13 | M | Senior Design Manager |
| 14 | N | Project Manager |

## FINDINGS

Three main themes emerged from the study, each of which is explained below. Firstly, the agile, iterative approach used by designers and how this may conflict with the structure of clients' project processes. Secondly, the use of experimentation to create boundary objects, allowing communication. Finally, the applications found for different forms of experimentation, from sketches to 3D printed models.

**Agile and design thinking in innovation projects**

Customers' processes can inhibit creativity and limit the ability to design. To avoid this, designers look for autonomy within the boundaries of the process, for example they have flexibility to implement their own process and deliver concepts or prototypes into the customer's reviews:

> *"I think the process with the big customers is more around the review system where… they gave us a project and then we go away and come up with a concept for a kind of solution, a design solution to the problem and then we go and comply with their design review system…we basically seem to use our own design process because we're working, not in isolation, but the actual physical design, we're left to our own devices really. It's the review process that we have to comply with… From what I see. It's more of a process where we are complying with the customer's system and then we go away and then do our thing our way and then come back." (Senior Design Manager)*

This autonomy, within an overarching structure is readily recognisable as a classic Stage-Gate style process. It also mirrors the approach of agile methods, in which the team are "left to our own devices" in sprints, punctuated by scrums when a minimum viable product is delivered to the customer. This freedom to experiment and deliver is very important, but typically needs to be negotiated and protected, since it often conflicts with the standard approaches used by customers.

> *"we are quite...what's the phrase they like using? "agile", so we are quite quick at getting on with things but the problem is [our customers] are quite risk averse. …if the process is shoving you down this path of "we need this for this date, this for this date, this for this...." and then you go "well if I had delayed that for two days, we would have had something twice as good. That's not agile, that's too rigid, but [the customers] are very strict on process because they are so risk-averse… They would have gone through the design review and rather than saying "we're not quite ready for the design review, let's take a step back" they would say "design review is today". And you just think that, "well we've hit our target" and the product is secondary almost. Because you do get that feeling sometimes that the product is secondary to the process...there's lots of paperwork like config management plans and plans. Everything has got to be planned to the Nth degree..." (Design Engineer)*

The purpose of using agile methods (e.g. Beck et al., 2001) includes ensuring a focus on interactions over mindless application of processes, and working outputs over documentation. The quote above demonstrates how the same issues can be seen in product innovation. The aim of using processes in innovation is normally to manage risk and uncertainty, yet designers may prefer to achieve such results through experimentation, if they are given the flexibility to do so:

> *"if you draw something, in your head you think that's the best idea in the world. If you put it on a piece of paper, you think hang on that's never going to fit because you can't get your hand in it sort of thing, simple things like that. It's easy to imagine things in your head and I think this is one of the issues I have with people doing things in CAD: it looks fine on screen but then you, if you make it in paper or cardboard or sketch*

*something up really quickly, before you've spent ages and ages getting something looking great, you realise hang on, why is my pen that long? I think it's just a really good initial de-risking exercise, sketching things." (Design Engineer)*

*"people have done something in CAD, sent it to the machinist and the machinist has gone "I can't make that because its got a hole somewhere that you can't get to with a machine" whereas if you'd got a bit of foam and just drilled the hole through, then you could say "I can't get in there, I can't get a drill in" so you could get something really simple. This is what we used to use 3D printers for. About 15 or 16 years ago, we used to use it for de-risking things because you'd initially make something on a machine, but then people started doing really simple tiny components on the 3D printer because its just as quick to do that, because you can press and go and leave it and walk away. It de-risks, doing something that's cheap and effectively disposable, it de-risks before you start spending because staff time is very expensive. If I spend all day on CADing something, that's like 100 quid or whatever it costs the company. Whereas if I take 15 minutes to get a bit of paper and go "oh I can't do that, there's a problem" its quite useful." (Project Engineer)*

**Experimentation and boundary objects**

When developing novel solutions to design problems, clarifying and communicating ideas can be a challenge. The experimentation tools that designers use may be seen as means of developing, de-risking, but also communicating concepts.

*"I'm talking to you and I want to explain something but I can't explain it very well, I just sketch it down. Maybe a few labels on there and after that I get the point across...if you're happy with the sketch, you might go through a CAD model, because obviously depending on how good a sketcher you are, it may not be a proper representation so a CAD model with a bit more detail is always...I think a CAD model is always included in the concept phase as far as I'm concerned, because once that phase, the concept, the CAD model has got to be there or thereabouts 'cause I think that gives you a good idea of what it is. But before that, you might have sketched it, you might have gone on the shop floor, got a bit of timber, depending on what it is and just screw something together… before I went into CAD I went on the shop floor and got where there were lying around bits of metal, cut them up, 3D printed parts, springs, levers and basically just knocked something up that worked, basically just got a working thing and that got transferred into a CAD model." (Project Engineer)*

Requirements are uncertain and often changing due to numerous factors, which may not be easily recognised. Firstly, the application and development of new technologies can create unexpected results.

*"…we've got the metal additive machine with a certain build volume. So you'd expect it to be able to build a part of that volume but the reality was that when we tried to build a part with that volume, we got...various thermal stresses building up in a large part which caused cracks and, you know, unacceptable flaws in the part." (Senior Design Manager)*

As additive manufacturing technologies are complex and still developing, the results are not accurately predictable and quality is difficult to control. Complexity comes from the mixture of technologies and underlying physical properties. Small temperature variations in the part can lead to unexpected and unacceptable flaws. Experimentation becomes essential when dealing with such novel technologies or applying them in novel applications. In this case, failure to produce a usable part generates knowledge that confirms or disproves expectations. The designer develops concepts but requires experiments to test them and move from concept to knowledge (Hatchuel and Weil, 2009). Another example comes from the way that mechanisms are developed, using small scale experimentation.

> *"So the concept was, I'd previously done a design for [a similar, but smaller mechanism], which is what I worked around. So I built this gearbox to go on the front and the way it works is that rather than having any complicated actuators, which take a lot of space, or anything like that, [the mechanism allows the speed and torque to vary, depending on the direction]. …So the customer was happy with that concept, so then I just redesigned it to the right speeds and torques using custom designed gears…But without prototyping it, it's difficult to get your head around on paper whether it is actually going to work or whether it is all going to lock up or what, but that proves it. And when you show the customer, there's no argument, it's like, it's there, it works. [laughs]. And it's fun as well!" (Senior Design Manager)*

Here the designer is confident in the solution, but possesses different knowledge to that of the customer, so the model – created using Meccano, as a low-fidelity prototype, communicates and helps cross boundaries. In other cases, customers may have fixed their plans too early, without awareness of the systemic impacts of design decisions. Creating models helps to demonstrate and communicate what the designer knows:

> *"they have come to you with an idea which is quite rigidly defined in their minds, and they don't want you to deviate from that, but we can sometimes find solutions which we think are better even though the customer doesn't necessarily want those. They can give you a whole host of reasons why you shouldn't do it like that, but at the end of the day we can sometimes come up with solutions to the knock-on problems. And then on the other end of the spectrum you've got people who just don't know, you know they're not engineers and they've just got an idea and they want us to develop it from zero to something that works, which in some ways is fine in other ways it's tricky because the customer doesn't know anything about manufacture and costs and all the rest of it, they may have pre-conceived ideas about how much something is going to cost, which is completely unrealistic so then you've got the challenge of trying to design something to a cost as well as design it." (Senior Design Manager)*

In these examples, it is necessary for the designer to educate the customer, helping to convince them that their ideas are not feasible or that there is a better solution. This is a challenge previously documented by Paton and Dorst (2013) whereby designers are often unable to contribute fully due to an overly restrictive brief, or involvement late in the process. Customers may not always understand beforehand how they would benefit from a design thinking approach, while designers may not fully understand the situation from the brief provided. In this respect, the role of experimentation is to negotiate and communicate ideas with customers, while overcoming knowledge boundaries.

One added benefit of this approach is that it helps to clarify and communicate what customers want, or what constraints have not been expressed.

> *"…so we've got so many constraints we've got light weight and they've got to be robust and things like this. So we're trying to think up ways... I modelled it up in a bit of cardboard, because I was thinking of ways of making these things out of just standard aluminium extrusion and riveting it all together, but then I was thinking...I was trying to get my head around whether you could fold something and rivet and then fold it and then you've effectively got the corners riveted. Could I do that with a single piece? So you'd make the box like that, but then can you fold that one round that corner and rivet it. So I did that in paper. You know cut the corners out, fold, rivet. Yeah you can actually do that sort of thing... before you go down the path of CADing something up, thinking "oh yeah that will work", just a bit of paper, get a scalpel, cut some boxes." (Project Engineer)*

**Modes of experimentation**

The findings reflect the value of prototyping and iteration as a tool for a) generating ideas, b) testing and improving ideas, and c) establishing and understanding unstated requirements. The approaches and tools used vary depending on the stage of an innovation process, but also the backgrounds and preferences of individual designers. For example, while some extoll the value of sketches or of making physical prototypes, others prefer simulation and computer based modelling.

> *"I'd rather sketch stuff, to get my head around things first... I can at times just knock up really rough models, I think we use, well we do use lego quite a lot here, but even lego is a bit too 'good' sort of thing sometimes, you sometimes just want to stick some paper together and things like that. I quite like being able to get my head around something if I just start sketching something. Even if I do it wrong, I can see where I've gone wrong and sort of like then refine the design before I even start looking at CAD. 'cause the problem with CAD is I think, you try to design it perfectly straight away, then you end up leading yourself down this path and you don't want to come back, whereas on paper, you just like rub it out and start again sort of thing." (Design Engineer)*

> *"[one previous colleague] was very very good at CFD and the theoretical analysis of airflow and, you know, the fluid dynamics. And he was perfectly happy sitting at a computer, analysing these shapes. I assumed that he would jump at the chance of going down to the workshop and actually building what he had analysed and he had developed himself and he'd want to do that. But it turned out that he actually didn't. You know, you take him down there and he's just not interested in the hands on aspect of it at all. He would rather sit in front of the computer and do analysis, which didn't invalidate his design at all, very good but he would never have sat down and sketched something… So there are certain people like that, who are very good at the shall we call it the engineering, almost the applied mathematics part of it and there are other people who are very good at the stylistic side of it and there are some people in the middle who are good at both. I think." (Senior Design Manager)*

A divide appears between those who use sketches or those who trust computers more than their own judgement or creative ability. The division may in part be generational– the more senior designers discuss the way that sketching or sketch models helps them to think. They also identify risks of using computer simulations (Thomke, 2003) or of overreliance on computers over intuition. In some cases, reliance on technology appears to compensate for a lack of experience – the more experienced designers could draw on their knowledge and were confident in their own abilities, showing some mistrust of simulation. Yet technologies, notably 3D printing, also have great value in combination with other techniques. For example, combining Legos with customized 3D printed components helps to quickly achieve valuable results, or a minimum viable product.

> *"mechanisms might be something that's based on gears, maybe some sort of leverage mechanism I tend to build in Lego because it's just quick, like super-quick to just change things over, you can try things out and go no, no, that's wrong. You haven't lost any time waiting for parts to be made, I just know, I just swap out bits to just experiment with ideas. I 3D print quite a lot of stuff. So if it's something a bit more formal like, say, one part that had to fit into another, say if it was a part dropping into a jig or another going into a hole or whatever, I'd 3D print them two elements just in isolation, just to see how it goes together or if I want to...see I've 3D printing with Lego before so if I want to get a certain bit of functionality out of the Lego just try something, I'll 3D print parts and then if it's something that's sort of, I want to try something out but it's a bit sturdier, I'll go and get stuff laser cut, occasionally if it's sort of feasible, like within the limits of 3D printing I'll print parts. Sometimes, in some ways it used to be you couldn't actually get stuff so strong. So yeah, it's generally Lego for simple mechanisms that don't have to fit the form of the final thing but, you know, you're just figuring out how a mechanism is going to work." (Design Engineer)*

## CONCLUSIONS

The study builds on prior research related to design practice, as well as seeking to link the academic debates relating to design thinking and agile management. The contributions to knowledge are threefold. Firstly, this work reveals the ways in which technologies – old and new – enrich the armoury of the designer, by facilitating the exploration and communication of ideas. Secondly, it provides insights into the role of experimentation (Thomke, 1998) in innovation by examining the use of low-fidelity prototypes. And finally it builds on a review of agile and design thinking methods to suggest a path for cross-fertilisation in future.

Most of the work people described was iterative, to some extent "the customer doesn't know what they want" and requirements emerge over time. In some cases, this was accommodated, but there were examples of project structures not quite fitting, either where processes intended for big projects are not ideal for relatively small projects or where the small project is part of a much larger programme, so there is agility in a self-contained manner within the project processes. In project management, methods and methodologies can co-exist, such that agile methods can be practiced within a framework such as Prince2.

In product innovation, the ideal combinations or which combinations work best in different circumstances can be explored in future research.

We found examples of work being done quickly to test ideas. The benefits seem to be a combination of reducing error (i.e. preventing rework later) or generating ideas (i.e. a tool to help explore and develop concepts). Using C-K design theory, we can see this as the means by which concepts are transformed into knowledge – either it works or it doesn't but either way you gain knowledge about what works. Sketching was widely used, but in many cases for the designer's own benefit – to test ideas or share with colleagues. Lego or other simple construction tools were also observed widely as a means of creating ideas and testing concepts. To present the ideas to customers, something more elaborate or convincing is required. For example, creating physical models to show scale or demonstrate mechanisms or building customised parts quickly with 3D printers in improvised low-fidelity models. Finally, while some people see CAD as either time consuming or itself restrictive, others work mainly in CAD through a combination again of experience, nature of projects and also the preference of clients/users. If the project is for someone who normally works with CAD, or it doesn't need to look nice or fit in a certain space, just support particular loads and be easy to produce, then the same rules don't apply.

The choice of method, timing and sequence was different in each example given, because of the preference and background of the individual. Some people are opposed to virtual simulations because they create a distance between the designer and the physical product. Others used CAD and FEA because they found it cheap and quick to test a number of parallel options. For some individuals the experiments are confirming designs, but others use them to create the options. The latter trust the simulation results as objective and more complete than their own ideas might be. The former trust their own intuition and experience, but use experimentation to verify and demonstrate to others. They may be sceptical of computer simulations, because of their black box nature – where the process cannot be seen, it cannot be trusted. Thomke (2003) found this a recurring theme, companies spend money on simulations, but do not trust the results when they do not support physical testing, so may spend more money on physical testing to (dis)prove the simulation results. There is an important distinction – both groups use the same tools but for entirely different approaches, either optimising or designing. The former relies on the computer to create geometries or the best configuration, whereas the latter is required when creating new options that cannot emerge from optimisation. The differences in perspective recall debates about the essence of design – whether it is something that can be carried by humans or can be automated through software (Archer, 1965; Beltagui, 2018).

Design can be viewed as a human activity requiring creativity rather than one that can be optimised based on analysis and algorithms (Archer, 1965; Simon, 1969; Boland and Collopy, 2004). Hatchuel (2001) compares these two options to the problems of 1. choosing a good movie; and 2. hosting a nice party. The first can be optimised if the choices (e.g. which movies are available) and the variables (criteria such as reviews, awards and recommendations) are known in advance. This is a case of Herbert Simon's bounded rationality, whereas the second requires what Hatchuel refers to as expandable rationality, since the terms nice and party allow for almost infinite expansion. The second problem requires design, i.e. it requires an iterative move from concept to knowledge in order to define parts of the problem before building a solution.

## MANAGERIAL IMPLICATIONS

This study provides important examples and evidence to support innovation managers in the early stages of innovation. In particular, it reveals the value of iteration and experimentation. Agile project management emphasizes these aspects and encourages them through time-boxes and daily stand-ups. The study proposes an approach to integrating these agile practices into innovation projects, to enhance the effectiveness of designers.

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