REAL MATERIAL ETHEREAL

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From Open Innovation to Design-led Manufacturing: Cases of Australian Art and Architecture

Abstract

Design Robotics is a program of research that places design and its processes and thinking at the forefront of robotic research to enable design-led manufacturing. This paper presents two cases of built works created by Brisbane based UAP Company (Urban Art Projects). UAP is a global manufacturer of urban artworks and architectural facades. The QUT Design Robotics research group and RMIT are collaborating with UAP on an Innovative Manufacturing Cooperative Research Centre (IMCRC) funded project (2017-2022). These cases are part of the Design Robotics Open Innovation Network that has been established to share the outcomes from projects with industry. This paper addresses the question, How can open innovation be employed as a strategy for architectural innovation within a design-led manufacturing organization?

In response to the research question, the cases are examined through the theoretical lens of 'Open Innovation', which describes how an organisation can purposively manage inward flows of external knowledge, and outward flows of internal knowledge to increase its ability to innovate in line with its business model (West & Bogers, 2014). The manufacture of the two cases employed an open innovation strategy to explore the potentials of advanced manufacturing technologies in collaboration with external partners. As a methodology, the researchers follow a case study strategy by co-locating within the industry partner to do on-site observations and findings. The cases are unique in that they reveal an account of the internal know-how and decision-making processes required to integrate advanced manufacturing technologies into established workflows as part of the innovation process. These built works demonstrate novel approaches to integrating robotic systems and virtual reality into the ideation, communication, design development, and manufacture required to deliver each project.

Introduction

Architecture and design industries are characterised by economic activities that rely on 'creativity' as their value offering, employing +530,000 Australian workers (5.9%), is growing at an average 2.8% annual rate, and accounts for 2.7% average annual growth in QLD creative employment (Higgs and Lennon, 2014). The Architecture and Design Baseline Reports compiled by the ARC Centre of Excellence for Creative Industries and Innovation (Hartley et al., 2012; Haukka et al., 2010) show that the architecture and design industries employ approximately 15,000 workers in QLD. In comparison, the Queensland Productivity Commission Report (2018) revenue to jobs ratio estimating that per $1B revenue in the manufacturing sector, 2207 jobs are generated. These statistics demonstrate the value of growing the creative industries and manufacturing sectors in Australia. To continue to increase job opportunities and growth in these sectors companies must be able to adopt new technologies and be innovative to increase their competitive advantage. Muller et al. acknowledge that the architecture and design industries affect the broader economy triggering innovation by generating ideas for new products and services, providing services or inputs to innovative activities of organisations in other industries, using and informing innovative development of technology (Muller et al., 2009). Similar to SMEs in other sectors, the data reveals that the architecture and design industries spend minimal resources on research or upskilling, however those that do benefit greatly.

Within the Australian context, UAP operates in an unique way; a dynamic combination of creative industries that straddles architecture, design, art, and manufacturing. UAP's clients increasingly demand mass customised products. These include complex building façade elements and interior panelling systems as seen in figure 1. In order to remain competitive, UAP has implemented an advanced robotics manufacturing capability into its workflow, a KUKA industrial robotic arm, broadening its base of digital fabrication equipment. UAP has also increased its in-house augmented and virtual reality capabilities for design development, visualisation, communication, and use in the manufacturing process. Within the Innovative Manufacturing Cooperative Research Centre (*IMCRC)* funded project *Design Robotics for Mass Customisation Manufacturing,* UAP has identified the need for transformative research into robotic vision. Combining robotic vision with their robotic equipment will increase the flexibility of their manufacturing capabilities to keep up with client demand for its products.

Figure 1. Legacy Way building façade manufactured by UAP. Photo Credit: UAP Company.

The following brief literature review presents the concepts of open innovation and design-led manufacturing to provide an overview of how these two domains of knowledge reveal pathways for architectural innovation through advanced manufacturing.

Open Innovation

Research into the implementation of advanced manufacturing suggests that using innovative processes require designers and engineers to reconsider design for manufacture where designers need to account and understand new technological processes (Mellor et al., 2014). The designer's understanding of the affordances and processes of advanced manufacturing technologies are influential factors in their implementation across industries (Mellor et al., 2014). There is a recognised need to adopt new technologies and continue to build and extend collaborative relationships and networks with clients, supply chain, partners, and researchers in order to increase capabilities and business growth. For this reason, the QUT Design Robotics group have worked with UAP to create the Design Robotics Open Innovation Network.

The concept of open innovation comes from business management referring to the manner in which an organisation manages inward and external knowledge flows. The purpose is to align knowledge adoption and creation with the business model for innovation (West and Bogers, 2014). In the Open Innovation paradigm model (Chesbrough, 2003) seen in figure 2, the boundary of a firm is represented with a dashed line to demonstrate that the boundaries are porous. The porous nature allows for the organisation to bring in and share knowledge to and from external sources in order to innovate. Chesbrough states "At root, the logic of Open Innovation is based on a landscape of abundant knowledge, which must be used readily if it is to provide value to the company that created it" Chesbrough, 2003, pg.xxv). The principles of open innovation is based on using acknowledging that making use of ideas regardless of if they come from internal or external sources is required to advance the organisation (Chesbrough, 2003).

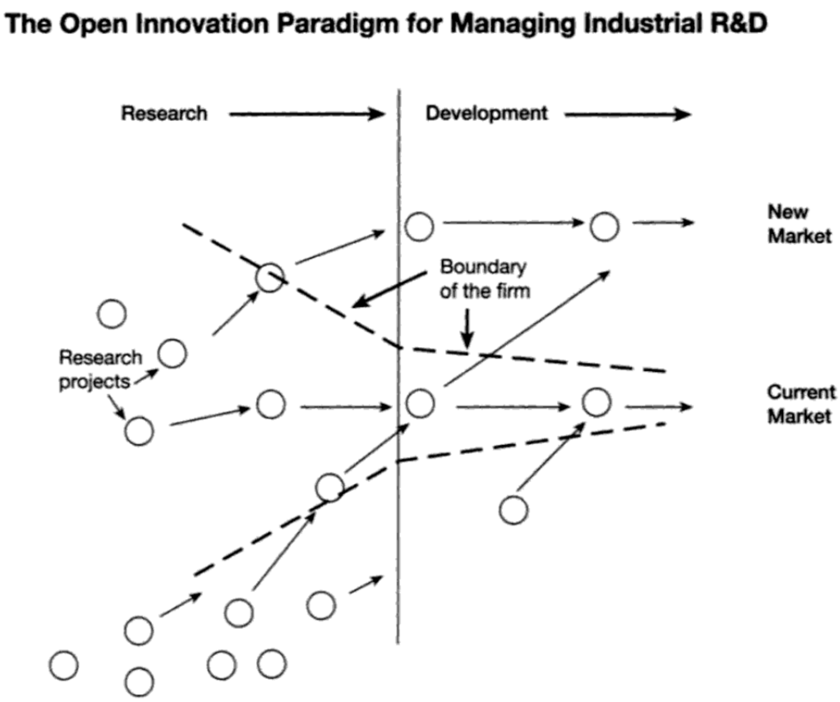


Figure 2. Open Innovation Model from (Chesbrough, 2003).

Creativity is defined by Amabile as the generation of ideas and results that are in response to an end goal and novel (Amabile, 1988). Innovation is the implementation of creative ideas, successfully contributing to the achievements within an organisation (Amabile, 2012). In the case of UAP - which is a highly creative organisation in its work, mindset, and its client base - creativity and innovation go hand in hand in their approach to problem solving.

The creative processes embedded in fields such as architecture, design and art are inherently suited to the notion of open innovation and networked conceptualisation of knowledge. Teece et al. (1997) define desirable dynamic capabilities as a "firm's ability to integrate, build and reconfigure internal and external competencies to address rapidly changing environments" (p. 516). This relates more broadly to the ability to adapt path dependencies, and overcome "cognitive inertia" (Bouchikhi and Kimberly, 2003, p. 20) in practice and management. Design professionals are trained to engage in both inductive and deductive problem-solving processes which is reflective of intrinsically dynamic shifts in thinking as part of everyday practice, as seen in figure 3.

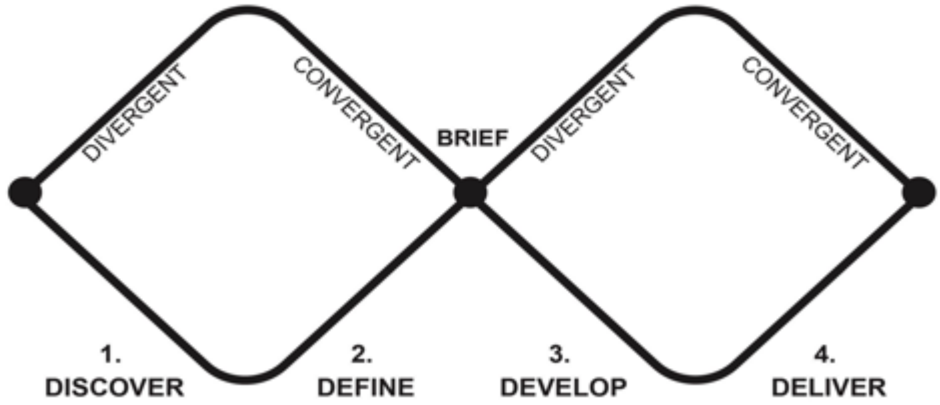


Figure 3. "Double-diamond design model" Adapted from (Design Council UK, 2017)

Design-led Manufacturing

There is a growing trend and interest in design-led innovation which refers to the integration of design thinking approaches as cultural transformation across business (Bucolo and Wrigley, 2014). Knowledge from design-led innovation research examines how design can support the manufacturing sector in driving global competition (Bucolo and King, 2013). According to Burns (2006), Design-led manufacturing is promoted as a means by which Small to Medium Enterprises (SMEs) in traditional industries can combat the threat of low-cost overseas labour and compete successfully in a global marketplace. Beverland and Farrelly state that organisations which embed design throughout, share common values and an appreciation of curiosity, empathy, and "design as a physical manifestation of the brand" (Beverland and Farrelly, 2007, pg. 12). Design-led firms locate design as the central aspect of their commercial position (Beverland and Farrelly, 2007).

Therefore, design-led manufacturing is the manufacture of a product that has focused on the design from concept through its manufacturing lifecycle. UAP employs its creativity and design thinking to address and overcome problems to innovate and achieve bespoke manufacturing, where we refer to UAP as a design-led manufacturer of art, design, and architecture. UAP's design-led approach fits the description of Verganti's (2009) "design as making sense of things". With the motivation to achieve the artist's intent, they are looking for innovative meanings to manufacture the artworks.

A design-driven innovative company like UAP are interpreters, they contextualize themselves both in sociocultural terms and in technical terms, in the context of their locality in Queensland and also as a global firm in the world. According to Verganti (2009), such companies understand that knowledge about meanings is diffused throughout their external environment; that they are immersed in a collective research laboratory where interpreters pursue their own investigations and are engaged in a continuous mutual dialogue (figure 4). By nature, UAP is constantly working with artists, designers, cultural organisations, technology suppliers and research and educational institutions.

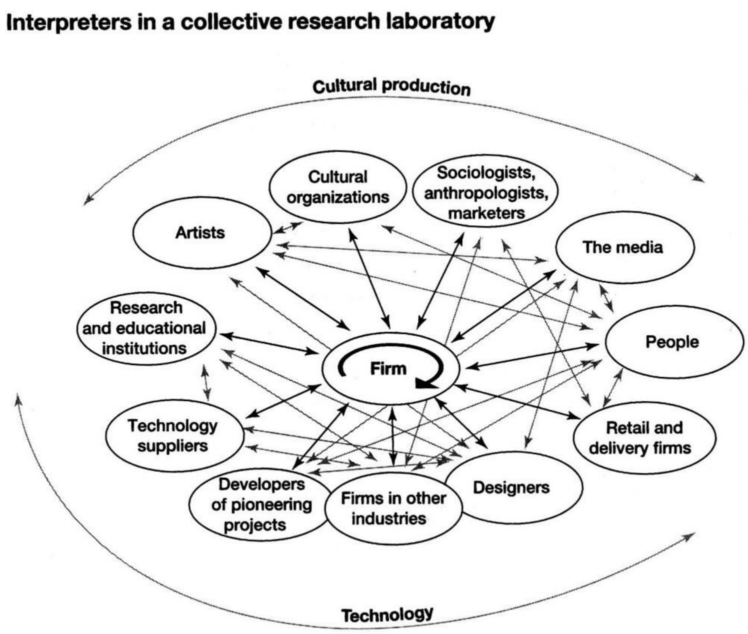


Figure 4. The interpreter and design discourse (Verganti, 2009)

The area of design-led manufacturing offers unique opportunities to explore the future of advanced manufacturing technologies in an applied industry setting. Artists, designers and architects continually push the limits of what is possible to manufacture. The companies that translate these artistic, design and architectural visions into reality need to balance between competing demands of maintaining the creative integrity of the work, liaising with external stakeholders including artists, commissioning bodies, developers, and suppliers, and finding cost effective and feasible solutions for the fabrication process. Art and design fabrication requires innovative experiments with new materials and manufacturing technologies to meet these demands and relies on the input of a highly skilled artisan workforce.

Methodology

The purpose of the IMCRC Design Robotics project is to address UAP's need to implement advanced manufacturing technologies into their workflow. This is achieved by making industrial robots easier to operate and in particular to create robotic vision capability for their industrial robot so that it can respond to bespoke forms. As part of the Design Robotics Open Innovation Network, the research team works closely with UAP to identify commercial projects which incorporate advanced manufacturing technologies such as robotic milling or augmented reality into their manufacturing process.

In this paper, we employ a case study methodology to examine a particular phenomenon in a set unit of time (Gerring, 2006). The research reports on two cases of built work manufactured by UAP between 2017-2018. We examine these two cases which demonstrate the range of processes employed by UAP required to address the needs of their clients and collaborators. The QUT Design Robotics research group has been co-located at UAP headquarters in Brisbane since March 2017. This co-location ensures that the research team is embedded and aware of UAP's needs and that the research is responsive to its firm-centric views and culture. In this way, the collaborative partnership is able to overcome some of the challenges associated with what Bogers et al. (2017) refer to as "face spatial challenges" in which access and separation of co-creators can limit communication (2017, p. 20).

Co-location of researchers at UAP has proven to enhance the partnership and absorptive capacity and knowledge-sharing. Research activities that occur within UAP headquarters includes the QUT Design Robotics research team to observe work practices, understand UAP's values, organizational structures, internal expertise, external drivers and influences. As such, monitoring and investigating the development and implementation of advanced manufacturing technologies into their processes informs the researchers' awareness of UAP's creative approach to problem solving and ability to innovate. In addition to the project briefs, UAP's design and project managers compile images of each project at different stages, including a summary of actions taken. Collectively, these documents provide an overview of the case study projects and the innovative application of advanced manufacturing technologies. Qualitative methods are used to capture the research team's observations in order to supplement the documents provided by UAP. Methods include note taking and memoing of work practices and project updates, questionnaires, and interviews informed by traditions of ethnographically informed design research (Crabtree, 1988; Pedersen et al., 2003). Non-intrusive questionnaire tools are used with the purpose of obtaining information about the manufacture of the case study project from staff across UAP's departments. Questions include:

- What was done differently with this project?
- How was an advanced manufacturing technology used in the process?
- Why was it done that way?
- What challenges were included?
- How would you do it differently next time?'

After compiling the questionnaire results, targeted conversations are conducted with UAP staff. This allows the research team to follow up and ensure that the information compiled through the questionnaire is accurate. The conversations allow for a discussion to emerge concerning specific points in the case study project manufacture that may have been unexpected or unclear.

The research methods used in this research are further reinforced by weekly team meetings between the QUT Design Robotics research team and UAP directors. This enabled sharing of project updates to inform the research team's understanding of the project's progress and allow for first-hand accounts of technical and process developments. Throughout the project, the research team work in collaboration with UAP's staff from departments including curatorial, design, documentation, and manufacturing. Through this, the research team compile reports for each Design Robotics Open Innovation project, where the learnings from the process, the challenges and opportunities with the technology are documented. These reports form the bases of the cases discussed in the following sections.

Findings

In this section, we present two case studies and provide an overview of the advanced manufacturing technology implemented in the manufacture of a sculpture (Case 1) and an architectural façade element (Case 2). Examining the outcomes of these Design Robotics Open Innovation cases illustrates the value of these projects for UAP in the development of design and engineering capabilities for mass customisation through an open innovation approach. The collaborations that have been developed by UAP with the research team, the artists, and clients also inform UAP's progress in developing mass customisation capabilities required to achieve complex architecture and large scale urban art works.

Case 1 – Artist Project, Emily Floyd

The first Design Robotics Open Innovation project was completed in August 2017 in collaboration with artist, Emily Floyd. The process combined the artist's traditional hand-carving techniques with advanced manufacturing technologies and was employed by UAP to complete a series of six 'literary' parrots. The KUKA robotic arm was used to mill sand moulds for aluminium casting of the different parts of the parrot sculpture named "Poll"; a literary reference to Daniel Defoe's character, Robinson Crusoe. The diagram in figure 5 explains the process of open innovation that informed the creation of Poll the Parrot where external sources of creative and technological knowledge that was new to the process, and external sources of research support were brought into the organisation's domains of practice. The open innovation diagram is based on the work of Henry Chesbrough (2003) as discussed in the earlier section on open innovation.

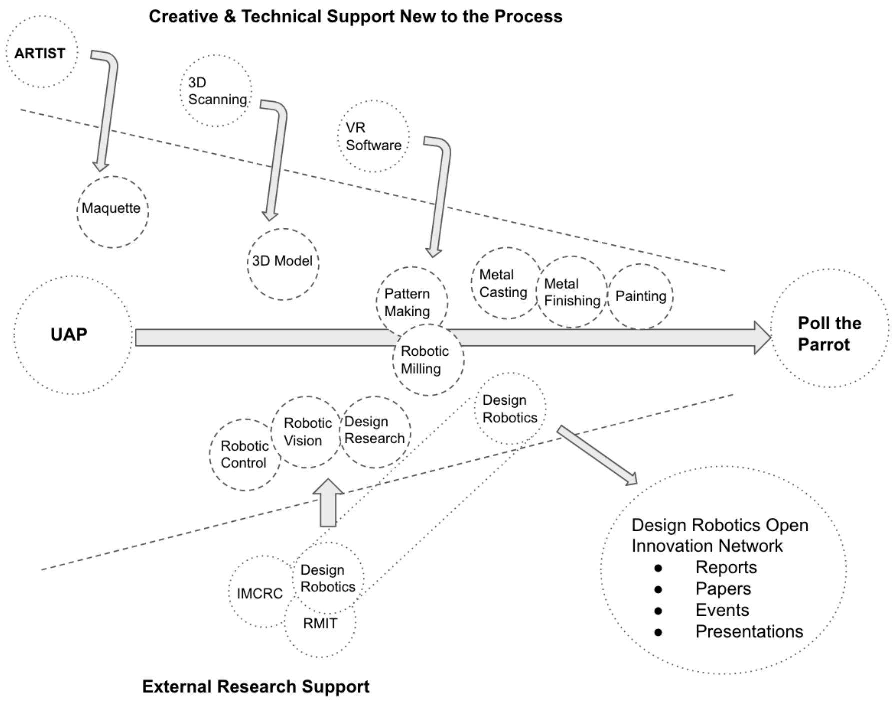


Figure 5. Open Innovation Diagram of Case 1 – Emily Floyd's Poll the Parrot

The diagram depicts how the artist Emily Floyd, an external client, provided the design brief and original maquette from which the sculpture was created. UAP translated the 300mm carved wooden maquette scaled at 1:10, into a 1400mm high sculpture. In order to upscale from a wooden maquette, such as that created by Floyd, UAP would previously employ their documentation team to create a digital 3D model from images of the maquette. Alternatively, in other instances UAP's pattern makers would scale directly from the maquette and hand-carve the pattern without a digital 3D model.

In this case, by bringing in external sources of knowledge to innovate, the process used to create “Poll” the parrot utilised a digital 3D model of each of its elements which was provided via a 3D scan of the maquette. To achieve this, UAP employed an external contractor with 3D scanning expertise to scan and create the 3D model of the parrot. Relying on internal knowledge from UAP’s mixed reality designer who had experience from the gaming industry, they used Oculus Medium software in virtual reality to scaled up the 3D model to final production size. The digital 3D model of the parrot generated by the 3D scan served two purposes:

1) Allowed the design team to scale the model up to actual size in virtual reality,
2) The artist was able to visualize the scaled-up digital model in UAP’s virtual reality system prior to commencing manufacturing works.

In the virtual reality environment, Floyd was able to provide live input into the design of the digital 3D model. The artist was able to identify any imperfections in the form of the parrot in the scaled-up digital 3D model. These imperfections were raised or smoothed using the Oculus Medium virtual reality sculpting software by UAP’s documentation team.

Using the scaled 3D model, UAP was able to prepare each piece of the sculpture for robotic milling of the sand mould. The 3D model was used by the documentation team to create an inverse form for each part of the parrot (i.e. head, wings, beak, tail) as seen in figure 5. The inverse form was used to model a sand block to be milled by the robot. These were used to create a tool path in Autodesk Powermill Software, creating the mould for casting each piece. The QUT and RMIT design robotics team provided research and expert support in terms of robot control, robotic vision, and using design research methods. The images in figure 6 are from the milling process.

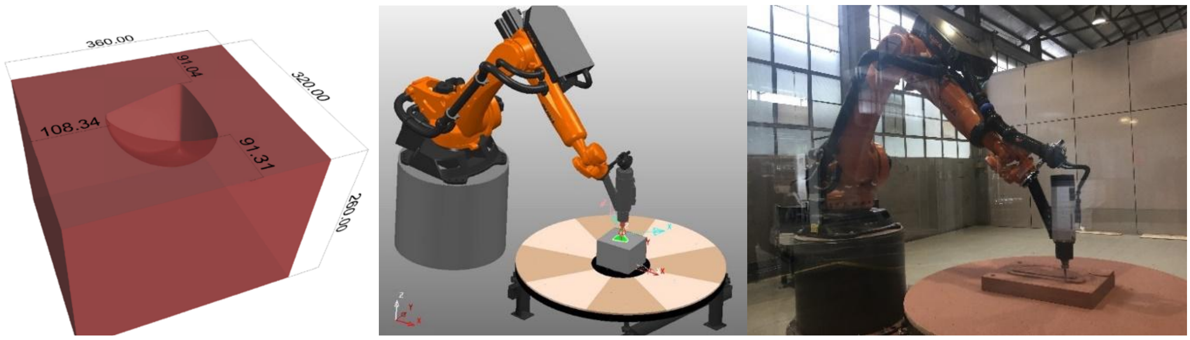
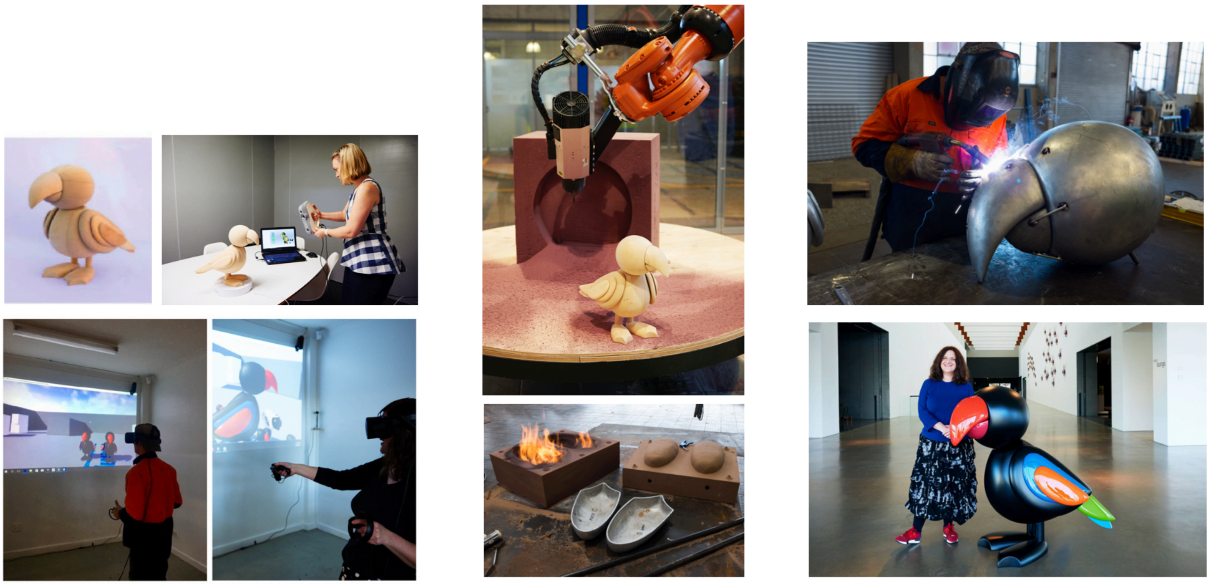


Figure 6. Model of sand mould, toolpath and robotic milling of sand mould. Photo Credits: UAP Company.

The sand moulds were then used to cast the aluminium pieces of the parrots. Traditional finishing processes were used in the assembly and completion of the sculptures. In figure 7 the manufacture of Poll the parrot is documented.



Digital scan and VR translation of maquette. Robotic milling of sand moulds & casting. Finishing and completed sculpture.

Figure 7. Poll VR Scaling and Robotic CNC Milling Workflow. Photo Credits: UAP Company.

Using virtual reality and a robotic milling process in collaboration with the artist allowed UAP to create a 3D model and final sculpture. This form was perceived by the artist to be a true replication of her initial intent; an outcome that was highly valued by the artist.

> *“Very high production, perfect, yeah. I've done well. It's a real achievement. It makes me very proud it and I'm very proud of it.”- Emily Floyd*

In terms of Open Innovation the case revealed that by bringing in external sources of knowledge to combine a range of digital tools and technologies with UAP’s traditional handcrafted approaches can maximise the benefits of advanced manufacturing. How these tools and approaches are combined is unique to each project, and is dependent on several factors such as the timeframe for completion, materials, scale and complexity of the form. The process used with Floyd demonstrated that the robot can be used to inform efficiencies in pattern making, which tends to be the most expensive and time consuming aspect of UAP’s manufacturing process. Improving the efficiency of the pattern making process allows more human hours to be spent on other parts of the process such as finishing and painting which are time and talent consuming. By using this unique combination of VR technology and robotic CNC milling the organisation was able to reduce the cost allowing the manufacture of 6 sculptures on Australian shores in comparison to the cost of handmaking one sculpture overseas.

Case 2 – Architectural Project, 80 Collins Street, Melbourne

In 2018, UAP began work on the design, development, and prototyping of a balustrade for the 80 Collins Street, Melbourne architectural project. Based on an organic woven pattern, the balustrade of the building is a complex form which would be time consuming and difficult to achieve through traditional pattern making processes. The open innovation diagram of this case in figure 8 demonstrates the external creative and technical knowledge that was new to the process, and research support that was brought into the organisation informing the creative problem solving required to manufacture a large scale prototype of the balustrade.

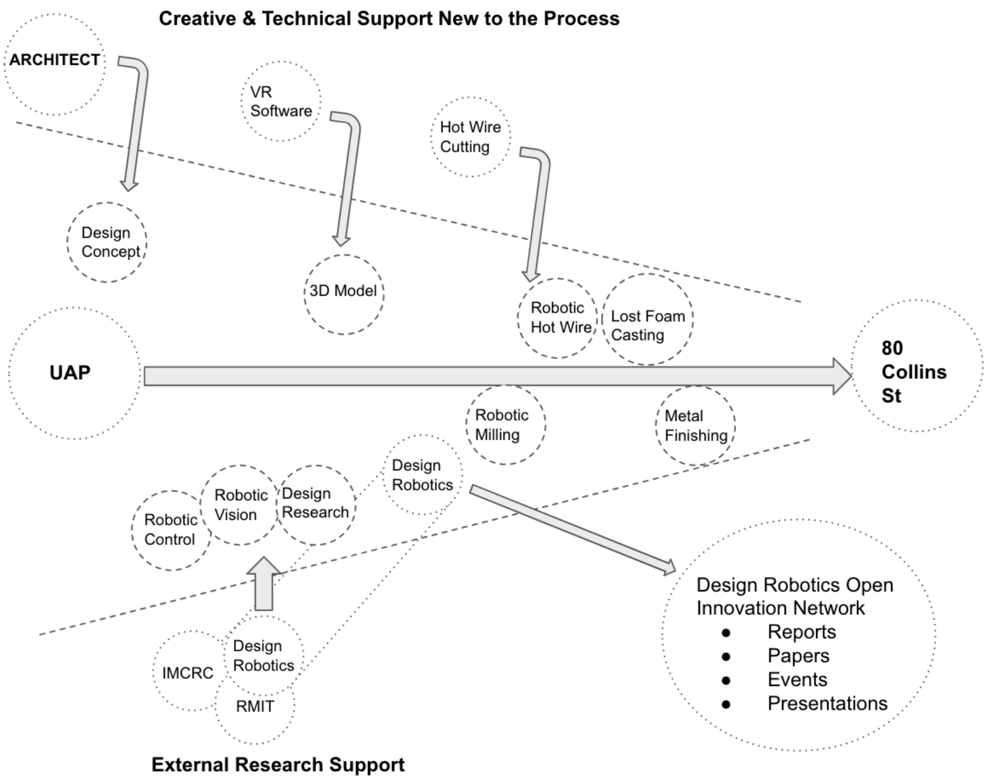


Figure 8. Open Innovation Diagram of Case 2 – 80 Collins St

The external client, the architect, provided the initial design concept of a woven organic form. Expanind on their internal expertise in virtual reality, UAP further developed the initial design by combining hand sketching with 3D models. The 3D models were created using virtual reality Oculus Medium software, allowing for revision and refinement of full scale panels by the design team. This streamlined the manufacturing process, as it allowed for the 3D model to be prepared and sent to the KUKA robotic arm for milling of the pattern out of polystyrene foam.

Based on its knowledge of traditional hot wire cutting and robotic milling experience, UAP created its own internal robotic hot wire cutting capability. A hotwire end effector was purpose built and used on the KUKA robotic arm to cut the robotic milled pattern out of a block of foam. Following this process, the pattern was moulded into sand blocks in preparation for casting as seen in figure 9.

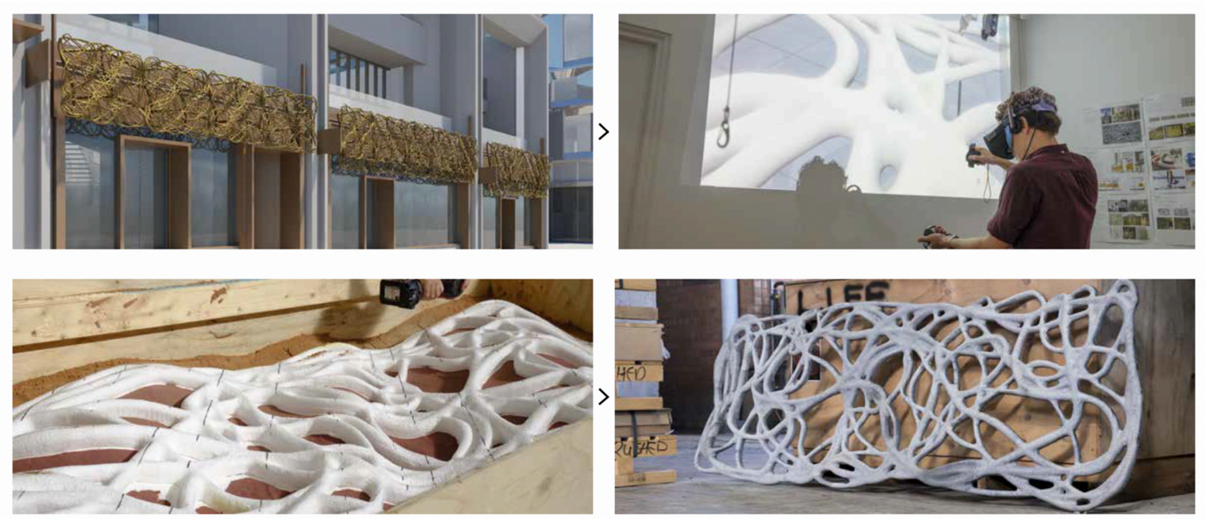


Figure 9. KUKA Robot Pattern Cutting and Lost Foam Workflow for Prototype Manufacture. Photo Credits: UAP Company.

A typical aluminum casting process at UAP would involve the creation of a foam pattern hand-carved from polystyrene by pattern makers. The pattern would then be used to create sand moulds for casting the aluminum. In this case, the design team were able to address imperfections in the 3D model in the VR environment prior to physical prototyping. The refined 3D model was used by the documentation team to create the tool path in Autodesk Powermill for the KUKA to cut a foam pattern (see figure 10).

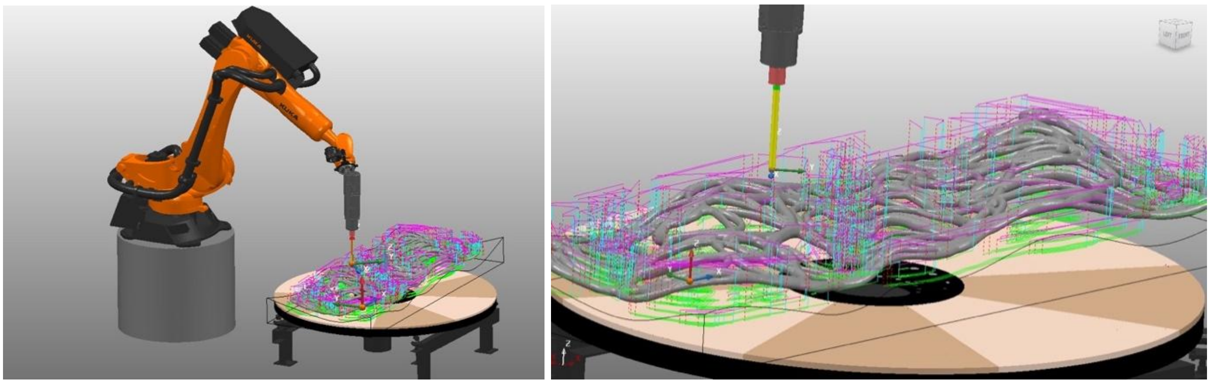


Figure 10. Robotic Simulation and Tool Path Images. Photo Credits: UAP Company.

Initially, a 'lost foam' process was tested with a small prototype. The lost foam process, similar to lost wax casting, involves pouring hot aluminium into the sand mould to melt out the foam pattern inside. Once the lost foam process was deemed a suitable approach, a large-scale 2200mm prototype was cut and cast. This approach was developed after consulting an external firm who does large scale lost wax metal casting. The idea to experiment with the lost foam casting process was a creative solution developed internally by UAP's manufacturing team.

The lost foam casting process reduced the labour and time from the pattern makers to create a complex organic form. To replicate this complex form by hand would require large amounts of time and skill. Further, it would be nearly impossible to achieve an accurate outcome with human skills, alone. By employing the robot to cut the foam pattern, it can be scaled in size efficiently and multiple unique patterns can be created at a comparatively low cost and speed. Traditionally, this type of design would have only a few pattern types and they would be used as repeated elements throughout an overall design.

The described process requires additional investment of time by the technical design and documentation team, but this is offset by time is saved in the pattern making process. The result of the lost foam casting process created a large-scale prototype which has no flashing (thin fingers of metal along the seam of the sand mould) and required only sand blasting and painting to finish. This is a significant improvement from traditional sand mould casting methods, which typically require large amounts of fettling (removal of flashing artefacts) for an organic form of this complexity.

In the 80 Collins St case, the open innovation processes employed to create the pattern and screen elements included three experimental and novel steps in UAP's workflow: 1. Inspection and revision of the digital 3D model in VR to refine the form; 2. A 3D model informing the robotic cutting of the pattern; and, 3. A lost foam casting process. The benefits of these novel steps allowed for improved communication with the client assisting final approval. The robotic milled pattern used in the lost foam casting process provided a quick method of testing the design and material as a full-scale prototype. Due to the efficient nature of the process used in the 80 Collins St prototype, it was found that by learning from and applying knowledge from external and internal sources a greater variety of forms can be used in the design of the balustrade. This allowed for a more varied pattern to be applied across the façade which opened up further opportunities for complex architectural façade designs to be achievable in future projects.

Discussion

In collaboration with UAP design, documentation, and manufacturing departments, the Design Robotics research team have observed and investigated design-to-manufacturing processes. The case studies documented in this research include Emily Floyd's sculpture "Poll" and the architectural balustrade prototype for 80 Collins Street, however the implications of the processes discussed point to the potential of design-led advanced manufacturing techniques. Critically, we highlight that these are only achievable through open innovation and collaborative creative partnerships.

Through these two cases UAP has demonstrated that the use of technology in the design process - when linked to robotic manufacturing - can improve Australia's advanced manufacturing capacity, and keep complex projects onshore. In this way, future significant projects do not need to be exported, creating jobs for the domestic manufacturing workforce. Other manufacturers similarly indicate the introduction of advanced manufacturing technologies can reduce human risk, while increasing productivity and revenue creation. In both cases the role of the Design Robotics Open Innovation network has been to monitor the inward flows of knowledge, how the organisation has used these sources internally to solve problems and innovate in their manufacturing process, and share the outcomes externally through presentations, reports and academic publications.

Conclusion

The analysis reveals the benefits of open mindsets, collaboration, critical thinking, and curiosity to allow for adoption of new technologies enabling the combat of the threat of low-cost overseas labour of jobs, increases in efficiencies, and growth in capabilities for manufacture. The cases indicate how the implementation of advanced and design-led manufacturing processes have promoted human creativity while harnessing the value of human skills required for the real and materially significant production of Australian art and architecture. Understanding the process of implementing the KUKA robotic arm in combination with virtual reality into UAPs workflow, including the challenges and the opportunities they have identified, will continue to inform the development of ongoing research in the IMCRC Design Robotics project.

Observing UAP's innovative approach to material use and the process of translating their clients ideas into final large scale products will assist in determining the skill requirements which architects and designers may need to incorporate into their design process. By rethinking design and architectural approaches to material use, creation, and fabrication through advanced manufacturing technologies (e.g. additive manufacturing, robotic vision and assembly, and virtual and augmented reality) previously impossible architectural structures are now within reach. The needs of clients and city inhabitants will continue to change and the ability to develop custom products will allow the design, architecture, construction industries, and their supply chains, the ability to respond through design-led and advanced manufacturing.

Acknowledgement

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Endnotes

Amabile, Teresa M. “A model of creativity and innovation in organizations.” *Research in organizational behavior* 10, no. 1 (1988): 123-167.

Amabile, Teresa M. “Componential theory of creativity.” *Harvard Business School* 12, no. 96 (2012): 1-10.

Bogers, Marcel, Ann-Kristin Zobel, Allan Afuah, Esteve Almirall, Sabine Brunswicker, Linus Dahlander, Lars Frederiksen et al. “The open innovation research landscape: Established perspectives and emerging themes across different levels of analysis.” *Industry and Innovation* 24, no. 1 (2017): 8-40.

Bouchikhi, Hamid, and John R. Kimberly. “Escaping the identity trap.” *MIT Sloan Management Review* 44, no. 3 (2003): 20.

Bucolo, S. and King, P. “Design for Manufacturing Competitiveness”, Australian Design Integration Network (ADIN), (2013).

Bucolo, Sam, and Cara Wrigley. "Design-led innovation: Overcoming challenges to designing competitiveness to succeed in high cost environments." In *Global perspectives on achieving success in high and low cost operating environments*, pp. 241-251. IGI Global, 2014.

Burns, Kathryn. "Clusters: A Possible Alternative to Ktps for Improving Design Knowledge?." *The Design Journal* 9, no. 3 (2006): 23-33.

Chesbrough, Henry William. *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Press, 2003.

Crabtree, Andy. "Ethnography in participatory design." In *Proceedings of the 1998 Participatory design Conference*, pp. 93-105. Stanford, CA: Computer Professionals for Social Responsibility, 1998.

Design Council UK. “Double diamond design model” 2017. https://www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond

Gerring, John. *Case study research: Principles and practices*. Cambridge university press, 2006.

Hartley, John, Jason D. Potts, Trent McDonald, Chris Erkunt, and Carl Kufleitner. "CCI-CCI Creative City Index 2012." (2012).

Haukka, Sandra, Gregory N. Hearn, Justin Brow, and Stuart D. Cunningham. "From education to work in Australia’s creative digital industries: Comparing the opinions and practices of employers and aspiring creatives." (2010).

Higgs, Peter L., and Sasha Lennon. "Australian creative employment in 2011." (2014).

Mellor, Stephen, Liang Hao, and David Zhang. "Additive manufacturing: A framework for implementation." *International Journal of Production Economics* 149 (2014): 194-201.

Müller, Kathrin, Christian Rammer, and Johannes Trüby. "The role of creative industries in industrial innovation." *Innovation*11, no. 2 (2009): 148-168.

Pedersen, Jesper, Jacob Buur, and Tom Djajadiningrat. "Field design sessions: augmenting whose reality?." *International Journal of Human-Computer Interaction* 16, no. 3 (2003): 461-476.

Queensland Productivity Commission Report (2018) https://qpc.blob.core.windows.net/wordpress/2018/09/QPC-Annual-Report-2017-18-FINAL.pdf (accessed 12 July 2019)

Teece, David J., Gary Pisano, and Amy Shuen. "Dynamic capabilities and strategic management." *Strategic management journal* 18, no. 7 (1997): 509-533.

West, Joel, and Marcel Bogers. "Leveraging external sources of innovation: a review of research on open innovation." *Journal of Product Innovation Management* 31, no. 4 (2014): 814-831.

Verganti, Roberto. *Design driven innovation: changing the rules of competition by radically innovating what things mean*. Harvard Business Press, 2009.