Technology in Design Education and Research: A Posthumanist Approach

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Abstract We already live in an AI-assisted, Instagram-obsessed, phygitally blended, NFT-invested and metaverse-immersed posthuman environment. What is the role of Technology in design education and research? Can a posthumanism approach to Technology facilitate a productive and creative relationship between design education, research and activism? This paper discusses three cross-disciplinary design pedagogy and research projects to contextualise our contemporary relationship with Technology across three scenes. Each Scene is a probe to reflect on what it means to be posthuman, exploring posthumanist approaches to Technology through its design agency, transformative potential and consequences.

Keywords *Design, Agency, Technology, Climate Action, Posthumanism, Creative Education*

Introduction

I	II	III
Education	Research	Art
Engagement	Sustainability	Practice
Material	Waste	Behaviour
Agency	Becoming	Posthuman

In this paper, I will offer no singular solution, vision or trajectory for our relationship with Technology. Instead, I aim to serve a posthumanist discussion on design education and research to unpack our relationship with Technology. From mechanical systems (such as the printing press) to sophisticated robotics and Artificial Intelligence (AI), our milieu is defined by how we use these systems as Technology. Technology from Greek *tekhnologia* refers to the "systematic treatment of an art, craft or techniques"; the root word *teks* means to weave, to fabricate (Sciolist, 2018). While the word *tool* is not a synonym for Technology, its origin in Old English *tol* implied a close relationship with an instrument used by a craft person, necessary for the treatment of craft (Pye, 1968).

In the first and second Industrial Revolution, we developed Technology to substitute and replace human labour with mechanical systems driven by steam and electricity using fossil fuel. By the mid-20th century, our technological advancement shifted towards the 3rd industrial revolution, where microprocessors disturb the linear relationship between labour, energy, and consumption (Rifkin, 2013). The late 20th century witnessed the disruptive power of digital networks, such as the World Wide Web, where knowledge hierarchy is distributed and turned on its head, manifested through the global rise of e-commerce, fabrication laboratory (or Fablab) and hackathon culture (Anderson, 2014). We are firmly settled in the 4th industrial revolution and verging on the cusp of the 5th, where AI, quantum computing, wireless Technology, and the Internet of Things (IoT) are accelerating exponentially. Full automation in manufacturing highlights the perpetual machine-to-machine relationship. Yet, what permeates our daily lives is Technology that aids and augments our behaviour from consumption to education. Within a short period of 260 years, the industrial revolutions have matching effects on our life expectancy, war-making capacity, GDP growth and energy consumption (Muehlhauser, 2017). While early mechanical systems required a direct human-to-machine input (a linear and mostly predictable output), it is the sense of loss of control when machine interact with machine and machine interact with Human (rather than vice versa) that we as a society are becoming more critical of Technology and its roles; primarily because it has become more "invasive" on our existence at the ethical and moral level. These effects of Technology remind us that it is not a passive system but has agency in its own ecology. As Malafoursis (2016) observed, agency is not a quality limited to humans. It can be satisfied by an object in so far as the object (tools and Technology included) can become an extension of the person.

This paper aims to unpack the agency of Technology over three scenes. In Scene I, we will explore how Technology can be used as a creative agent in design education toward direct climate action. Through the lens of Actor-Network Theory, we explore Technology as a probe for design action. In Scene II, we look at the transformative power of Technology. If Technology has agency as a transitional object (Ratto, 2011), it too has the potential to transform knowledge and the ability to enact on climate issues directly. Indeed, what we have observed as changes in our society are often the after-effects of the transformative power of Technology. We will explore this through a research case study where a novel Technology was developed to disrupt existing manufacturing practice: an adjustable mould device that questions the wasteful practice of concrete casting. Here, I want to highlight the positive impact of Technology on design waste and its agency for change. In Scene III, we reflect on the Posthuman effect of Technology through an artwork called The Anthropomorphic Machine. Here, a physical machine attempts to be human through similarities in anatomy and behaviour. Through creating a new and possible future "being", we question the relationship of our body and Technology.

Background and Posthumanism

The motivation of this paper is to provoke or perhaps reconsider our relationship with Technology and provide some methods of engaging with Technology beyond passive consumption. I present the three scenes as reflections and demonstrators that such Active Engagement could be scholarly activities with potential impacts - Matt Ratto (2011) called this Critical Making. Typically, when presenting papers on Technology, its technical resolution, innovation, novelty, and significance tend to be the primary focus. In this paper, I hope to do the opposite. Instead, we will reflect on the effect of the case studies, dare I say, on Technology at its ontology level. Each Scene would refer to other papers that detailed the technical background of the projects so as not to distract from this framing.

As an educator, maker, architect, and designer, I see myself as part of a posthumanist creative ecology. Indeed, there are many human collaborators in each of these case studies who, like me, are part of the creative agencies in a continuous design environment that also consist of non-human agents such as tools, materials, electronics, and machines - a posthumanist approach to learning that is non-human centric, material-focused and often a technologically-rich learning environment (Peppler et al., 2020). Here, I begin questioning: What is NEXT posthuman? We already live in an AI-assisted, Instagram-obsessed, Tik-Tok motivated, phygitally-blended, NFT-invested and metaverse-immersed posthuman environment. Our bodies are situated both in the digital and the physical space, consuming and producing more waste than ever. How do we learn, interact, and collaborate with Technology to address issues of climate, waste, collective behaviour, consumption and its aftermath?

While posthumanism criticises anthropocentric humanism and embraces non-human life (machine and Technology), its lens is still vastly formulated as a critic from a human perspective. As Ferrando (2012) claimed, "Posthumanism reflects on the terms of human sustainability, but it does not dismiss the significance of human survival" (p. 10). She went on to argue the need for a pluralistic methodology in addressing posthumanism studies towards a condition where "biological, AI and advanced robotics may become fully aware and able to express their phenomenological perception of existence in a human accessible-code, so ending the human solipsistic supremacy in the intellectual domain and opening to the configuration of an actual posthuman methodology" (p. 13). When this day comes, this paper will become obsolete.

SCENE I: Material Engagement

The knowledge hierarchy in designing Technology has been inverted in the past two decades; see Figure 1. What used to be a highly specialised knowledge domain of electrical and software engineering has now shifted to a more open system – a bricolage method of appropriating kit-of-part, electronics components and open-source software. Designers, educators, and learners have, therefore, been able to engage with electronics through hacking or tinkering with Technology (Massimo Banzi, 2015). In education, using computers as material was discussed by Papert (1988) as a means to construct active learning through incremental knowledge-building. Sanders & Stappers (2014) further define electronics as probes and toolkits, as "materials that have been designed to provoke or elicit response," and as components to "make artefacts about or for the future". Ratto (2014) refers to this notion as Critical Making, where he situated the hacker culture within scholarly activities that examined making as a social, technological engagement. He suggested that through making, the maker not only "writes" with material to construct the logic of a system but also makes sense of the relationships between the user and Technology; the process of making sense of these relationships is the critical process of enquiry.

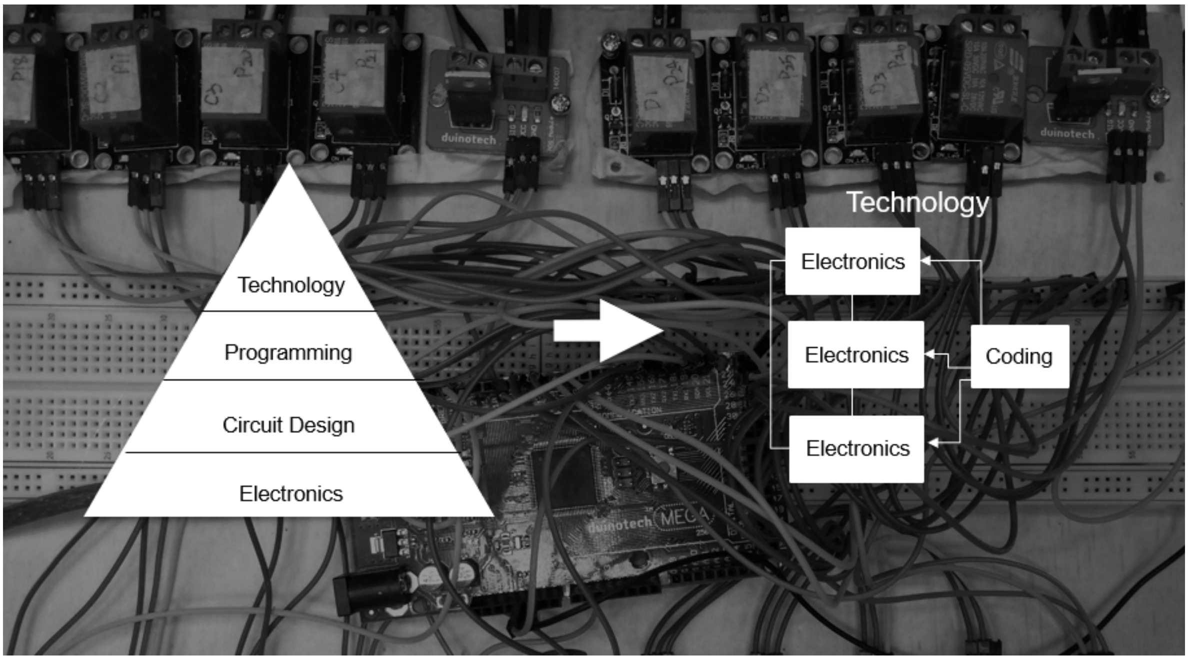

Figure 1. Diagram illustrating the flattening of knowledge in electronics and circuit design towards a model where open-source coding forms the primary links to construct a piece of Technology.

As a design educator, I used Critical Making approach to articulate the brief for a Master-level Architecture design studio at the University of Melbourne. The Studio, titled Machining Aesthetics, was run in collaboration with David Leggett from 2012-2019. The brief asked students *to make a machine to create architecture*. It demands students to construct their Technology either from scratch using an electronic prototyping kit or hacking an existing technology to invent and test new methods of making architecture, see Figures 2. The objective is to use novel techniques to counteract the convention of construction and its aesthetics. These projects shared a common aspiration: to address non-standard material production using automation and, consequently, reconsider material waste as part of the production of architecture. Projects ranged from single-use mould design to fabric formwork, 3D-printed clay structures and dynamic pneumatic façade, see Figure 3. Through making and hacking Technology, students search for what we call '*Affordance For Design*'. James Gibson (1986), who coined affordance, remarked, 'Architect and designer know such facts, but they lack a theory of affordances to encompass them in a system'.

Figure 2 illustrates six projects developed by students in Machining Aesthetics between 2016-2019.

Affordance For Design implies that Technology can be seen as part of the creative ecology that enables active change – as having design agency. Lambros Malafouris (2016) called this Material Engagement, where the formal outcome (as an artefact) may not directly result from preconceived ideas. Instead, the design intention is developed through the experience of making or 'directly embodied and realised in the hybrid space of situated action' (Ihde & Malafouris, 2019). He demonstrated this by unpacking how primitive humans could make flint axe heads through knapping. He argued that knapping flint is an exercise of multiple agents at work, including the hand of the knapper, the knapping stone, and the stone being knapped. Each subsequent strike of the flint determines the angle of the next strike. This idea of an iterative negotiation of agencies shifted our understanding from the traditional concept of a preconceived image of an axe head within the flint, which we often call a design, to a more dynamic process of designing through material negotiation. He states, 'There are no fixed agentive roles in this process; instead, there is a constant struggle towards a "maximum grip"' (Malafouris, 2016, p. 176).

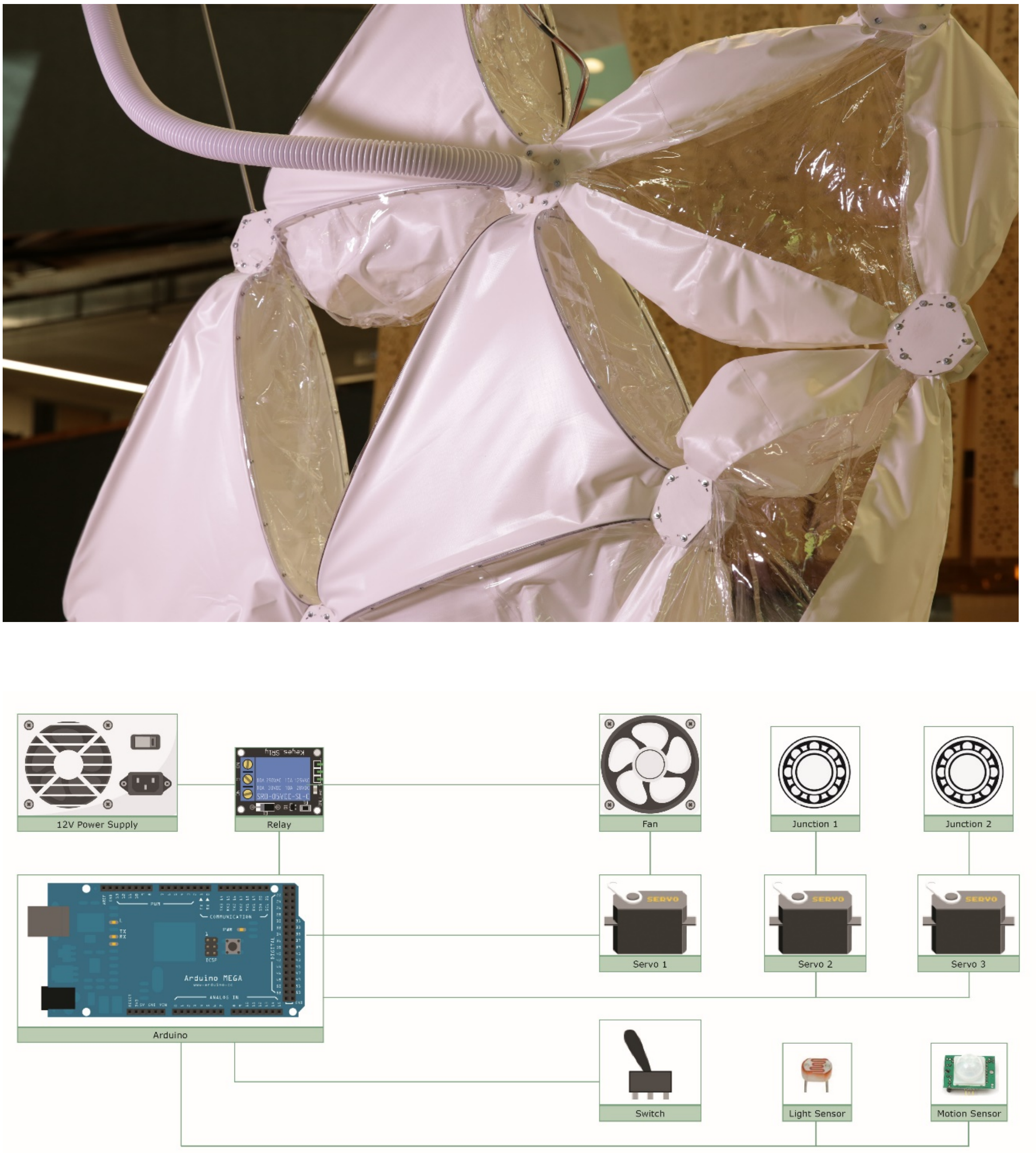

Figure 3. A pneumatically actuated façade prototype with a circuit design that controls airflow to the various air compartments to inflate and deflate the cladding system to regulate heat gain to a building. A dynamic façade would produce a responsive architecture that reacts to climate variation—project by Daniel Parker, Suyi Zha, Yuanye Huang.

As makers and technologists, the students are part of a more inclusive design ecology or environment encompassing knowledge, material, tools, and techniques as active agents. Knowledge is explicit and tacit in this case (Frayling, 2011). Explicit knowledge is often retrieved from the internet or through open-sourced forums. Tacit knowledge is learned mainly through making and experimentation, as documented in Figure 3; we will return to discuss this in Scene II. Here, the designer, knowledge, tools and materials are on equal terms and in constant negotiation until the designer quits. We observed how materials and tools can become creative agents of the design process, driving design intent and outcome. It is not a total surrender of the designer's role to material effects but a measured sense of agency through Making (Malafouris, 2016) where material, geometry and algorithm are privileged over design intent, see Figure 4.

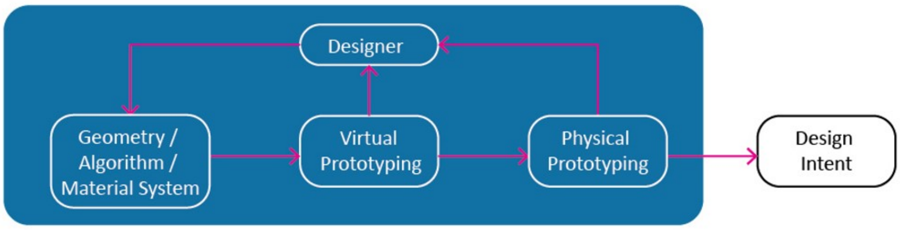

Figure 4. Diagram illustrating the subversion of design intent through privileging geometry, algorithm and material as a system.

SCENE II: Transformative Potential

The construction industry contributed 37% of energy-related CO_2 emissions (UN Environment, 2021), of which 11% resulted from construction materials such as steel, cement and glass (UN Environment, 2019). The industry also contributed an estimated a third of world waste, mostly in landfill sites (Miller, 2021). While most research is focused on waste management, including recycling and up-cycling (Osmani, 2011), the fundamental problem lies in how a building is constructed, designed, and assembled.

My research for the past decade has been around the question of *How can Technology and advanced manufacturing remove or reduce waste from our current construction practices?* We used robotics and digital fabrication techniques to minimise material usage and design waste. The latter will form the emphasis of this Scene. Design waste is generated as the outcome of the design process, directly or indirectly, often caused by design changes, complexity in detailing, inadequate or incorrect specification and poor coordination of information (Othman & Abdelrahim, 2019). Indeed, architects are responsible for an estimated 33% of construction waste due to failing to design out waste (Innes, 2004). Until recently, design waste was seen as unavoidable among architects and builders (Li et al., 2015). However, this attitude is shifting as designer looks towards advanced fabrication and Technology, primarily enabled by the "flattening" of knowledge structure in Technology, discussed in Scene I.

Concrete casting is a wasteful process requiring a mould or formwork to support the liquid mixture before it chemically hardens as concrete. Traditional casting methods utilised single-use mould, often in timber, fibreglass, or metal; only metal is recycled, with the rest ending in landfill. In 2016-2018, we developed a computer numerically controlled machine called Parametric Adjustable Mould (PAM) for fabricating curved concrete panels with a single adjustable mould frame, thereby avoiding single-use mould design, see Figure 5.

Figure 5. PAM technology and its fabrication procedure for the doubly curved concrete panel using a single adjustable mould. A full-scale rainscreen façade prototype was constructed as proof of concept to commercialise the technology.

PAM is a patent technology (Loh et al., 2019a) consisting of a CNC adjustable mould frame that can produce accurate doubly-curved concrete panels (Loh et al., 2018, 2019c). The Technology consisted of four numeric controlled actuators to make a variable-shaped mould for casting up to 50mm thick concrete panels. The single adjustable mould received digital information from a panelised surface using a custom script to actuate the mould into the desired positions for concrete casting, see Figure 5. The converted data of the virtual surface was made possible by analysing the transformation of the doubly-curved ruled surface geometry (Loh et al., 2018, 2019b). The Technology is in the process of an international patent application and has been licensed to a new start-up company, Curvecrete, to commercialise.

The design and fabrication of PAM challenged the research team to compound their skills in problem-solving (the technical aspect) and puzzle-making (the creative applications). Figure 6 illustrates the layering of knowledge necessary to design and fabricate the device with multiple agents at work. It includes what I call the Background knowledge from the precedent studies, current fabrication methodology, and the casting process as tacit know-how (Malafouris, 2016) gained. The descriptive geometry was pivotal in translating the know-how into a practical solution. Here, the physical prototyping process gave form and meaning to the techniques. The digital code translated the mathematical model into an algorithm that delivered instructions to the stepper motors as travel distances corresponded to each panel's numeric data. The microprocessor created the serial handshake (to borrow a term from computing) between the software and the hardware to deliver the desired outcome.

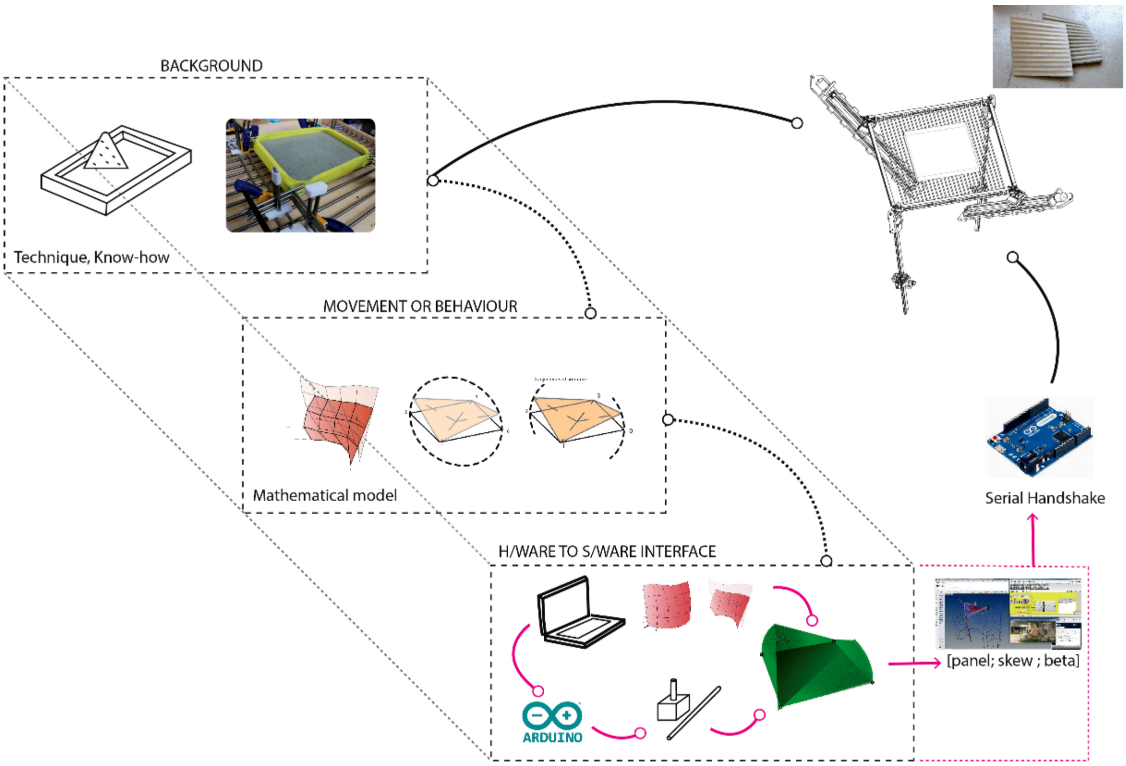

Figure 6. The knowledge structure behind PAM Technology illustrates technology design's non-hierarchical and layered cross-disciplinary nature.

PAM project demonstrated the complex knowledge structure in tool-making. It brought forth a design research methodology that facilitated the emergence of design through engaging with Technology, geometry and tacit knowledge. Critically, the relationship between the various agents was not just an interaction but a transactional one, where the outcome is not merely a by-product of the exchanges between agents but transformed by their agency; Ihde and Malafouris (2019) rightly termed this "becoming". Here, the transformative potential of Technology is two-fold. First, it is a form of Critical Making - transforming the Technology into an active solution towards reducing design waste. Second, electronics become a transitional object (Ratto, 2011) when transactions with human agency synthesise knowledge into new Technology.

SCENE III: Posthuman Effect

The Anthropomorphic Machine is a two-year design project with the performance artist STELARC. It demonstrated the elasticity of Design Research, where design as a research activity can reach forward into the future to structure or acquire new knowledge. It is tested in a design studio with students as collaborators. In the final development phase, the knowledge is synthesised and coordinated through a cross-disciplinary group of researchers from the Melbourne School of Engineering, structural engineers, fabricators and installers. Our role as architects is no longer confined to imaging the project but building prototypes as proof of concept, writing code to regulate airflow, designing electronic circuits and choreographing complex mechanical behaviour to produce an interactive experience.

The project was installed in the Science Gallery Melbourne from August 2022 to June 2023. It consisted of an 8-meter-tall stainless-steel structural frame with a circular ring boom and supporting struts at the top from which a tensegrity "cloud" is suspended 4 meters off the ground, see Figure 7. The 8-meter diameter tensegrity "cloud" consists of 204 tensegrity cells. Twelve pneumatic rubber muscles actuate the "cloud," each 2.5m long, that take advantage of the dynamic quality of the tensegrity to create a set of choreographed movements.

Figure 7. The Anthropomorphic Machine installation in Science Gallery Melbourne with an actuated suspended tensegrity "cloud" actuated by 12 pneumatic rubber muscles.

The early concept for human-machine interaction took inspiration from Loren and Rachel Carpenter's Audience Participation project based on the Cinematrix Interactive Entertainment System presented at the 18th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH, 1991). Carpenter pioneered the deployment of computer vision, moving from bi-directional one-on-one interaction between a human and a computer towards multiple audience participation using images captured with a conventional camera and a computer to process the images as data (Carpenter, 1994). In SIGGRAPH 1991, the system was tested on an audience, where each participant was provided with a green and red paddle to collectively play the classic computer game Pong (Maynes-Aminzade et al., 2002).

The Anthropomorphic Machine extended this idea of collective behaviour and re-conceptualised it to produce a set of artificial machine responses, see Figure 8. Using an open-source software called OpenPose, we connected three go-pro cameras to provide a 360-degree computer vision of the Gallery. The density of Human activities and their speed of movement in the Gallery were mapped to four pre-defined sets of choreographed performances. Each set of performances creates a seamless behaviour that changes the cloud shapes and forms through the pneumatic muscles' expansion and contraction speeds and frequencies. The vision to behaviour feedback is deliberately non-linear, and the outcome is therefore not explicit but always tentative - STELARC intended this to encourage the audience to engage with the machine as a collective rather than an individual. Over the installation period, three co-performances were choregraphed with the Anthropomorphic Machine including a dance by Carol Brown titled *Tensegrity*, a concert by BOLT Ensemble and a sonic performance by STELARC and Petros Vouris, titled *Amplified Anthropomorphic Machine*. In STELARC's words, "Art is not about information; it is about generating experiences that enrich what it means to be Human."

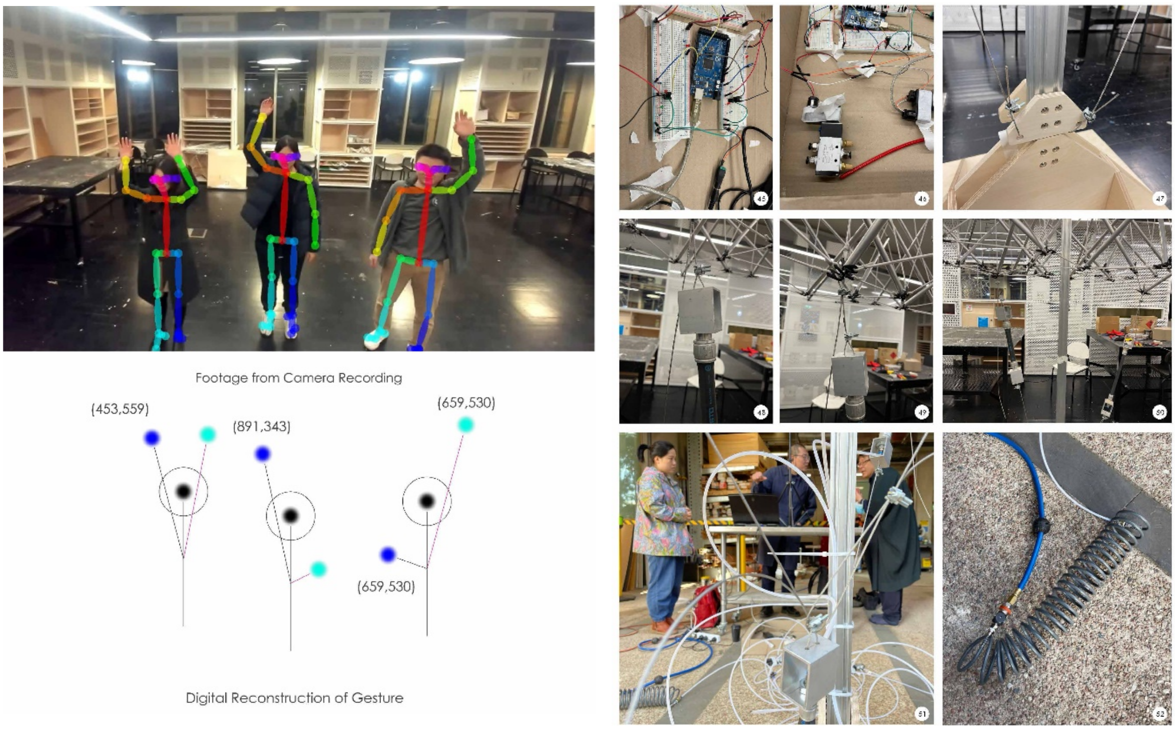

Figure 8. Early exploration with design students to test out the computer vision and physical prototyping of the actuated cloud in a design studio setting with STELARC.

The project proposes an alternative anatomical architecture and interrogates what it means for architecture to be a self-regulated system – a body with distributed organs – a play on Deleuze and Guattari's idea of a Body without organs (1987). It is anthropomorphic, and not figurative, in so far that it has a steel skeleton frame, a tensegrity structure that behaves like thick skin, pneumatic rubber muscles, steel tendons, a circulatory system of compressed air regulated by solenoid valves as pneumatic lungs, vision and a computational system for responsiveness. The project looks towards a posthuman condition. STELARC described the perception of the project from a human perspective, "When you are looking up at the canopy, what you are seeing is the subtle motion of the tensegrity struts and hearing the compressed air sounds, solenoid clicks and the collision of the stainless steel." When there is no interaction, the machine will simply breathe, slowly exhaling and inhaling air, setting an almost human-like presence in the Gallery. We know it is not human; it does not look like a human, but we have created a replica of a human-like being through artificial intelligence and sensing to reflect our presence in space.

Conclusion

In this paper, I presented three posthumanist approaches to engaging with Technology through education, design and research. As we question the effect of Technology on our society, we are reminded of its agency for change through Critical Making. Using electronics and engaging with the hacking culture, we observed how educators and learners used Technology as design probes for active learning to provide *Affordances for Design*. It allows designers to formulate new design trajectories and machine agency by privileging non-human systems such as material, geometry and algorithm. Here, learners as makers and technologists are part of a more inclusive ecology of design environment and on equal terms. The transformative potential of Technology was examined through the lens of a research project that explores means to reduce design waste. It highlighted how Technology can act as a transitional object, useful in synthesising knowledge to enact on climate issues directly. Here, we discussed the multiple agents at work and considered their interaction as a transactional relationship where the outcome is not just a by-product but a transformed value. As future praxis, I proposed a more radical evaluation of current manufacturing practices - calling for the design industry to review and shift their attitude towards design waste as unavoidable towards a designing process of reduction and active elimination. Last, we encounter the rhetorical question of *What* *is NEXT posthuman*? As a non-figurative simulation of a being, a self-regulated system, and an environment-aware machine, the Anthropomorphic Machine questions what it means to be human and to reflect our presence in space.

Acknowledgement:

The authors acknowledged and credit the work of the students used in the discussion of this paper, Figure 2 and 3: Ziyi Liu, Jiyuan Lin, Xiao Wang, Nutthanee Banditakkarakul, Daniel Parker, Suyi Zha, Yuanye Huang, Daniel Wang, Cuiting Yang, Emma Ke, Sebastian Song, Edward Yee, Gregory Yeo, Sohan Mitra, Zoe Yue, Luke Kim, Xiaocheng (Oriana) Wei, Jiaqi Mo, Yuhan Hou, Chun Tung Tse, Nan Li, Joyce Zhu, Neil Luo, Nattaporn Pornvarojanabun, Jeremy Cheang, and Kun Wu. Use of images of student's project is collected under ethic approval: CHEAN B 0000018963-10/14. For the Anthropomorphic Machine, the authors acknowledged the generous commission of Science Gallery Melbourne with support from Festo, Melbourne School of Design and School of Computing and Information Systems, the University of Melbourne. Special thanks to Dr Jeffrey Ryan, Elise Brokensha and Philippa Brumby for coordinating and making the project possible. Design and Pneumatic system: Paul Loh, David Leggett, Psyche Hou. Model Making: Haoyu Chen. Electrical and Electronic Engineering: Dr Eric Schoof. Computing and Information Systems: Dr Eduardo Velloso, Qiushi Zhou and Gabriele Marini. The Architectural Association Visiting School Melbourne 2021, led by Paul Loh, David Leggett and Psyche Hou with students Mason Mo, Ying Lee, Lu Bai, Mingjia Shi and Yichen Sheng.

References:

Anderson, C. (2014). *Makers: The New Industrial Revolution*. CROWN PUB INC.

Carpenter, L. (1994). *Cinematrix, Video Imaging Method and Apparatus for Audience Participation* (Patent No. US Patents #5210604).

Deleuze Gilles, 1925-1995, & Guattari Félix. (1987). *A thousand plateaus capitalism and schizophrenia*. University of Minnesota Press.

Ferrando, F. (2012). Towards A Posthumanist Methodology. A Statement. *Frame, Journal For Literary Studies*, *25*(1), 9–18. https://www.frameliteraryjournal.com/wp-content/uploads/2014/11/Frame-25_01-Ferrando.pdf

Frayling, C. (2011). *On craftsmanship towards a new Bauhaus*. Oberon Books.

Gibson, J. J. (1986). *The ecological approach to visual perception*. London : L. Erlbaum.

Ihde, D., & Malafouris, L. (2019). Homo faber Revisited: Postphenomenology and Material Engagement Theory. *Philosophy & Technology*, *32*(2), 195–214. https://doi.org/10.1007/s13347-018-0321-7

Innes, S. (2004). Developing tools for designing out waste pre-site and onsite. *Proceedings of Minimizing Construction Waste Conference: Developing Resource Efficiency and Waste Minimization in Design and Construction*.

Li, J., Tam, V. W. Y., Zuo, J., & Zhu, J. (2015). Designers' attitude and behaviour towards construction waste minimization by design: A study in Shenzhen, China. *Resources, Conservation and Recycling*, *105*, 29–35. https://doi.org/10.1016/j.resconrec.2015.10.009

Loh, P., Leggett, D., & Prohasky, D. (2018). CNC Adjustable Mould to Eliminate Waste in Concrete Casting. In S. Kępczyńska-Walczak, A and Białkowski (Ed.), *Computing for a better tomorrow* (pp. 735–742). eCAADe (Education and Research in Computer Aided Architectural Design in Europe) and Faculty of Civil Engineering, Architecture and Environmental Engineering, Lodz University of Technology.

Loh, P., Leggett, D., & Prohasky, D. (2019a). *A Variable Shaping Form* (Patent No. WO/2019/148242). https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2019148242&tab=PCTBIBLIO

Loh, P., Leggett, D., & Prohasky, D. (2019b). Robotic fabrication of doubly curved façade system. *Intelligent and Informed - Proceedings of the 24th International Conference on Computer-Aided Architectural Design Research in Asia, CAADRIA 2019*, *2*.

Loh, P., Leggett, D., & Prohasky, D. (2019c). ROBOTIC FABRICATION OF DOUBLY CURVED FAÇADE SYSTEM. In T. Haeusler, M and Schnabel, M and Fukuda (Ed.), *Intelligent & Informed, Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2019*. The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) in Hong Kong.

Malafouris, L. (2016). *How Things Shape the Mind*. The MIT Press.

Massimo Banzi, M. S. (2015). *Make: Getting Started with Arduino*. O'Reilly UK Ltd.

Maynes-Aminzade, D., Pausch, R., & Seitz, S. (2002). Techniques for interactive audience participation. *ACM SIGGRAPH 2002 Conference Abstracts and Applications*, 257–257. https://doi.org/10.1145/1242073.1242270

Miller, N. (2021). *The industry creating a third of the world's waste*. BBC. https://www.bbc.com/future/article/20211215-the-buildings-made-from-rubbish

Muehlhauser, L. (2017). *How big a deal was the Industrial Revolution?* https://lukemuehlhauser.com/

Osmani, M. (2011). Construction Waste. *Waste*, 207–218. https://doi.org/10.1016/B978-0-12-381475-3.10015-4

Othman, A. A. E., & Abdelrahim, S. M. (2019). Achieving sustainability through reducing construction waste during the design process. *Journal of Engineering, Design and Technology*, *18*(2), 362–377. https://doi.org/10.1108/JEDT-03-2019-0064

Papert, S. (1988). Computer as material: Messing about with time. *Teachers College Record*, *89*(3), 408–417.

Peppler, K., Rowsell, J., & Keune, A. (2020). Editorial: Advancing posthumanist perspectives on technology-rich learning. *British Journal of Educational Technology*, *51*(4), 1240–1245. https://doi.org/10.1111/bjet.12979

Pye, D. (1968). *The Nature & Art of Workmanship*. A & C Black.

Ratto, M. (2011). Critical Making: Conceptual and Material Studies in Technology and Social Life. *The Information Society*, *27*(4), 252–260. https://doi.org/10.1080/01972243.2011.583819

Ratto, M. (2014). Textual Doppelgangers: Critical Issues in the Study of Technology. In M.

Ratto & M. Boler (Eds.), *DIY Citizenship, Critical Making and Social Media* (pp. 227–236). MIT Press.

Rifkin, J. (2013). *The third industrial revolution: how lateral power is transforming energy, the economy, and the world* (First St. Martin's Griffin edition.). St. Martin's Griffin.

Sanders, E. B.-N., & Stappers, P. J. (2014). Probes, toolkits and prototypes: three approaches to making in codesigning. *CoDesign*, *10*(1), 5–14. https://doi.org/10.1080/15710882.2014.888183

Sciolist. (2018). *Online Etymology Dictionary*. www.etymonline.com

SIGGRAPH. (1991). *"Audience Participation" by Carpenter*. ACM SIGGRAPH Infomration and Artifacts History. https://history.siggraph.org/animation-video-pod/audience-participation-by-carpenter/

UN Environment, P. (2019). *2019 Global Status Report for Buildings and Construction Sector*.

UN Environment, P. (2021). *2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*.