LEARNING THROUGH MAKING USING AUGMENTED REALITY

A Case Study in Accelerated Learning

PAUL LOH[1] and GWYLLIM JAHN[2]
[1]*Bond University.*
[2]*RMIT University.*
[1]*ploh@bond.edu.au, 0000-0003-3336-505X*
[2]*gwyll@fologram.com, 0000-0003-2072-5423*

Abstract. While the use of AR in digital fabrication research has been well documented with numerous case studies, its implications for design pedagogy remain under-explored. This paper discusses using Augmented Reality (AR) technology in design pedagogy to accelerate learning through making. The research aims to demonstrate the process and mechanism of developing tacit knowledge for design research using AR through a case study project. It examines the use of research workflow and pseudo-code diagrams as methods for reflective practice. The installation used a combination of AR pipe bending, digitisation and Generative Artificial Intelligence (GAI) patternation techniques to construct a site-specific installation over a three-day workshop. The analysis highlights the roles and value of AR as probes and toolkits in creating prototypes, which formed the foundation for scaffolding design learning through making. The paper concludes with a discussion on reflective practice in understanding the relationship between critical reflection and design intention through research and learning facilitated by AR technology.

Keywords. Design Pedagogy, Augmented Reality, Digital Fabrication, Prototyping, Artificial Intelligence, Reflective Practice

1. Introduction

The integration of digital design and fabrication tools and their impact on architecture design education has been widely researched (Bates et al., 2015; Carota & Tomalini, 2023; Kalay, 2004). Educators identify complacency of tools and techniques in ideation (Holzer & Loh, 2020) and methods of navigating digital fabrication skill learning through design experiments as critical challenges in architectural education (Marcus et al., 2014). It is widely recognised in constructionist pedagogy that physical making can accelerate learning (Papert, 1988; Schank, 1995), and the Critical Making movement has re-aligned the productive nature of technology with design to engage participation (Ratto, 2011, 2014; Schwartz, 2016).

Augmented Reality (AR) refers to a class of display systems that blend digital

ACCELERATED DESIGN, Proceedings of the 29th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2024, Volume 3, 99-108.

content with a viewer's physical environment (Milgram & Kishino, 1994). Early prototypes of AR displays were developed to assist in manufacturing complex objects such as aircraft (Caudell & Mizell, 1992) or structural frames (Webster et al., 2000). Recent improvements in the capabilities of commercially available AR devices, such as the Microsoft HoloLens, have resulted in a proliferation of research into the application of AR to architectural fabrication (Song et al., 2021b). These include the ability to support craft through human-robot collaboration (Song et al., 2021a; Varela et al., 2022) or the fabrication of complex forms with high levels of precision in short time frames (Jahn et al., 2018, 2019). While the use of AR in digital fabrication research has been well documented with numerous case studies (Fologram, 2023), its implications for design pedagogy remain underexplored. The research questions: How does AR accelerate design learning through making?

The research aims to demonstrate how learning in the design and fabrication of a site-specific installation at Bond University can be accelerated using a combination of AR pipe bending, digitisation and GAI patternation techniques. The paper elaborates on the workflow and pedagogical intent behind the installation and unpacks how the design-build studio impacted the teaching and learning process. Tacit knowledge learning was evident through the fabrication process and synthesised in research workflow diagrams produced by the students. Reflective practice learning was captured through pseudo-code of the computational workflow to demonstrate learning outcomes. The paper discusses the roles and value of probes, toolkits, and prototypes throughout the project, forming the foundation for scaffolding design learning through making (Loh, 2018).

Figure 1. Left, the Stair Monster installation within an existing curved stairwell. Right, Surface patternation using HoloLens. Photography by Chor Cheung Mok.

2. Background

The research was conducted through a Master-Level Design-and-Make intensive studio led by the authors. The subject was structured over two 3-day making workshops interspersed with seminars on fundamental theory in making and design thinking, research methodology and reflective practice. Eight students cooperated with the lead educators on the project; four had prior knowledge of Rhinoceros 3D, and only three had foundational knowledge of Grasshopper 3D. No students had previous experience with the fabrication techniques used in the project or with AR. Figure 1 illustrates the studio outcome, titled the Stair Monster.

The learning objectives were three-fold. Firstly, to expose students to direct design to fabrication workflow using AR and associated software. Secondly, to design through experimentation with technology introduced in the studio. Finally, to critically understand the role of design research through making. While most AR research focused on the first and second objectives, this research took a step further by asking students to examine the design research method through making. We used Downton's (2003) definition of design research, where he defined "design is a way of inquiring, a way of producing knowing and knowledge; this means it is a 'way' of 'researching." Research is defined as "the creation of new knowledge and/or the use of existing knowledge in a new and creative way to generate new concepts, methodologies, inventions and understandings" (ARC, 2023), which could include synthesising and analysing previous research to the extent that it is new and creative. Downton further defined a research method as the how-to of the research and methodology as the meta-method of studying the design methods.

In addition to presenting the outcome of a novel technique and installation using AR and GAI, this paper discusses and reflects on using AR as a learning device. The studio teaching focused on the research methods, while the paper's underlying study focused on the methodology of teaching and learning using AR. To address this, we asked students to reflect on the research methods used in the projects and evident their learning or understanding through two sets of diagrams as outcomes: (1) research workflow that captured the research methods, and (2) pseudo code of the computational processes that would unpack their technical understanding of the projects. Through reflective practice, the aim was to allow students to develop an understanding of material research through examining their own actions as a process of continuous learning (Schon, 1984). The hypothesis was to use these diagrams as a meta-mapping of the project with the objective of highlighting moments of accelerated learning, such as detecting problems and developing tacit feedback, using AR as a proposed methodology for future study. Workflow diagrams have been extensively used to map digital fabrication workflow. Their purposes are twofold: (1) to provide an overview of the process and the technique deployed (Marble, 2012). (2) Some researchers used the workflow to explain the methodology behind the research and, in doing so, attempted to reveal the mechanism of Critical Making (Loh & Leggett, 2018). Pseudo-code is the plain English or diagrammatic description of the parametric code to make it more accessible by identifying the primary operations and parameters (Snooks, 2014). Through diagramming the workflow and Pseudo-code, the role of technology and techniques as design probes and generative toolkits can be unpacked. Probes are materials or technology that provoke design responses, and toolkits are physical or software components to make the artefacts (Sanders & Stappers, 2014).

3. Learning through Making using Augmented Reality

The project workflow consisted of eight pre-defined stages, as illustrated in Figure 2. Step [1]: An approximate form of the installation was modelled using subdivision (SubD) surfaces in Rhino 7. A Grasshopper definition was then developed to extract and isolate the edges of each surface patch as an individual polyline. These polylines served as frames that can be shrinkwrapped to form panels in the installation. Step [2]:

The edge length of each frame was extracted as a list of data from the digital model, which was physically measured, cut to length and bent into shape using a standard pipe bender guided by AR with Fologram. Each pipe was crimped to form a closed loop to construct the frame. Step [3]: Where a surface is applied, a 30um polyolefin heat-shrink film in white colour was cut into shape and adhered to the aluminium frame using a double-sided adhesive tape. Step [4]: Fabricated panels were assembled using HoloLens with Fologram. Step [5]: Once assembled, a heat source, using a heat gun or hairdryer, was applied to the film, which contracts and induces tension in the frame to form a minimal surface. Step [6]: Each minimal surface was digitised using Fologram, and the digital mesh surface was adjusted using AR to a near match of the physical surface. Step [7]: A pre-prepared pattern was applied to the digitised surface. The AR overlay on the physical structure allowed collective participation when applying the pattern by hand. Step [8]: The installation consists of three parts assembled in situ.

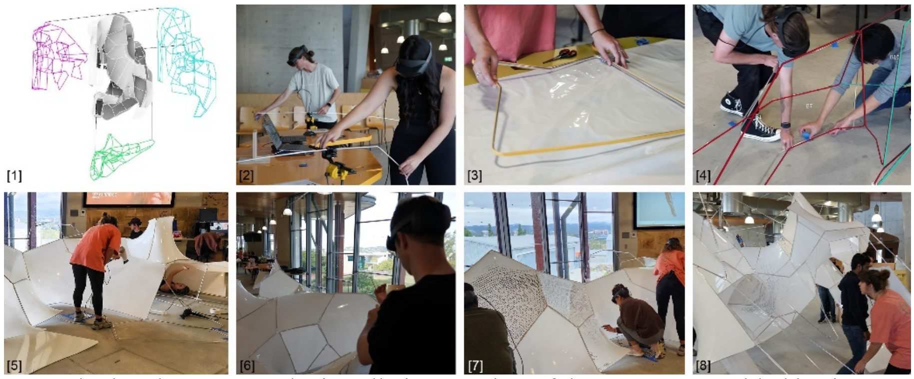


Figure 2. Project workflow from design to fabrication, heat shrink wrapping of the envelope, digitisation of the surface, AR painting and assembly.

Both authors are experienced educators and have conducted several similar design-and-make workshops with published outcomes on using AR in installation and construction projects. It should be acknowledged that this project is a second iteration using the same techniques, with another group of undergraduate students at RMIT University led by the second author. Given the limited timeframe to design and implement the project, many techniques (Stages 1-6) outlined were tested in the prior studio. Stage 7 is a novel process developed in this project with some experimentation also tested in the preceding studio. There were two distinct parallel design processes. The first was designing and modelling the installation in stage 1, with stages [1] to [5] as a linear workflow. The pattern for surface application was designed as a separate exercise concurrent to the SubD modelling – it entered the workflow in Stage [6].

3.1. LEARNING THROUGH PROTOTYPING

In the first 3-day workshop, students were introduced to the tools and software by designing and prototyping a 1m x 1.5m x 1.5m prototype consisting of 15-18 panels, using Rhinoceros 3D and HoloLens with Fologram and other physical tools. The aim is to give the students an overview of the making technique from start to finish.

Students work in four groups to design their form and fabricate their prototypes. At the end of the workshop, we asked the studio to reflect on issues around design parameters, limits, tolerance, and potential for errors they have experienced, see Figure 4C-E. To conclude the workshop, students were given a 3D scan of the site using the HoloLens to develop their design for a lantern-like structure that would articulate the threshold as students and visitors ascend the stairs. Figure 3 illustrates the design constraints, such as existing light fixtures and head clearance for the stairs leading to the final design.

Figure 3. On the top left is a 3D scan of the stairwell using HoloLens; the cyan-coloured objects identified physical constraints. Centre and Right, design proposal for a structure that would sit on the balustrade and form around the concrete stairwell.

3.2. FABRICATION AND ASSEMBLY

Students and educators collaborated on the design over two weeks and reconvened for the final 3-day workshop where the team fabricated and installed the Stair Monster. The installation took approximately 360 working hours collectively, occupying a volume of 5m x 3.6m x 5.5m. Structurally, the design is anchored on the existing stair balustrade and encloses the curved stairs, which consist of 133 panels. The panels were connected using 3mm wide cable ties. Some panels are filled with minimal surface skins, adding strength to the installation. The installation used 411 linear meters of 6mm aluminium tube with 28.6m2 of polyolefin heat-shrink film. The structure was split into three parts for assembly. A lower section rests on the curved handrail, and the main volume is spliced vertically along its length to avoid a visible seamline evident to viewers.

3.3. GAI AND PATTERN APPLICATION

Concurrent with the fabrication process, two students worked with the second author to develop the pattern on the minimal surface envelope. The skin was digitised using Fologram, and the digital mesh was adjusted using AR to match the physical surface closely. To create a cohesive image across the multiple surfaces of the installation, two critical views of the installation were used as the reference points from which AI-generated images were applied. Initial patterns were generated using Mid-journey and Dreamstudio. As the design was refined, the digitised surface was used to create depth maps, allowing ControlNet in StableDiffusion to generate decorative images corresponding to the surface geometry. The images were then applied to the physical surface by hand using AR. Learning from the previous installation at RMIT, we limited the pattern application to using a 5mm wide chisel tip permanent ink marker in black colour only. The objective was to produce the pattern as quickly as possible, acknowledging that we could have up to 10 different pairs of hands in creating the pattern. As the drawing technique developed, it informed the pattern selection, see Figure 4A and 4B. Crucially, it points towards a pointillism approach to the image, leading the team to use a half-tone filter on the final outcome.

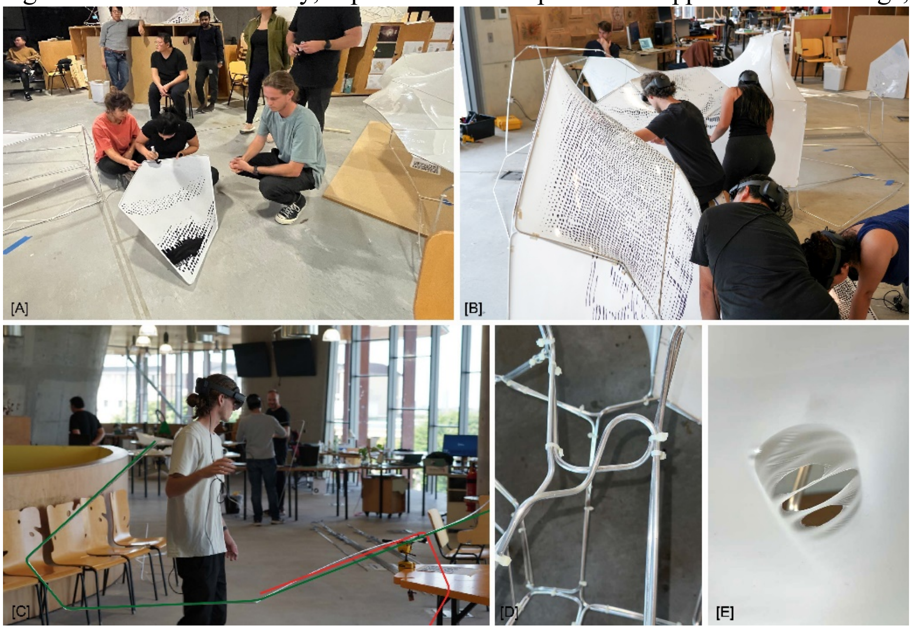


Figure 4. [A] Developing drawing techniques. [B] Collaborative drawing session. [C] Evidence of students reframing problems from learning 'bad fit' with AR. The red line indicates a clash between the pipe geometry and the desk. [D] Geometric constraints of pipe-bender on a consecutive tight radius. [E] Overheating of shrink film during the wrapping process.

4. Discussion: Accelerated Learning through Reflective Practice

The above description of the workflow and experimentation process highlighted the following key moments of reflective practice in the project.

- Iteration and practice of the techniques. We observed in Section 3.1 that the prototyping process allowed students to develop confidence. By the end of the first 3-day workshop, the students had effectively rehearsed the entire workflow. Based on the pace of production, the educators could reasonably estimate and define the scope and scale of the final installation, limiting it to around 130 panels.
- Detecting 'bad fit' through making. This is a crucial learning process for the students as the difficulties in bending some forms and errors produced along the workflow were experienced in their prototype. Students learn how to reframe the problems or avoid working against the material through their design geometry, see Figure 4C-E.
- Tacit feedback. While prototypes inform the final design, more direct tacit feedback is evident in Section 3.3, where the marker tests informed the design direction of the text prompt for the AI image generation – leading to the application of half-tone

graphics to the surface.

The above described the relationship between Reflecting-in-Action and Knowing-in-Action, an "enactive" approach as reflective practice (Malinin, 2018). The exchange of detecting a 'bad fit' and reframing the problem is what Schon (1984, p. 56) described as developing the 'artistry' of the project.

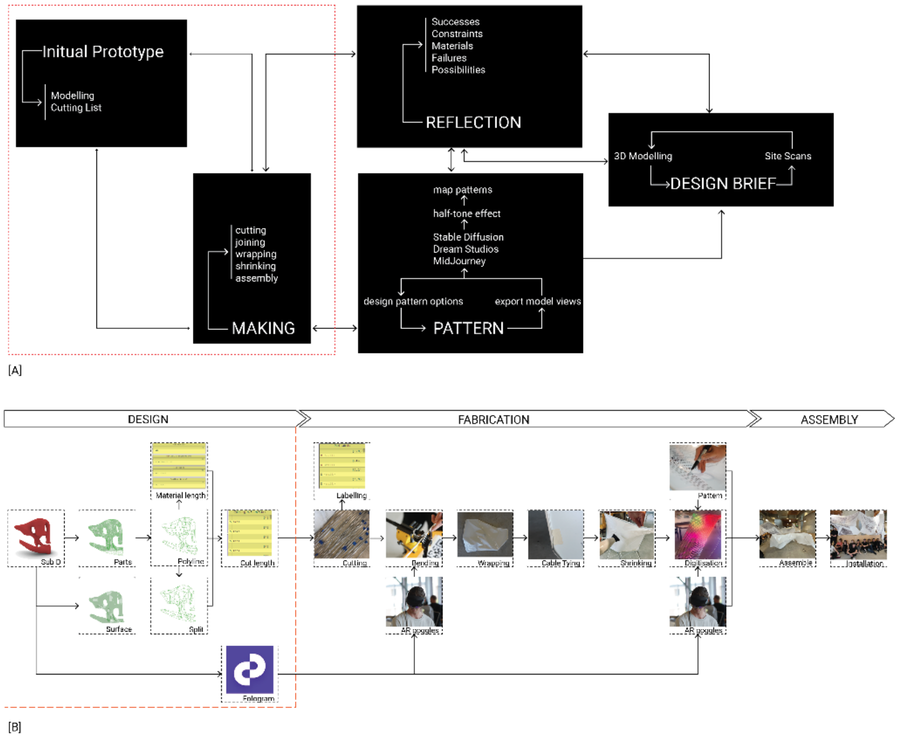
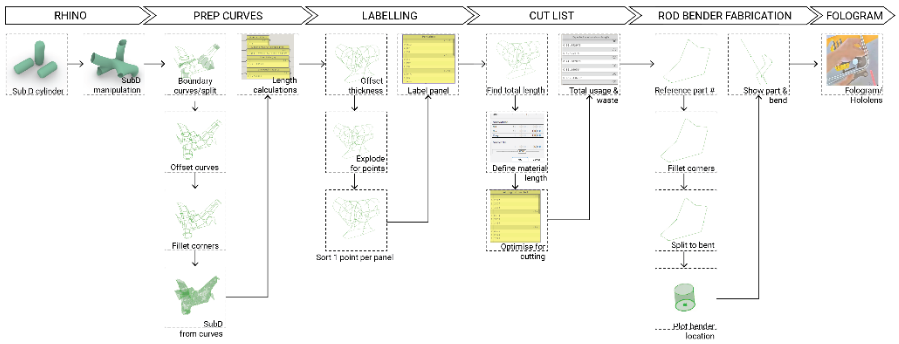


Figure 7. [A] Workflow diagram by Gemma Borra describing a circular feedback through reflective practice. [B] A linear workflow by Justin Stokes, where AR tool is identified as design probe.

4.1. PROBES AND TOOLKITS

The use of AR as both probes and toolkits for prototyping the design enables the 'artistry' to be enacted in the project. Figure 7 illustrates workflow diagrams by two students, demonstrating their understanding of the project post-installation as a means to capture reflective practice. Diagram 7A shows a circular feedback process, attempting to map the complexity of the techniques. In doing so, it identifies the prototypes as the starting point of design and the design brief as the outcome – an inversion of the traditional problem-solution design process. Diagram 7B attempts to organise the workflow as a linear approach. Here, the role of Fologram (and not HoloLens) is seen as the probe for design insofar that applying AR techniques (from pipe bending to digitisation and pattern application) is used to provoke the design of the Stair Monster. For a start, a rectilinear form is more difficult to fabricate than a curvilinear structure, hence providing affordances for a more fluid design that can address multiple interfaces with existing structures (the stair, handrail and wall) in a tight space, see Figure 3. When read in conjunction with the Pseudo-code diagram where each design parameter is outlined, the Grasshopper definitions become toolkits to accelerate the fabrication process, see Figure 8. The black-box nature of the definition abstracts the code to its core functions and provides the students with



foundational understanding while still allowing a deep dive into the code.

Figure 8. Pseudo-code diagram by Justin Stokes where GH definitions are used as toolkits to accelerate the fabrication process.

4.2. MECHANISM FOR AN ACCELERATED TACIT KNOWLEDGE

There are two moments of accelerated learning in the interface between digital modelling and physical fabrication.

One key learning in the first workshop was for students to develop a tacit understanding of the exact and in-exact nature of using AR for pipe bending, balancing the speed of production with the visual perceptions and cognitive accuracy of the digital model. The accuracy of the pipe bending was understood as a degree of variant. Through the first prototyping process, students developed a tacit understanding of material tolerance, such as the spring back of the aluminium tube after bending, and its effect on the outcome. Students soon know how much tolerance or in-accuracy they can get away with in the bending process to achieve a similar result. For the final assembly of the Stair Monster, the squishy nature of the structure allowed the team to assemble the structure flat on the ground and drop it in the stair void, see Figures 2-8. A similar understanding of variants occurs during the AR painting process, where ten pairs of hands apply the pattern, with four headsets operating simultaneously. The team practised the drawing technique on a palette to gain tacit knowledge, such as how to hold the chisel marker and the application angle, see Figure 4A. The collective exercise allows any 'new' hands to mimic the pattern applied beforehand.

The second moment of accelerated learning facilitated by AR was the speed of critical awareness and reflection level developed during fabrication. The AR super-charges the students with tacit know-how, and within an hour of practice with the HoloLens and the pipe bender, they assumed confidence in tacking different shapes. The Knowing-in-action process was immediate; for example, students would know through the AR projection that a specific pipe was not feasible to bend as they cycled through the bending sequence and noticed how it clashed with the bender and the table, see Figure 4C. Interestingly, Reflection-in-Action or the evaluation process was equally immediate. Students would question how to overcome the problem by re-orientating the model in Rhino 3D to make the fabrication feasible. We observed the accelerated Reflecting-in-Action and Knowing-in-Action at work, partly due to the collapse of digital representation on the physical environment, eliminating the need for students to anticipate or extrapolate outcomes. Here, the cognitive judgement was applied to the tacit – an incremental and yet accelerated form of learning.

5. Conclusion

The research examines the implication of AR on design pedagogy. In addition to exposing students to direct design to fabrication workflow using AR and associated software, the intensive design studio seeks to critically understand the role of design research through making using AR technology. It demonstrates how the design and fabrication of a site-specific installation at Bond University can accelerate tacit and design learning – evident in the various research workflow and pseudo-code diagrams produced by the students post-installation as a mechanism for reflective practice. The research highlights the roles and value of probes, toolkits, and prototypes throughout the project, where prototype and AR software such as Fologram could act as design probes. The analysis identified two critical moments of accelerated tacit knowledge in understanding material tolerance and critical awareness. Here, Reflecting-in-Action and Knowing-in-Action interact to develop 'artistry' in the project.

Acknowledgements

The project acknowledge the contributions of Chris Grieve, Cameron Newnham, Nick van den Berg, and Ryan Wirth with participating students: Parnian Agahi Najafabadi, Gemma Borra, Kuan U Chan, Lara Damelian, Chor Cheung Mok, Homesh Seetah, Justin Stokes, and Grace Tetley.

References

ARC. (2023). Excellence in Research for Australia 2023 Submission Guidelines.

Bates, D., Mitsogianni, V., & Ramírez-Lovering, D. (2015). Studio futures : changing trajectories in architectural education. In Changing trajectories in architectural education. Uro Publications.

Carota, F., & Tomalini, A. (2023). VPL as Design Learning Tool Between Geometry and Fabrication. Nexus Network Journal, 25(Suppl 1), 285–292.

Caudell, T. P., & Mizell, D. W. (1992). Augmented reality: an application of heads-up display technology to manual manufacturing processes. Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences, ii, 659–669 vol.2.

Downton, P. (2003). Design Research. Royal Melbourne Institute of Technology, RMIT.

Fologram. (2023). Research. https://docs.fologram.com/c3641859642d4bfc8e1db6b1cd87c9a8#Research

Holzer, D., & Loh, P. (2020). Digital Stupefaction - Seduction and Complacency of Digital Techniques. In I. K. D. Holzer, W. Nakapan, A. Globa (Ed.), Anthropocene, Design in the Age of Humans - Proceedings of the 25th CAADRIA Conference - Vol 2 (pp. 351–360). CAADRIA.

Jahn, G., Newnham, C., & Beanland, M. (2018). Making in Mixed Reality. Holographic design, fabrication, assembly and analysis of woven steel structures. Recalibration. On

Imprecisionand Infidelity. Proceedings of the 38th Annual Conference of ACADIA, 88–97.
Jahn, G., Wit, A., & Pazzi, J. (2019). [BENT]. Ubiquity and Autonomy. Proceedings of the 39th Annual Conference of the ACADIA, 438–447.
Kalay, Y. E. (2004). Architecture's New Media. Paperbackshop UK.
Loh, P and Leggett, D. (2018). Machining Aesthetics: Tool Making as Design Research. In D. Maxwell (Ed.), Proceedings of the 1st Annual Design Research Conference, Sydney (pp. 517–529). The University of Sydney.
Loh, P. (2018). Making as Pedagogy: Engaging Technology in Design Teaching. In N. Llevot-Calvet & O. B. Cavero (Eds.), Advanced Learning and Teaching Environments. IntechOpen. https://doi.org/10.5772/intechopen.72202
Malinin, L. (2018). Situated Design-Thinking in Architectural Practice: Analysing and Extending Schön's Epistemology. Ardeth, 2, 53. https://doi.org/10.17454/ARDETH02.05
Marble, S. (2012). Digital workflows in architecture : designing design -- designing assembly -- designing industry. Birkhäuser.
Marcus, A., Ikeda, M., & Jones, E. (2014). Architecture In The Making: Performance, Prototyping, and Pedagogy at Full Scale. ACADIA 14: Design Agency [Projects of the 34th Annual Conference of the ACADIA, 75–78.
Milgram, P., & Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. IEICE Trans. Information Systems, E77-D, no. 12, 1321–1329.
Papert, S. (1988). Computer as material: Messing about with time. Teachers College Record, 89(3), 408–417.
Ratto, M. (2011). Critical Making: Conceptual and Material Studies in Technology and Social Life. The Information Society, 27(4), 252–260.
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.
Sanders, E. B.-N., & Stappers, P. J. (2014). Probes, toolkits and prototypes: three approaches to making in codesigning. CoDesign, 10(1), 5–14.
Schank, R. (1995). What We Learn When We Learn by Doing. Institute for the Learning Sciences, Northwestern University, 60.
Schon, D. A. (1984). The Reflective Practitioner: How Professionals Think In Action. Basic Books.
Schwartz, C. (2016). Critical making: Exploring the use of making as a generative tool. Journal of Curriculum and Pedagogy, 13(3), 227–248.
Snooks, R. (2014). Behavioral Formation Multi-Agent Algorithmic Design Startegies. RMIT University.
Song, Y., Koeck, R., & Luo, S. (2021a). AR Digi-Component - AR-Assisted, real-time,immersive design and robotic fabrication workflow for parametric architectural structures. PROJECTIONS - Proceedings of the 26th CAADRIA Conference - Volume 2, 253–262.
Song, Y., Koeck, R., & Luo, S. (2021b). Review and analysis of augmented reality (AR) literature for digital fabrication in architecture. Automation in Construction, 128, 103762.
Varela, A., Lacroix, P., Güzelci, I., Zeynel, Sousa, O., & Pedro, J. (2022). Democratizing Stereotomic Construction through AR Technologies - A reusable mold methodology to the production of customised voussoirs using HoloLens. In B. Pak, G. Wurzer, & R. Stouffs (Eds.), Co-creating the Future: Inclusion in and through Design - Proceedings of the 40th Conference on eCAADe (pp. 225–232).
Webster, A., Feiner, S., Macintyre, B., Massie, W., & Krueger, T. (2000). Augmented Reality in Architectural Construction, Inspection, and Renovation. Proceedings of 1996 ASCE Congress on Computing in Civil Engineering.