FABRICATE 2020: MAKING RESILIENT ARCHITECTURE

The fourth volume in a triennial series of conference publications that began with ‘Making Digital Architecture’ in 2011 at the Bartlett School of Architecture, UCL. The first conference emerged from a need to explore the ways in which technology, design, and industry are shaping the world around us.

In 2020, the conference returns to London, with a focus on how we design and make resilient architecture within the context of global challenges in access to, and deployment of, technology. This book features the work of designers, engineers, and makers within architecture, construction, engineering, computing, and manufacturing, all of whom are working towards exciting goals within fabrication.

Exploring case studies of completed buildings, analyses of works-in-progress, the latest research in design and digital manufacturing, and interviews with leading thinkers, Fabrikate engages with the key challenges we face at an extraordinary time for the built environment.

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House #05 explores the integration of custom moulds with a proprietary construction system for in-situ concrete casting (Fig. 2). The project foregrounds a design methodology that allows the fabrication procedure to drive the design process, primarily using tooling and construction procedures as agents to inform the architectural design.

The design methodology is made possible through the setup of LLDS’s practice, where the architectural studio also fabricates building components. The project devises a unique digital workflow that incorporates feedback and evaluation of as-built information into the live design data to incrementally modify the fabrication information for construction. The aim is to overcome the challenges of integrating highly precise digitally-fabricated components to suit the on-site condition, specifically the interfaces between different work packages (Denari, 2012). The project asks: Can this very pragmatic desire allow digital fabrication to challenge the design through making?

In studying the making of tools in archaeology, Lambros Malafouris (2016) proposed that the prehistoric man makes tools, such as an axe head, without picturing the shape of the tool in the flint stone. Instead, the design of the axe head emerges through a continuous process of shaping the material to eventually produce a useful form that is fit for purpose. Every strike on the flint by the maker informs the following strike until the stone is incrementally shaped. It implies that design is a process that develops through the act of making and requires a positive feedback loop (Johnson, 2001).

House#05 adopts Malafouris’s notion of material engagement into practice, whereby the making and digital fabrication techniques lead the design through a continual process. That is to say that the tooling and making procedure are deliberately privileged above other criteria to inform the design. Here, the project demonstrates a methodology of designing in which digital fabrication is much more akin to a traditional sense of craftsmanship (Pye, 1968) where construction constraints and opportunities are fed back into the making procedure. The research asks: If tooling can inform the design process, then how can the construction procedure produce feedback that can also shape the design?
House#05 is a single dwelling situated in a narrow four-storey-wide leftover site in the inner suburb of Melbourne, Australia. The house is conditioned by the existing terrace typology with two boundary walls. Responding to the lack of garden space for the dwelling, the roof of the house is conceived as an elevated ‘plant pot’, which is raised eight metres above the ground so that it receives natural daylight and is not overshadowed by neighbouring buildings. The void below the roof becomes the dwelling. The roof is supported by two concrete boundary walls that are anchored to the ground, forming a three-mile-deep concrete plinth. The plinth contains the most private spaces of the dwelling: the snug, bedrooms, utilities and bathrooms. In this project, digital fabrication is utilised across multiple packages of work. This paper will focus on the in-situ concrete package to examine the workflow of incremental construction.

LLDS has a unique setup. Alongside its architectural practice, it operates a 500m² micro-manufacturing workshop with a three-axis CNC router and a seven-axis robotic arm (Fig. 5). The parallel mode of making and designing allows for a fluid dialogue, from experimentation to the integration of research into construction workflow. It allows the practice to fabricate construction components and integrates them into a standard building contract for the project. The integration of digitally fabricated components with a proprietary construction technique enables the practice to manage the level of complexity associated with the construction. It allows for a more natural adoption of such techniques by small-scale contractors that predominantly operate within the bespoke housing market in Australia.

Design Intent

The boundary of the terrace typology set up a condition where the parallel walls create a flutter echo effect in the open plan interior. To reduce the echo effect, the design intent is to texture the surfaces of the off-form concrete to scatter the sound (Brady and Olesen, 2010). While the effect is simulated in digital model using a ray-tracing methodology, the physical acoustic test has not yet been performed at the time of writing. The fair-faced concrete is exposed internally, providing thermal mass to regulate the environment, especially useful with Melbourne’s extreme temperature changes.

To achieve the textured concrete, CNC-fabricated moulds are inserted into a proprietary formwork system. The pattern for the concrete formwork is produced by generating a series of parallel lines as toolpaths in Grasshopper® (Fig. 6), which is visually simulated in RhinoCAM. The tooling is performed on a polystyrene core (PIR) panel coated with a two-part polyurethane coating that forms a hard impact-resistant surface. The thickness varies depending on whether the mould is applied to the interior wall or external retaining surface. The thicknesses are conditioned in the digital model using a ray-tracing methodology, the physical acoustic test has not yet been performed at the time of writing. The fair-faced concrete is exposed internally, providing thermal mass to regulate the environment, especially useful with Melbourne’s extreme temperature changes.

The pattern for the concrete formwork is produced by generating a series of parallel lines as toolpaths in Grasshopper® (Fig. 6), which is visually simulated in RhinoCAM. The tooling is performed on a polystyrene core (PIR) panel coated with a two-part polyurethane coating that forms a hard impact-resistant surface. The thickness varies depending on whether the mould is applied to the interior wall or external retaining wall. The coating provides a smooth and gloss finish to the cast as well as acting as a release agent. The PIR is re-used as insulation for the cavity wall and screeded floor. Early prototypes (Figs 4A–4J) explored the textural potential of the surface. The marking left by the tool profile with variation to the depth of the toolpath. The marking left by the tool produces depth to the surface. Of the tools tested, only the PIR produced a value effect to the concrete wall.

Designing Through Tooling

Prior to engaging with the concreter, the practice developed over 15 prototypes (Fig. 4). In the experiment, a standard concrete mix was used. The texture is based on a standard tool profile with variation to the depth of the toolpath. Early prototypes (Figs 4A–4J) explored the textural potential of the surface. The marking left by the tool produces depth to the surface. Of the tools tested, only a small portion proved to be feasible, as some formed undercuts which made the mould challenging to remove. Some created an intrusion that was too fine and easily damaged when the mould was struck (Figs 4K–4L). The tool’s profile, cut depth and width conditioned the pattern but at the same time provided a series of unique aesthetics that were useful for the design process. The resulting pattern (Figs 4K, 4L, 4M, 4N) was developed based on an interference of two toolpaths which produced variable plating across the surface (Fig. 5).

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To understand the constraints of the tooling, the toolpath was tested on several geometric scenarios. The linear motion of the toolpath produced an uneven load when applied to a radial layout. However, the transition of depth works best when the linear toolpath is maintained, and variation in height is used to deliver reinforcement bars along the diagonal shift across the topography. This technique is applied to the concrete soffit. For the final iteration of the soffit design, the toolpath converges into a series of vaults. Figure 6 visualises the toolpath for the entire project for fabrication. The vaulted soffit is a design response to the engineer's requirements to add two 300mm-deep down stand beams to take the load of the green roof. For the soffit, a medium-density fibreboard (MDF) mould was coated with a high gloss polyurethane is used instead of the PIR, as the mould needs to support the weight of reinforcement bars prior to pouring the concrete. The mould is first milled using the three-axis CNC router and is finished with a final set of toolpaths using the Kuka KR120 robotic arm (Fig. 7). The two-step process helps reduce excessive waste, but critically allows the layer of MDF that makes up the mould to be screw fixed from the underside. As each mould weighs up to 126kg, when the concretors strike the formwork, the mould is removed in layers from the underside to ensure the full weight does not collapse on the workers.

The fabrication workflow uses tooling and construction procedures to inform the design and deals with the practical demands of the mould. It integrates the constraints and opportunities of the proprietary system within a self-contained digital workflow (Fig. 8). Lessons learned from the various prototypes feedback into the detailing, such as the articulation around cast-in power sockets, and the alignment of the toolpath along the tie points and its interface at the part line. The tie holes are plugged with brass plates which are sometimes used for hardwoods, coat hooks and picture hangers to support the inhabitation of the rooms.

Negotiating As-Built Tolerance to Construct Feedback

When the PIR mould panels were installed on-site, each being 1.5m tall and 0.9 metres wide, the main tolerance issue was caused by the proprietary modular formwork panels, which varied in width by up to ±10mm. This led to creep in the tie hole positions along the 13-metre long wall, resulting in misalignment with the corresponding holes within the PIR mould panels. Following the first pour of the wall, the as-built information was captured using a high-resolution point cloud scan of the site (Fig. 9). The point cloud identified areas of discrepancy and error, such as edges where the vaulted soffit rests were found to be 5 to 10mm out of plumb. While this is within the tolerance of the concrete structure, it would cause the soffit mould to misalign and create large gaps between the mould (Fig. 10). The two-step milling procedure of the mould allowed the final geometry of the soffit to be adjusted and trimmed by the robotic arm to match the as-built geometry (Fig. 10).

Incremental Construction in Practice

In this project, LLDS put into practise a ‘just-in-time’ method of fabrication in which the fabrication data was aligned with the site information. The research highlighted the importance of looping in the as-built information as part of the file-to-production protocol. The use of fabrication information as a live data set to incrementally inform the design and construction also helps to avoid the contractor manually hacking precise components for them to fit on site.

The practice set up the partnership with the concreter provided a unique opportunity in this project to design, fabricate, construct, survey and readapt the fabrication data to account for site discrepancy. The two layers of feedback allow the practice to challenge the design through making. First, using iterative prototypes, both physical and digital, the tooling and making procedure informs the design process. Second, the scanned as-built data to account for site discrepancy. The two layers of feedback allow the practice to challenge the design through making. First, using iterative prototypes, both physical and digital, the tooling and making procedure informs the design process. Second, the scanned as-built data informs the fabrication process and allows the practice to be nimble in responding to site tolerance and error. These feedback loops are rare in construction as it's time-consuming and not often cost-efficient. However, the feedback processes create an agile workflow that begins to address the messiness of on-site construction. The result is an incremental construction methodology that enabled LLDS to embed architectural detailing within the digital workflow, encoding craft into the algorithms.

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