EDFAB

Design and Building of a Plywood Research House

Neill McCulloch, Dr Yusef Patel and Sēmisi Potauaine

Introduction

EDFAB: Eco-digital Fabrication Research Project was a collaboration between researchers and students from the University of Auckland's and Unitec Institute of Technology's Schools of Architecture. The research sought to investigate and develop a new housing typology with off-the-shelf materials and simple digital fabrication machinery. EDFAB aims to radically challenge conventional construction processes and relationships by proposing an alternative fabrication process to address problems of affordability, personalisation, energy performance and indoor comfort. The research investigates how simple automated technology can enhance the design process, labour, productivity, organisation and quality in ways that avoid stigmatising construction professionals.

Over the past six years, there have been four major project iterations of EDFAB. As New Zealand's construction sector is largely comprised of small-to-medium enterprises (SMEs),[1] design concepts were developed to provide a pathway for conventional building contractors to upskill and increase productivity. The purpose of EDFAB, therefore, was to investigate what possible added-value changes could be made to existing balloon-framing house methodologies with 3-axis CNC automated processes.

The original EDFAB prototype investigated the design and fabrication of a 10sqm 'plywood centric' proof of concept that was displayed at the 2014 Whau Arts Festival (Figure 1). In 2015, University of Auckland architecture students designed EDFAB 2.0, a 10sqm plywood and laminated veneer lumber (LVL) iteration on the original prototype. This prototype sought to reduce waste and simplify design complexities. The design worked on the premise of CNC milling plywood components to create modular boxes. The LVL was cut and assembled into portal frames to provide structure and flexibility to the construction system. In 2017, students furthered the research by producing the EDFAB 3.0: Living Pod for the 'Prefab NZ Interactive Display, Brought to You by Unitec' exhibit at the BuildNZ | Designex expo (Figure 2). The purpose of the iteration was to seek industry feedback and refine details from the previous iteration. In 2019, the 65sqm two-bedroom EDFAB 4.0: The Carter Holt Harvey Research House was built in a collaboration between students, researchers and

1. Ian Page, *Residential Construction and Costs*, paper for BRANZ workshop, July 9, 2009 (Wellington: BRANZ, 2009).

Figure 1. Dr Dermott McMeel working on the original EDFAB at the Whau Arts Festival.

Figure 2. EDFAB 3.0 at BuildNZ | Designex expo. Photographs: Yusef Patel

building contractors. The development sought to resolve deficiencies in the assembly process, include building contractors in the construction process and reduce the dependency on CNC plywood components by discarding the portal frame.

Design Method and Value of Research

There is no need to radically reinvent or to challenge what already exists, but rather we should work to improve and enhance current construction practices with technological innovation. Innovation within EDFAB research does not seek to replace the relevance of architects and building contractors, but rather to enhance it. EDFAB seeks to understand how to combine traditional analogue and digital workflows to ensure that experienced practitioners can participate in the digital revolution. All construction products specified within the design of EDFAB were purchased off the shelf from a local building supplier. The ultimate aim is to provide quality, compliance and effective construction management. This led to the EDFAB research team consisting of a cross-disciplinary team of students, academics and construction experts. At every major design milestone, the work was presented to the construction community at industry events for valuable feedback.

The simple file-to factory workflows enable the team to iteratively prototype their design by constructing models and mock-ups on laser cutters and computer numerical control (CNC) routers. This approach requires the researchers to firstly 'design and detail' in schemes within a virtual environment. The digital data from the virtual models or drawings is subsequently extracted to 'create and simulate' the milling 'tool paths' within the appropriate computer-aided manufacturing (CAM) software.[2] The process that the EDFAB research prescribes (Figure 3) is not dissimilar to University of California Professor Alice Agogino's series of 'design-process models,' created for NASA. At its simplest, Agogino's 'standard model,' which follows three phases: (1) define a design; (2) build to prototype; (3) test to evaluate, is used to dictate the EDFAB prototyping process. When required, feedback loops can be inserted into the model to address design errors that may be discovered during the evaluation phases.[3]

2. Lisa Iwamoto, *Digital Fabrications: Architectural and Material Techniques* (New York: Princeton Architectural Press, 2009).
3. Geoffrey Makstutis, *Design Process in Architecture: From Concept to Completion* (London: Laurence King Publishing, 2018).

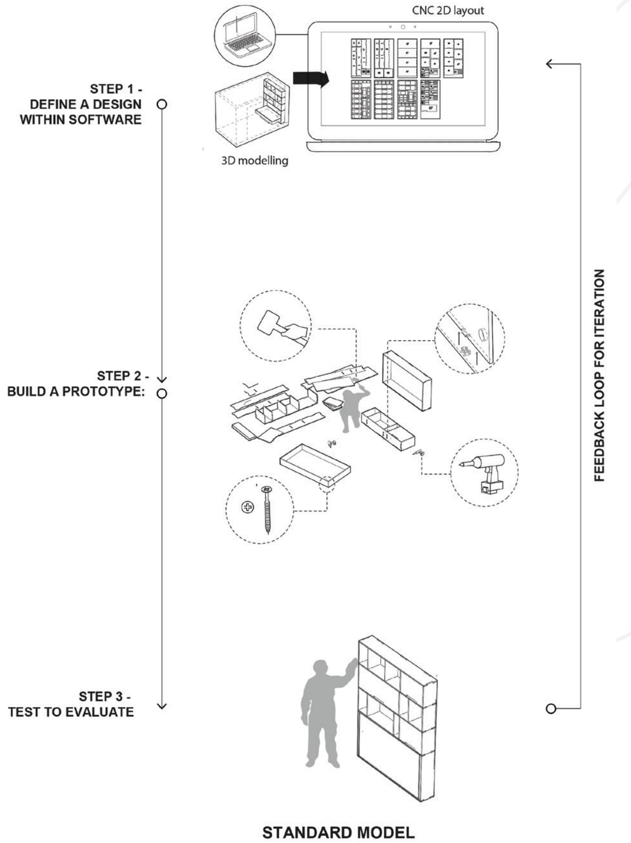


Figure 3. EDFAB prototyping and evaluation workflow.

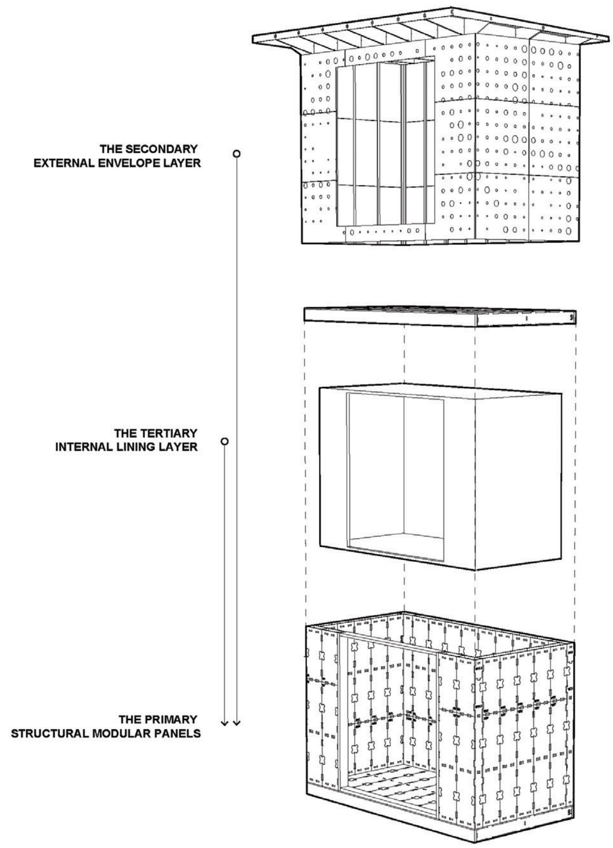


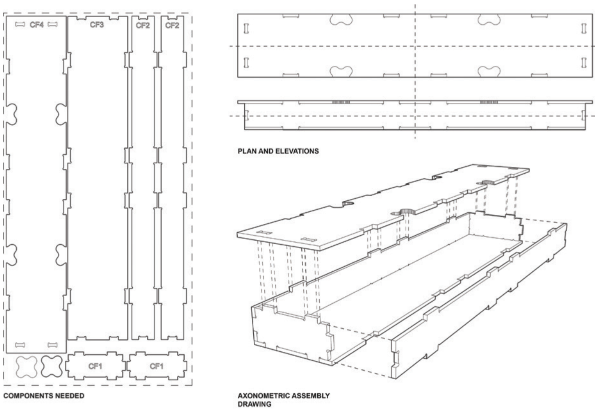
Figure 4. Three layers of EDFAB 1.0. Images: Yusef Patel

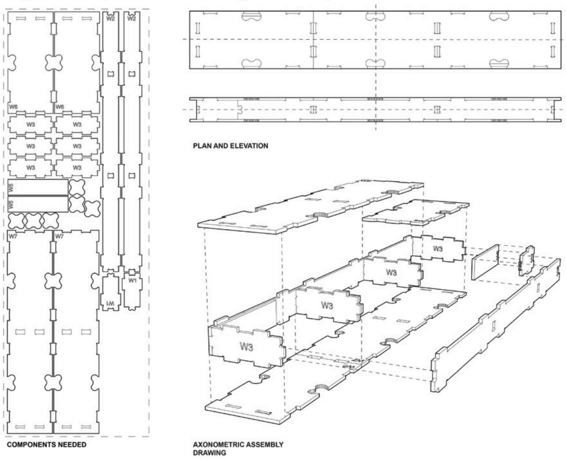
EDFAB Developments

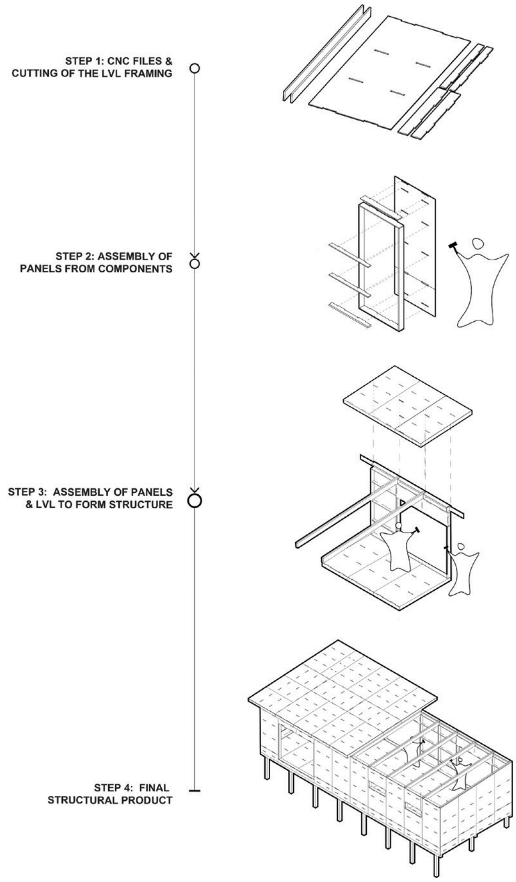
The four major project iterations allowed for gradual improvement to the EDFAB concept in order for it to become an industry-sponsored and regulatory-approved construction system. The development also enabled efficiencies around labour, material cost and waste to be optimised, to ensure productivity could be passed on to all stakeholders. While the CNC machine produced flat-pack plywood components, all LVL framing components were cut to length by mitre saw.

The findings between the first three iterations revealed that the students, the architect and the contractor needed a highly refined workflow to be effective. These iterations did not need to obtain building consent and, therefore, everything from digital workflow, testing of design details, structure and division of labour between stakeholders could be tested without being limited by conventional process and approvals. When issues arose, they were discussed, understood and properly managed to ensure the best system could be developed for future iterations.

All the EDFAB flat-pack and timber framing elements were assembled into prefabricated panels within a workshop setting to ensure quality controls were in place. While EDFAB 1.0 and 2.0 did not incorporate pre-milling or pre-drilled holes for services, EDFAB 3.0 and 4.0 amended this design flaw to ensure the jobs of electricians and plumbers were simple and straightforward. Prefabricated elements such as Altus Smartfit windows and doors were incorporated into EDFAB 1.0 and 3.0 iterations as they allowed for low tolerance construction. Due to cost, they were not incorporated into EDFAB 4.0, to the detriment of







Figures 5 and 6. Designs for EDFAB 1.0, iteration 3.0 for the floor and ceiling panels, top, and wall panel, bottom.

Figure 7. EDFAB 2.0 construction system. Images: Yusef Patel

quality and tolerance. The design of the architrave details had to be amended late in the construction programme, at extra cost. While EDFAB 3.0 incorporated Apex's modular wiring system, EDFAB 4.0 incorporated 'draw-wires' during the assembly process to allow the electrician to install wires with the final finished internal layer already affixed onsite. Similarly, while EDFAB 1.0 and 3.0 used Knauf blow-in-insulation onsite, EDFAB 4.0 used Knauf's Glasswool insulation, which was inserted in assembled panels in the workshop.

The greatest achievement of EDFAB 4.0 was that it furthered the research into obtaining regulatory Auckland Council building consent approvals. This required aspects such as plumbing and electrical wiring systems, and interior elements – kitchens, doors, handles and built-in furniture – to be addressed. To ensure offcuts were not disposed of into landfill, they were recycled to create the kitchen and internal door leaves.

Design–Build Studio Challenges

In any project, managing expectations from everyone involved is one of the challenges; even more so when it comes to a new system process. Funding and willingness for individuals to employ our system beyond a novelty product were challenges. From a client's perspective, there were issues around budgets and how to obtain loans. As the project was student-based, there were barriers and conflicts between the way students and professional building contractors operate. Professional contractors were at times annoyed with the variable availability of students to work

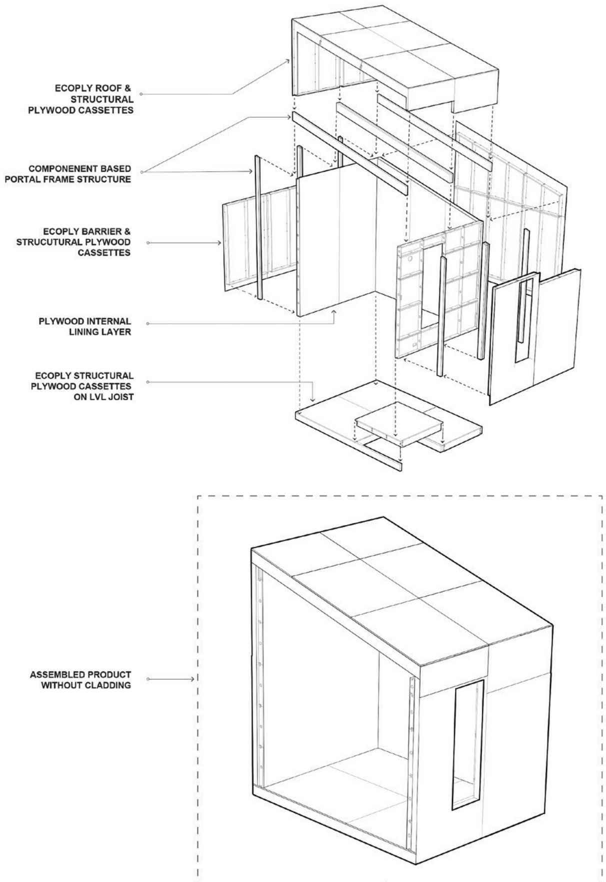


Figure 8. EDFAB 3.0 BuildNZ | Designex iteration. Image: Yusef Patel

on the project. While teaching academics understand this as a normal occurrence, and can accommodate it, it is something that contractors aren't used to, and can find difficult work around. Similarly, contractors forget that students are by no mean expert professionals. They can make simple mistakes that normally do not occur on a build project, which in turn will require the building timeline to be amended. If this is not properly communicated or accounted for by the project manager it can create problems. At times, some very minor mistakes have cost the client financially, as building contractors would turn up to site and have no work to do.

Building Landscape Comparison

The limitations of plywood mean that the modular panels are only 1200mm in width, meaning window or door

Figure 9. EDFAB 4.0 prefabricated panels being assembled and lined up ready for install onsite. Photographs: Yusef Patel

Figure 10. EDFAB 4.0 completed. Photographs: Ivan Majid

widths cannot exceed 1100mm. Future iteration will be required to overcome this engineering challenge. It is difficult to quantify whether this house is any quicker to build than a conventional house, as it was built by students over the course of a semester, and they needed to work on the project in between their classes. Elements such as foundations, cladding and windows were built or installed in a typical way, no different to conventional practice.

Integrating this building project into the students' programme and timeline put us out of competion with other projects of the same size, in terms of timeframe and critical path. This build equates to $3000 per square metre for the building component only, excluding all consents and other infrastructure. Extra costs came with site-specific items relating to this project, such as extra windows, scaffolding and shrink-wrapping.

It must be noted that the EDFAB house is a bespoke build, with every single module manufactured to a custom design. The price is slightly above the cost of an average Auckland catalogue housebuild of $2500 per square metre.[4] The cost of the research house is on par with, and is at the bottom end of, the base price of house prefabricator Box: the cost of their houses ranges from $2500 per square metre at the economy end to $10,000 per square metre at the bespoke architectural end.[5]

Conclusion

The EDFAB research shows that the control of digital fabrication technologies is accessible and can be integrated into conventional construction practice. It is important to understand that ease of access and digital literacy levels will differ between practitioners and would-be practitioners, so the investigation sought to show that automation is not so far-fetched or intimidating. The skills and knowledge of the experienced stakeholders can be capitalised on, rather than their role being diminished or replaced by technology. Design parameters were created to test whether a product could be manufactured both by machine and hand. This was done to ensure design systems connect well with conventional construction processes to support and encourage adaptation among building practitioners. Working collaboratively with industry partners and building contractors such as engineers and installation specialists allowed us to ensure off-the-self products conformed to their code-compliant product statements. Lastly, practising architects and builders were constantly consulted to ensure that the outcomes would be realistic.

Acknowledgements

The EDFAB experiments would not be possible without Unitec New Zealand, PrefabNZ, The University of Auckland, Carter Holt Harvey Woodproducts, Apex Wiring Solutions, Adevfa Builders, Fortress Fasteners, Pro Clima NZ, Altus (formerly Fletcher Window and Door Systems), Juken New Zealand, Knauf Insulation, Holdfast, XPO Exhibitions and Eco Insulation.

A special thank-you goes to all the students, architects, engineers, industry experts and academic staff who made the EDFAB research a reality: John Chapman, Dr Dermott McMeel, Peter McPherson, Dr Paola Leardini, Sēmisi Potauaine, Jon Davies, Pamela Bell, Ano Lo Tam, Merryn Jolly, Heidi Misseldine, Dimitar Penchiev, Madeline Stuart, Dr Garry Raftery, Michael Mosely, Adrian Janus, Rohini Contractor, Annaliese Mirus, Gemma Campbell, Kristian Deianov, Houston McCoy, Richard McIlroy, Murry Durbin, Morgan Gallagher, Haydon Rogers, Ronnie Pocock, Ernest Auora, Alice Couchman, Jonah Kim, Andrew Porteous, Peter Cleveland, Franca Bertani, Daniel Swain, Kenneth Murgitroyd, Scott Facer, Che Michalski, Peter Shaw, Peter Stuart, Emily Wood, Natasha Trumic, Nina Massie, Shaun Fletcher, Antonio Lara Hernandez, Priscila Besen, Olivia Chiang, Pasawhtee Kuku, Glenna Taulilo-Makaea, David Guov and Torben Laubscher.

4. Greg Ninness, "The Average Size of New Dwellings Dropped from 200 Square Metres in 2010 to 158 Square Metres in 2019 While the Average Construction Cost Rose by a Third," Interest, February 10, 2020, https://www.interest.co.nz/property/103551/average-size-new-dwellings-dropped-200-square-metres-2010-158-square-metres-2019.
5. Dan Hayworth, "Compare Apples with Oranges: Understanding m²," Box, March 28, 2019, https://www.box.co.nz/2019/03/28/understanding-square-metre-cost/.

Authors

Neill McCulloch

Neill McCulloch is currently studying for a Master of Architecture (Professional) at Unitec New Zealand, and is a qualified and practising electrician.

https://orcid.org/0000-0002-3032-8029

Dr Yusef Patel

Yusef Patel is the Academic Programme Manager for the Bachelor of Architecture and Master of Architecture Professional programmes at the School of Architecture, Unitec New Zealand. He recently completed his PhD in Architecture at The University of Auckland. A large focus of his research investigates social building activities with the use of digital fabrication technologies.

https://orcid.org/0000-0001-6389-0969

Sēmisi Potauaine

Sēmisi Potauaine is a Lecturer, a Teaching Fellow and a researcher at Unitec New Zealand, and is a practising multimedia artist with a primary focus on architecture and related arts. Both his academic and his practice research revolve around the tā–vā (time–space) Indigenous philosophy. He has authored and co-authored books, book chapters and journal articles on this subject, and has produced sculptural, architectural and related artworks.

https://orcid.org/0000-0002-2928-6642

Bibliography

Hayworth, Dan. "Compare Apples with Oranges: Understanding m²." Box, March 28, 2019. https://www.box.co.nz/2019/03/28/understanding-square-metre-cost/.

Iwamoto, Lisa. *Digital Fabrications: Architectural and Material Techniques*. New York: Princeton Architectural Press, 2009.

Makstutis, Geoffrey. *Design Process in Architecture: From Concept to Completion*. London: Laurence King Publishing, 2018.

Ninness, Greg. "The Average Size of New Dwellings Dropped from 200 Square Metres in 2010 to 158 Square Metres in 2019 while the Average Construction Cost Rose by a Third." Interest, February 10, 2020. https://www.interest.co.nz/property/103551/average-size-new-dwellings-dropped-200-square-metres-2010-158-square-metres-2019.

Page, Ian. *Residential Construction and Costs*. Paper for BRANZ workshop, July 9, 2009. Wellington: BRANZ, 2009.