ZERO HOUS[ING] 1:1 Prototype + Process: Collaborative and Experiential Education in the Global Housing and Climate Crisis

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Zero Hous[ing] is a recently built energy neutral midrise housing prototype that investigated alternative sites, and alternative forms of practice and production. It used prefabrication and a carbon sequestering palette to address the housing affordability and climate crisis. While it was produced and reads as a single family house— it was designed to work as housing for metropolitan areas.

This project considers urban typology, architectural design for aesthetics, function, health and well-being, and innovative construction methodologies to look at this problem from the bottom-up and across sectors. The objective was to build demand with consumers and industry for net-zero energy and carbon sequestering housing by making a healthy and attractive architecture, creating site location and construction efficiencies, and demonstrating through this built prototype and its life-cycle cost and energy analysis, that it might be accessible to the many rather than the few.

We realized this building with custom prefabrication and a deeply integrated design process engaging a cross-disciplinary team of professionals, educators, builders and students in all stages of the work. This project is remarkable for the ambition and scope of its definition of sustainable design (urban design, carbon footprint, energy use and construction methodology) and for its recognition that, in order to change existing paradigms we need to actively interact, and through experiments like this, develop new ways to design, build, and live collaboratively.

This educational project integrated architecture, engineering, and business faculty and students at Ryerson University, Toronto Canada and an industry construction/education partner called The Endeavour Centre. We collaborated on this one-to-one scale prototype using Passive House principles, and prefabrication as an ethic. We built it using our industry partner's team of apprentice carpenters and it is now being enjoyed as a full time residence for its owner while we monitor its performance.

> "Rather than be characterized as a technocratic burden to be satisfied, energy can, and should, help architecture finally and powerfully fulfill the terms of its ambitions: form, space, technology, program, and urbanism."
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> —Kiel Moe, *Convergence: An Architectural Agenda for Energy*[1]

DIRE

We are now in the Anthropocene and the social and ecological repercussions of the way we design cities are now dangerously self-evident. It is thirty three years since the Brundtland Report was published and less than ten years to 2030[2] and yet we continue in North America to design and build housing and cities to feed a market economy as though there was no climate or societal emergency. Our cities are becoming the enclaves of the wealthy, and as designers and clients, we still prioritize aesthetics over sustainability as though they are mutually exclusive. For most architects and their clients, sustainable housing translates as either too, expensive, formally banal, or a problem for engineers and equipment to resolve.

Yet, educated as generalists, we are best positioned to see the interconnectivity of place, matter, infrastructure, systems and all the various actants in the manifestation of our cities and societies. Housing is the largest single ingredient of our urban fabric both physically and socially. The carbon emission from the building sector for this project in its locale has been determined to be 43% of all human sectors, and 8% more than transportation.[3] What we choose to build and the processes we choose to build with, have an enormous impact on a great web of issues and matter. Ecologists, engineers, urbanists, politicians, social psychologists, building scientists, developers, and carpenters need to share knowledge, lore and objectives. We desperately need to motivate our profession to recognize our critical agency to educate, connect, and lead this diverse network of actors if we hope to minimize the damage at this already too late stage of ecological and social crisis.

This design/build house, as an integrated educational project for the design of zero-emissions, financially accessible, midrise housing in a global metropolis addresses the importance of breaking down the silos in the construction and design industry and developing housing alternatives that make cities

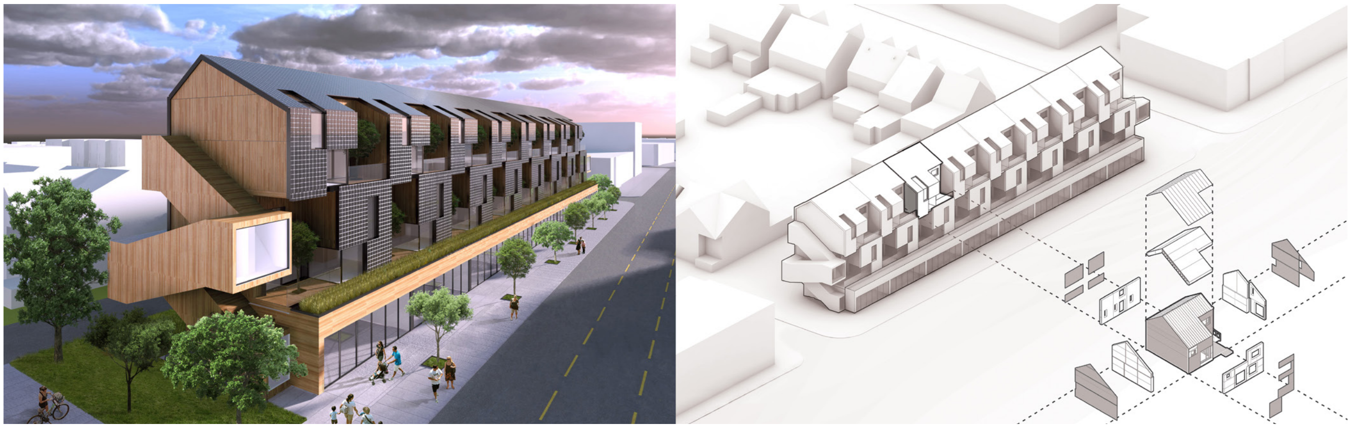

Figure 1. 5 Storey Walk up infill along existing east west arterials.Solar wrap +prefabrication Design: Atkinson Architect +ECOstudio Drawing:Matthew Ferguson

that are ecologically sustainable and equitably accessible to all members of our society. As Bruno Latour advises [4], each human endeavour—as part of 'The Terrestrial' must be considered in terms of its *geo-social* impacts.

CONTEXT

Toronto our site, is in the midst of an eighteen-year long and continuing high-rise condominium boom.[5] This concentrated growth in the city centre driven by immigration, employment expansion, housing speculation, and planning policy (to prevent sprawl), has generated stock consisting almost entirely of small studio and one bedroom units. At units selling for $1000psf CAD, 3 bedroom units are not affordable for most families. While the density created by these towers have increased urban liveliness and walkability—as glass and concrete, highly engineered constructions, they have high embodied 'emergy' and construction cost compared to typical low rise wood frame construction out of the city.

While the core intensifies, there is simultaneously an ongoing quiet de-population of the large and leafy, zoning-protected low-rise neighbourhoods immediately adjacent. These single-family homes are also financially out of reach for families, and the existing high calibre community infrastructure supporting them is becoming underused or abandoned. Public schools in the centre city are closing because of the lack of children to attend them.[6] This situation is symptomatic of a variety of destination cities where global patterns of migration, concentration of wealth, and the commodification of housing are driving out all but the wealthy and increasing rather than reducing the cost and carbon footprint of its new fabric.

THE BACKSTORY: THE SOLAR DECATHLON CHINA

This project emerged out of Ryerson's entry to the Solar Decathlon 2018. A group of enthusiastic mechanical and civil engineering students came to me as a practicing architect and design educator within our common faculty of Engineering and Architectural Science, looking for help to shape their proposed entry to this competition. This seemed like a wonderful way to spend an upcoming sabbatical, to consider these concerns with Toronto's housing crisis, and to try to better integrate the siloed nature of our respective educations. The competition team had also recently included students and a faculty member in the Business school.

However, one of the problems with the Decathlon design brief was that it was modeled after a suburban single-family setting and an energy indulgent North American lifestyle. Instead of advocating for a more compact urban model and conscientious energy use, it looked for technological solutions to help the East live more like resource profligate Westerners. The house was to demonstrate during the exhibition that it could simultaneously power multiple loads of laundry, large dinner parties and an electric vehicle commuting 200 miles a week. The hypocrisy of designing, fabricating and shipping 13,900 nautical miles all the materials and equipment to Dezhou China to demonstrate the energy efficiencies of a single family house on a green field site was problematic for me as an architect.

We decided to reboot the project with a different approach and venue. We found a local exhibition to demonstrate our idea and abandoned the Decathlon. Toronto was preparing to host an international expo called EDITdx[7] (Expo for Design, Innovation & Technology) initiated by the Design Exchange and the UN Development Program (UNDP) and based on the themes of Shelter, Health, Sustainability and Innovation. This home event solved many of our logistical problems and allowed us to target a scalable prototype that was specifically local and holistically sustainable rather than just through its direct energy loads.

URBAN FORM SOLAR WRAP

The strategy for the housing hinged on finding an appropriate site typology that was plentiful, inexpensive, transit-connected and integrated into the abundant, central and walkable pre WW2 neighbourhoods suffering from gentrification, reduced populations of children, and public school closures. The site also needed to have capacity to generate its own solar source energy, and to support midrise infill strategically.

Our five-storey walk-up rowhouse over commercial typology is designed to intensify and reanimate the abundant low-rise, but decrepit arterial streets in central Toronto that were brutally widened, deforested, and devalued to accommodate the suburban commute post WW2. (fig.1)

With the reduced roof to floor ratio created by stacked housing, this housing is designed with a building integrated photovoltaic collection surface available as a wrapper on its on its south facing facades and roof. Sunny, northern cities like Toronto have adequate low altitude winter can generate up to 80% of the energy[8] on vertical surfaces as they do on optimally tilted PV. In our test development scenario, sixteen, three-bedroom family units and eight office/commercial units comfortably fit on sites that would originally have afforded only three houses. The shared walls and floors reduce envelope and energy loads, and the new office and commercial space has the capacity to reanimate and beautify these streets.

NATURAL VENTILATION

These two-storey 'through' units are designed to optimize daylighting and cross ventilation. Recessed south facing courtyards and their common access porch provide units with four orientations for capturing light and air. These access corridors with walk up staircases at each end create a north-facing buffer zone, with large sliding windows for summer. This generous common entry can store outdoor gear but more importantly acts as a third space for residents to interact with neighbours, and for small children to play. The double height space within each unit facilitates stack effect cross ventilation and spatial interest. (Fig.2)

CONSTRUCTION COLLABORATION

After unsuccessfully trying to team up with some larger panelized construction companies and fundraise for materials and labour, we discovered builder and construction educator, Chris Magwood. Magwood's Endeavour Centre in Peterborough Ontario builds a small net zero energy building each year with their students, training them in Passive House calibre construction theory and methods. The template building is sold to a customer at the outset which funds the yearly project.

Together we formed the ECOstudio to translate the design into construction. We were able to procure some donated materials and equipment from manufacturers and design funding from Ryerson. We eventually found a buyer of the finished house. We prototyped the prefabricated panel system and the Endeavour students and staff built the 1100 square foot house over the summer. Our Ryerson team provided design concept and details, energy modelling, systems design, project management and approvals drawings. The Endeavour students provided construction labour, and the staff provided construction management and a deep knowledge base of strawbale and other carbon sequestering construction materials.

Figure 2. Multiple orientations + stack effect Drawing: Matt Ferguson.

We established and prioritized target outcomes. No oil industry products were allowed. An almost entirely organic palette of materials meant no presence of VOC's or material off-gassing. Net zero energy use, net zero construction waste, net zero carbon footprint, and net zero cost differential to comparable housing were the achieved goals within the context of Ontario's coal free, all hydro-electric energy grid.

PREFABRICATION

From the outset we identified that factory fabrication of a panelized passive house construction system, scaled to address the magnitude and geographic extent of this problem, would drive affordability and quality, and reduce our emissions footprint. Construction accuracy is critical to an airtight high-performance building. BIM integrated into both the design and fabrication facilitate coordination and eliminate site system interferences. The value of savings in this industrial construction method scaled to mass produce multi-unit buildings we theorized would aggregate to offset the current material cost differentials of high performance windows, additional framing and insulation, and sustainably sourced materials.

Conventional stick-built construction with extensive transportation time to and from site, and the interruptions and construction delays due to seasonally constrained weather conditions creates significant onsite labour and supervision

Figure 3. Craning prefab panels into place Photo:Endeavour Centre

Figure 4. Finished installation at EditX Expo, Toronto 2017. Photo:Jamie Fine

costs. This also translates into a large carbon footprint for the cumulative transportation and temporary site heating costs. Off-site construction is particularly optimal for the short construction season in most of Canada and the northern US.

Standard off-the-shelf 12" and 16" deep wood trusses provided substantial insulation cavities for wall and roof panels eliminating the labour expense of Passive House double wall framing. The custom panels were built by ten carpentry students and two instructors from Endeavour in a temporary tent 'factory' set up in a donated field 85 miles north of Toronto over eleven weeks. Four mobile solar panels on a wagon powered all electric tools and equipment.

Panels were craned into place in a single day. Over five further days, the structurally complete building was wrapped, taped and clad with high performance, smart, vapour permeable sheathing membranes (by Proclima) from Germany ensuring an airtight but breathable envelope.

CARBON FOOTPRINT I MATERIAL CHOICES

The entire insulated panel structure is organic. Students experimented with a range of alternative materials including wool, cork, and mycelium, a foam-like mushroom-derived insulation by Ecovative currently being used as packaging infill. Our lower wall panels are insulated with strawbale (built into the panels), and the roof and upper walls are blown-in cellulose. We used a pressed wood-fibre outsulation from Quebec, and the interior panel closures were made from a made from boarding made from compressed drink cartons (a product called Rewall.)

The exterior cladding panels are the only non-organic material in the building. We used metal roofing and siding as it was lighter, recyclable and a suitable substrate for visually integrating the 'peel and stick'membrane (Flextron by BIPVco in the UK) photovoltaics that visually disappear between the standing seams.

The unit interior is finished with pre-cut and prefinished sustainably sourced (FSC Certified) maple veneer plywood with a reveal detail to facilitate installation. An oil-finished solid ash flooring was made with material reclaimed from the Emerald Ash beetle infestation in Ontario. The flooring was pre-installed over each floor panel with perpendicular inset filler panels designed to lock into the panel joints as a design feature once installed. The construction considerations that translated into the paneling details facilitated the speedy and resilient dismantling and reconstruction of this building for its various destinations allowing students to see the literal repercussions of these detail design decisions.

The building's materials were calculated to store 25 metric tonnes of carbon versus the 45 metric tonnes typically added to the atmosphere, using conventional construction materials and methods. At the end of construction only eighteen pounds of un-recyclable waste was produced; the equivalent of four construction-grade garbage bags rather than the 8000 pounds typically sent to landfill.

Conventional construction materials like polyurethane spray foam, rigid foam, fibreglass and even rockwool insulations have high embodied energy, and foams using hydrofluorocarbons

Figure 5. Image of Interior.

(HFC) blowing agents comprised of virgin petrochemicals that are unhealthy to humans both in their processing and installation. Spray foams contaminate and make non-reusable and non-recyclable any other building materials with which they come into contact. They were avoided as they do not upcycle or recycle back into the environment safely.

Standard strategies for heating and cooling Passive House buildings were incorporated including energy recovery ventilators, an on-demand water heater, an air-source heat pump powered by the roof integrated solar photovoltaics, and ventless dryer,kitchen and bathroom fans.

THE HUMAN FACTOR

The owner and resident of this two-bedroom house is a retired film maker. There wasn't a suitable affordable site to be found in the city. She ultimately found a site in a small town on southern Georgian Bay, Ontario with the right orientation and spectacular views to the Niagara Escarpment. After the exhibition the building was disassembled and shipped there on a flatbed truck for a third and final installation of the building on her new foundations. She sells her surplus energy back to Ontario's, carbon neutral hydro-powered electrical grid and buys it back if and when she is short during the darker days of winter. We are currently monitoring energy use to verify the house's actual versus modeled performance. She is an active participant in the building's ecology. She has planted a vegetable garden, puts on a sweater when it is cold, and opens windows when it is hot. So far the net energy use appears to be zero.

CONCLUSION

The engagement of students in a time sensitive, logistically complex design and construction process exposed them in a direct and engaged experience of what Keil Moe calls the 'literal' versus the 'abstract' impacts of design. His 'Total Emergy' accounting of the material,labour and transportation footprints of architecture (including its duration over time) demonstrates the entire direct and *indirect* impacts our global architectural industry has politically, socially and ecologically [9] .

As a design build project governed by the scarcity of time and funding, students got an immediate sense of the pressures to pare a project to its essence as they would in a 'real' project. They learned from one another and the professional and academic leads. The architecture students learned to appreciallte gravity, and to value craft, buildability, and the coordinated technique of the building team; while the student carpenters appreciated the style, detailing, and performance modeling that the design team contributed.

For the Engineers it was revelatory that a full embodied carbon and energy tally actually also needed to include the building's urban siting, typology and material structure, and construction process. Like the Solar Decathlon brief, they had only focused on energy use, post construction.

The architecture students learned that their formal and detail decisions have critical impacts on time, labour, safety, waste, precision, performance, durability, and the ultimate emergy footprint of a building. They gained an appreciation of the equally significant impacts of human agency post construction by modeling appliance and electronic use on energy consumption.The collaboration between these typically siloed students gave them a respect for the interdependency of their respective trades and professions, and an immediate awareness of the complexity of the externalized web of global and ecological processes related to building in a city that are typically abstracted in a merely imagined studio project. The fact that we could make it beautiful as well as sustainable in all these ways was an inspiration to everyone involved.

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