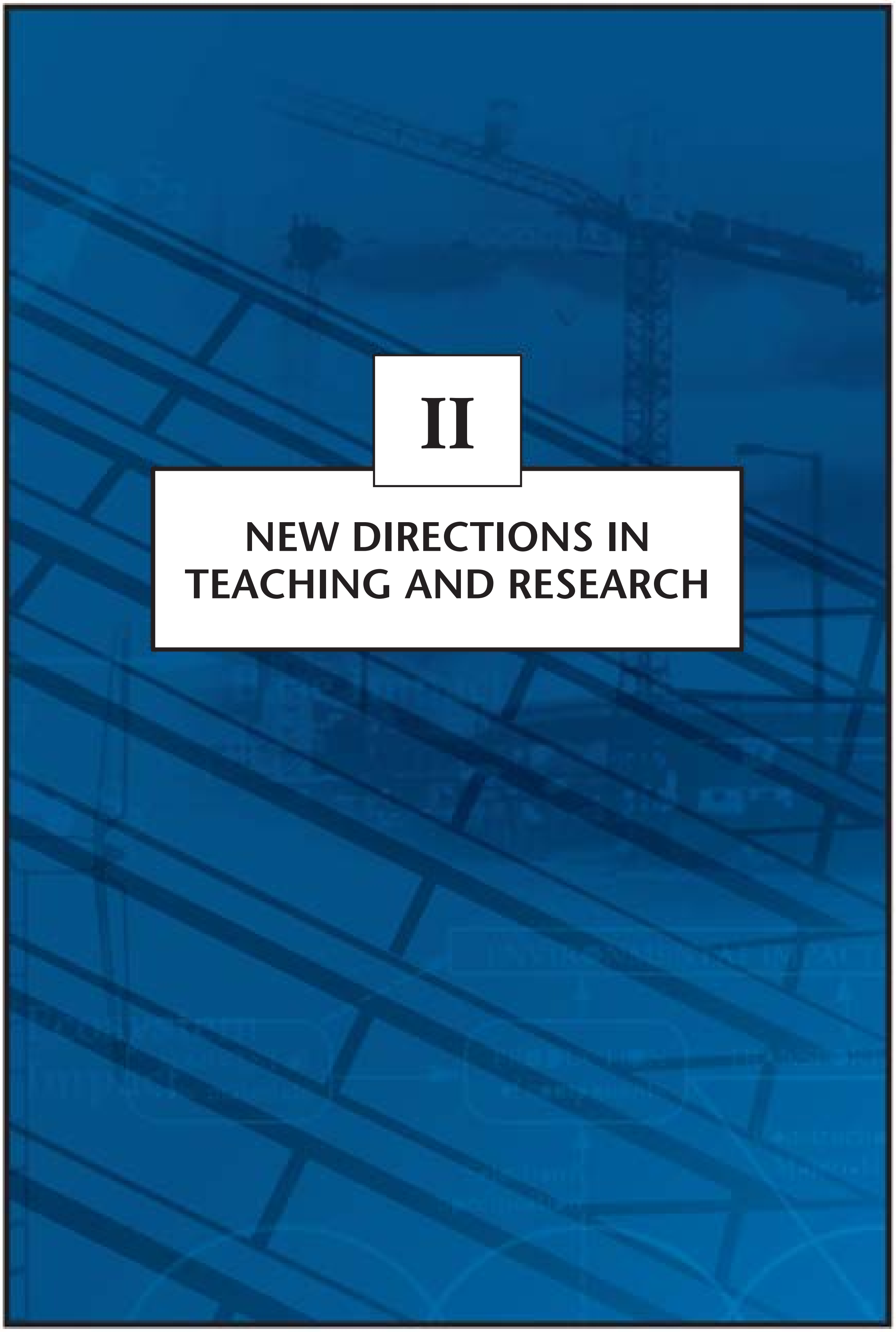

II

NEW DIRECTIONS IN TEACHING AND RESEARCH

BIG IDEAS IN TINY HOUSE RESEARCH AT NORWICH UNIVERSITY

Matthew Lutz[1]

INTRODUCTION

A small but notable trend that may offset energy consumption is emerging in a grass-roots architectural counterculture movement focused on designing and building tiny houses. These small dwellings, ranging between 120 square feet and 400 square feet, simultaneously aim to consolidate, simplify, and minimize the energy requirements of the average size house while relieving their occupants of the burdens that come with owning a typical house. Tiny houses are entering the mainstream, showing up in unexpected places and catering to people from diverse backgrounds. Full-scale design/build prototype tiny houses developed at Norwich University serve as case-studies that may help prove, disprove and bring into question the effectiveness of the tiny house. This article will examine the second prototype house designed and built by Norwich University and will dive into some of the dynamic forces behind the tiny house movement and question how that movement might evolve and adapt to accommodate future scenarios.

KEYWORDS

tiny house, IPAT, conservation, design/build, experiential education

CONVENIENCE, AFFLUENCE, AND GREEN SPIN

From one perspective, the tiny house can be seen as a rejection of affluence; a deliberate reversal from the trappings of material goods, consumer-based conveniences, and consumer-culture. In light of historic and current projections of anthropogenic climate change, perhaps consumers, industrialists, and designers are beginning to recognize the historical and factual costs of convenience and affluence. To acknowledge the role that these things play in climate change, it's helpful to look at historic data related to energy consumption and compare how this data evolved relative to population growth, our personal energy budgets, and our collective approach toward conservation.

In his keynote address [1] at the ninth annual North American Passive House Conference (NAPHC), Senior Research Architect at the University of Illinois Urbana-Champaign's Sustainable Technology Center, Bill Rose presented in a case-by-case manner how predictions made in the first annual report by the United States Council on Environmental Quality *(CEQ)*

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[2] significantly relate to current environmental conditions. In 1970 the CEQ predicted that by the year 2000 global population would reach 7.5 billion people and that those 7.5 billion people would be producing 9 trillion kWh's of electricity globally. Real-world figures from 2000 put global electricity production at 14.6 trillion kWh's, with a staggering 23.3 trillion kWh's of electricity produced in 2013 [3]. Curiously though, global population just reached 7.6 billion in 2018; we actually have fewer people on the planet than the 1970 CEQ predicted, but those people are consuming far greater amounts of energy per person. Why then, despite the obvious advances in technology, are we consuming over twice the amount of electricity per person as compared to 1970 CEQ estimates?

To get a better understanding of this, it's also helpful to dive deeper and look at the bottom line: CO^2 emissions. Remember those 7.5 billion people the CEQ predicted would be producing 9^{12} kWh's by 2000? Well, the CEQ also predicted those conditions would result in atmospheric CO^2 levels reaching 400 ppm, which would result in a warming of the atmosphere. In actuality, we reached 400ppm of CO^2 in the atmosphere in 2014, while producing 21^{12} kWh's [4]. So, it seems we were able to consume over twice the amount of electricity while resulting in approximately the same amount of estimated CO^2 emitted. From a 1970 perspective, consuming twice the amount of energy per person as predicted should have resulted in catastrophic levels of CO^2 and consequently a catastrophic warming of the planet. Instead, it resulted in the same net CO^2 emissions, and consequently respectively higher, albeit not yet catastrophic, global mean temperatures. In fact, the 1970 CEQ predicted that if we released half of the carbon dioxide contained in the remaining fossil fuel available on the planet, global mean temperatures could rise by 2° F to 3° F. As of 2018, global mean temperature has risen 1.8° F since 1880 [5].

From this, it seems as though humanity has become clever in its use of the kWh. We can get more work out of a kWh today than in 1970. And, we produce and consume that kWh in much cleaner ways. So, it appears technology can save the day, right?

Maybe. Maybe not. The cold, sober warning issued by the CEQ in 1970 illustrated that rising CO^2 levels and the subsequent rising of global mean temperature of just 2° F would result in substantial melting of the polar ice caps, and the onset of flooding of coastal regions. So, despite the astonishing advances in technology since 1970, we're in almost the exact place the CEQ said we would be in terms of pending catastrophic environmental threat. So, if technology isn't the solution to countering rising CO^2 levels, what is?

THE LONG TERM COST OF SHORT TERM AFFLUENCE

Although there are innumerable ways of expressing and projecting the rise in CO_2 levels, a heavily referenced method is the *IPAT* equation. Where Environmental Impact (*I*) = Population (*P*) • Affluence (*A*) • Technology (*T*). The IPAT equation, and derivations like Dietz and Rosa's stochastic version of IPAT [6], and the KAYA Identity [7], consider climate change an anthropogenic condition influenced by the relative wealth of the population. Both IPAT and the KAYA Identity use gross domestic product per capita (GDP/pc) as a variable to solve for CO_2, but in IPAT, GDP/pc is expressed as affluence (*A*). As population or affluence (GDP/pc) increases, environmental impact increases, unless technology offsets the impact of increases in population and affluence.

The IPAT equation may be able to help illustrate how the fifty eight percent increase in per capita electricity generation that developed between the 1970 CEQ report estimate and current conditions was caused by an increase in affluence. In IPAT, technology (*T*) is a multiplier used to indicate advances or regressions in the efficiency of production. Roland Mitchell, professor of Political Science and Environmental Studies, argues that contemporary application of IPAT assumes the variables of affluence and population growth as near absolutes, something unlikely to change, and that conventional application of IPAT assumes technology is the only active lever able to reduce carbon emissions [8]. While technology has certainly increased efficiencies in production since 1970, it may be that those efficiencies in production were radically offset by the radical *new* consumption ability they afford. This scenario, when a new technology intended to increase efficiency results in an increase in consumption, is termed the Jevons Paradox, after William Stanley Jevons [9].

For example, the Pew Research Center estimates that ninety-five percent of all Americans have a cellphone, with seventy-seven percent of Americans owning smartphones [10]. While the smartphone is clearly a technological advancement with undeniable evidence of advanced efficiencies in computing, it has also become an indispensable, almost cybernetic appendage that demands constant connectivity and electricity. In the IPAT equation, the handheld digital device as a technological advancement may actually best be represented as an entity working against CO_2 reduction.

For example, Passive House Standards [11] use region specific energy benchmarks for heating and cooling demands in buildings. Meeting this metric can represent a fifty percent or greater reduction in kBtu's required for space heating and cooling over space heating and cooling demands in typical code-compliant structures. While the Passive House Standard is a current benchmark for high-performance buildings, it is not exempt from the trappings of affluence. As a rough example, let's say that a super high-performance, 10,000 sq. ft. single family home with two full-time occupants, consumes approximately 47,500 kBtu's annually, or about 23,750 kBtu's per person for space heating and cooling. Although the building meets a super high-performance energy metric in terms of building science, it's arguable whether it's truly helping reduce CO_2 emissions, since it takes an egregious 23,750 kBtu's per person to keep the space warm. To convey the impact of these decisions, we can re-express IPAT where *I* represents environmental impact per occupant, *A* represents house size in sq. ft., *T* represents building performance (1T = code compliant, .5T = high-performance, Passive House Standard), and *P* represents the number of occupants:

FIGURE 1. Supersized, code compliant (highest environmental impact)

$$I = A \bullet T/P$$

$$5000I = 10{,}000A \bullet 1T/2P$$

FIGURE 2. Supersized, high performance (second highest environmental impact)

$$2500I = 10{,}000A \bullet .5T/2P$$

FIGURE 3. > average size, code compliant (typical environmental impact)

$$1500I = 3{,}000A \bullet 1T/2P$$

FIGURE 4. < average size, high performance (lowest environmental impact)

$$500I = 2{,}000A \bullet .5T/2P$$

FIGURE 5. Average size, code compliant (half environmental impact of supersized high-performace house)

$$1250I = 2{,}500A \bullet 1T/2P$$

Beginning with Figure 1, we see two occupants sharing a 10,000 sq. ft. house built to current building code, without any high-performance technology (1T). The resulting impact shows a result of 5000I. Figure 2 represents the same conditions except that now the house is built using Passive House Standards (.5T). The result is obviously significant and utilizes existing high-performance technology to achieve a performance standard above-and-beyond that required by minimum building code. Figure 3 looks at the same conditions as Figure 1, but looks at affluence as the variable; a house built to code, still larger [12] than the average American home, has a sixty percent less environmental impact, and does not use high-performance technologies (i.e. less up-front cost). Figure 4 represents a high-performance house (.5T), but now with only twenty percent of the floor area as Figures 1 and 2. Figure 4 sees a ninety percent environmental impact reduction over Figure 1.

Figures 1 through 4 illustrate how consumers, designers, industry leaders, and politicians can non-voluntarily 'spin' what it means to have low environmental impact. Meaning, an architect can rightfully say they have reduced environmental impact in half from that of Figure 1 because they've built beyond the accepted standard. Or, stated another way, they've done better than average by *using technology as the metric for deciding how to measure the success of environmental impact*. Here, environmental impact is measured not against what is possible, but *what advances in technology tell us is acceptable*. Seen from another perspective however, the environmental impact per person is twice as high in the high-performance 10,000 sq. ft. house as it is in the house expressed in Figure 5, which represents the average American home size (U.S. Census) built to existing energy code.

The implication of this example is that using technology as a modifier to predict environmental impact is limited, in part, by how technology is interpreted. For example, a third fewer people consuming twice-as-much energy, due to 'improvements' in technology does not reduce environmental impact. The tendency to accept that technology is the greatest agent for reducing environmental impact is what Professor Roland B. Mitchell coined as '*technophilic optimism*' [13]. And while technophilic optimism has many credible theoretical positions [14] for reducing environmental impact, technology may not be the most immediate or effective solution to improve environmental recovery. If building arts professionals concentrated as much on moderating extravagance as they did on utilizing technology, the overall carbon footprint of our built environment might be drastically reduced. Perhaps the only operative predictor for reduction of environmental impact is the affluence agent.

ACTION PLAN 101

Data gathered from the U.S. Energy Information Administration then analyzed and published by the non-profit climate change activist organization Architecture 2030 [15] reveals that over forty-seven percent of all energy consumption is building related. Curiously, the question of how much energy the building sector consumes was never asked in the first, tenth, or final reports by the CEQ. Broadly, the CEQ reports seem to provide inclusive representations of energy consumption, carbon emissions, and how these emissions might be mitigated, and while approximately one-third of the first CEQ report is dedicated to recommendations for lessening environmental impact, there is little mention of the specific role that the built environment plays in energy consumption or emissions. Although key points of environmental threat outlined in the first CEQ report end with a summation of '*What Needs to be Done*', the report concludes with three broad view recommendations, which are summarized respectively as 1). calls for expanding international cooperation, 2). increased citizen participation and 3). improved environmental education. How designers of the built environment might play a role in reducing environmental impact is a missing question.

This is curious since building arts professionals are so well positioned to address key environmental issues. While architects have a complex, almost tempestuous relationship with affluence (from Latin *affluentia*, or 'plentiful flow') as it relates to IPAT, they're also key to making a substantial global environmental impact. It's a complex predicament, since building arts professionals are essentially stuck between the demand for more extravagant buildings and the reality that 'architectural affluence' is potentially lethal in terms of environmental well-being. And although these issues are awkward and confront the ethical quandary of using massive quantities of Earth's resources while simultaneously working to reduce environmental impact, buildings arts professionals can offer genuine leadership that can have significant and immediate impact.

ENTER THE TINY HOUSE

A critical breakthrough for the building arts profession may be the development of a code of conduct that encourages *unregulated virtue* in terms of environmental impact. Whereas current metrics like the Passive House Standard or LEED Certification [16] don't offer a mechanism for praising a reduction in the *necessary extravagance* that some high-performance buildings seem to employ, a small but notable group of emerging architectural activists are designing and building *tiny houses* that challenge conventional building codes and energy metrics in an effort to reduce environmental impact. These activists recognize the relationship between affluence and climate change and are engaged in a type of environmental education that's gaining worldwide attention. This grassroots architectural counterculture movement consists of architects, builders, do-it-yourselfers and those seeking to move away from the trappings of modern economy. These small dwellings, ranging between 120 square feet and 400 square feet, have a dual mission; they simultaneously aim to consolidate, simplify, and minimize the energy requirements of the average size house while relieving its occupants of the burdens attached to owning a typical house. These tiny houses are gaining popularity in the mainstream, with half a dozen reality television programs airing on cable networks, municipalities adapting local codes to allow for accessory dwelling units in urban areas and some banking institutions developing interest in tiny house lending models.

Whereas population growth and pollution dominated environmental concerns in the early 1970's, today the focus seems to be split between concern for depleting natural resources, (a conservation-based concern) and the atmospheric and oceanic consequences of depleting those resources, (a human habitation concern). The tiny house is a reflection of these concerns and offers a small but effective sketch of how building arts professionals might rethink *design* *behavior*. The tiny house model effectively represents the convergence of environmental education, tempered affluence, and appropriate technology. The tiny house is a virtuous example of environmental austerity, a rejection of *affluenza*, and offers a timely lifestyle narrative of improving the quality of life while reducing the cost of that lifestyle. The tiny house movement may be a response to public awareness that unregulated affluence in critical areas can cause severe environmental distress.

Prototype tiny houses being constructed at Norwich University [17] serve as test rigs that can prove, disprove, and bring into question the effectiveness of the tiny house as a model for environmental sustainability. The second Norwich University prototype tiny house, SU_CASA (Single Unit_Creating Affordable Sustainable Architecture) (Figure 6), designed and constructed during the spring semester of 2017, concentrates on appropriate use of technology, reducing environmental impact through lowering embodied energy, and via these two concentrations, is a vehicle for environmental education. The project team, which consists of a multidisciplinary team of faculty and students from architecture, engineering, and construction management programs focused on three design objectives:

1. *Bio-Based Construction:* Avoid use of petrochemical based materials by only allowing bio-based materials for use as insulation, exterior cladding, interior finishes, and structural systems.
2. *Honestly Local Materials:* Use locally grown, locally *harvested* materials for structural framing, exterior cladding, interior finishes, and cabinetry (i.e. CSA: Community Supported Architecture).
3. *Honestly Local Production:* Employ native facilities, systems, and labor force.

A fourth, albeit less overt design aspiration was to ask the SU_CASA tiny house to exhibit an alternative way of living, and perhaps through doing so, to exhibit an alternative set of values. In this regard, the SU_CASA stands apart from many tiny houses because at just 348 sq. ft.

FIGURE 6. SUCASA, Norwich University's second prototype tiny house, Image credit Nicholas Schmitt

FIGURE 7. Long Axis Section, showing loft, image credit Lutz

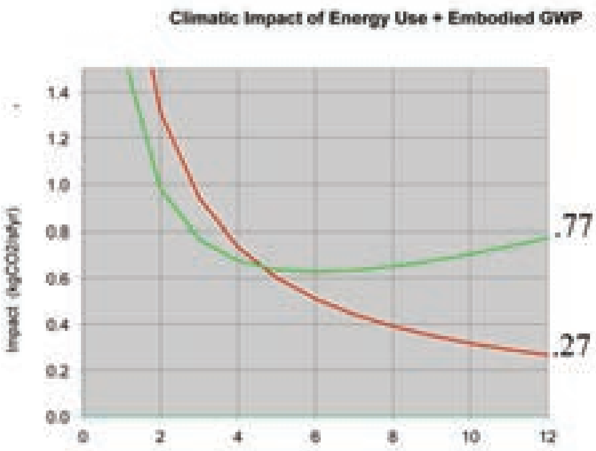
it's designed to accommodate a family of four. A murphy-bed downstairs for two parents, and small sleeping loft upstairs for two children. A bathroom, the only private room in the house, offers a toilet, lavatory, and shower with integrated hand-wash laundry system. This tiny house for four is unique in that so many tiny houses are single occupancy, or double occupancy units.

BIO-BASED CONSTRUCTION

Bio-based construction means using materials for insulation, exterior cladding, interior finishes and structural systems that were once living organisms and that can quickly and easily re-enter Earth's bio-nutrient stream. The building envelope, minus its roofing membrane, can simply return to the soil and act as bio-nutrients for growing new bio-based products. Following a strict 'no petrochemicals' attitude toward construction products often times means reducing insulation performance per-inch of envelope thickness, which translates into a thicker envelope. Whereas spray polyurethane foam (SPU), an insulation product made from tiny plastic beads, has a thermal resistance value (R-value) of approximately R7 / inch, cellulose fiber insulation, a product made predominantly from recycled newsprint, has an R-value of approximately R3.8/inch. Comparing two walls of equal insulation values we see that the wall insulated with SPU can be thinner, which dedicates more floor area to the interior because of the thinner wall section, but at a cost of higher carbon footprint. Using David White's Climate Impact Calculator for Insulation [18], we see that the overall kg CO_2/sfyr is nearly three times as high for SPU than it is for cellulose at wall thicknesses (Figure 8). Meaning, although we see a greater R-value in the SPU wall, the overall impact of global warming potential (GWP) is nearly three times higher than cellulose.

Focusing on a bio-based envelope also supports the use of vapor open/vapor permeable materials that allow moisture vapor to freely pass between the interior and exterior of the envelope. Allowing the wall system to dry to both sides of the envelope reduces potential for mold growth because there's no vapor barrier to block vapor and allow it to build up in the wall cavity. A critical counterpoint to this theory is that bio-based materials tend to be hydrophilic and thus be more susceptible to mold growth and rot. While in many cases this is true, the priority should be set on not letting the vapor condensate and build up in the first place, and allowing any build up to freely dry.

FIGURE 8. Climate impact analysis of insulation materials



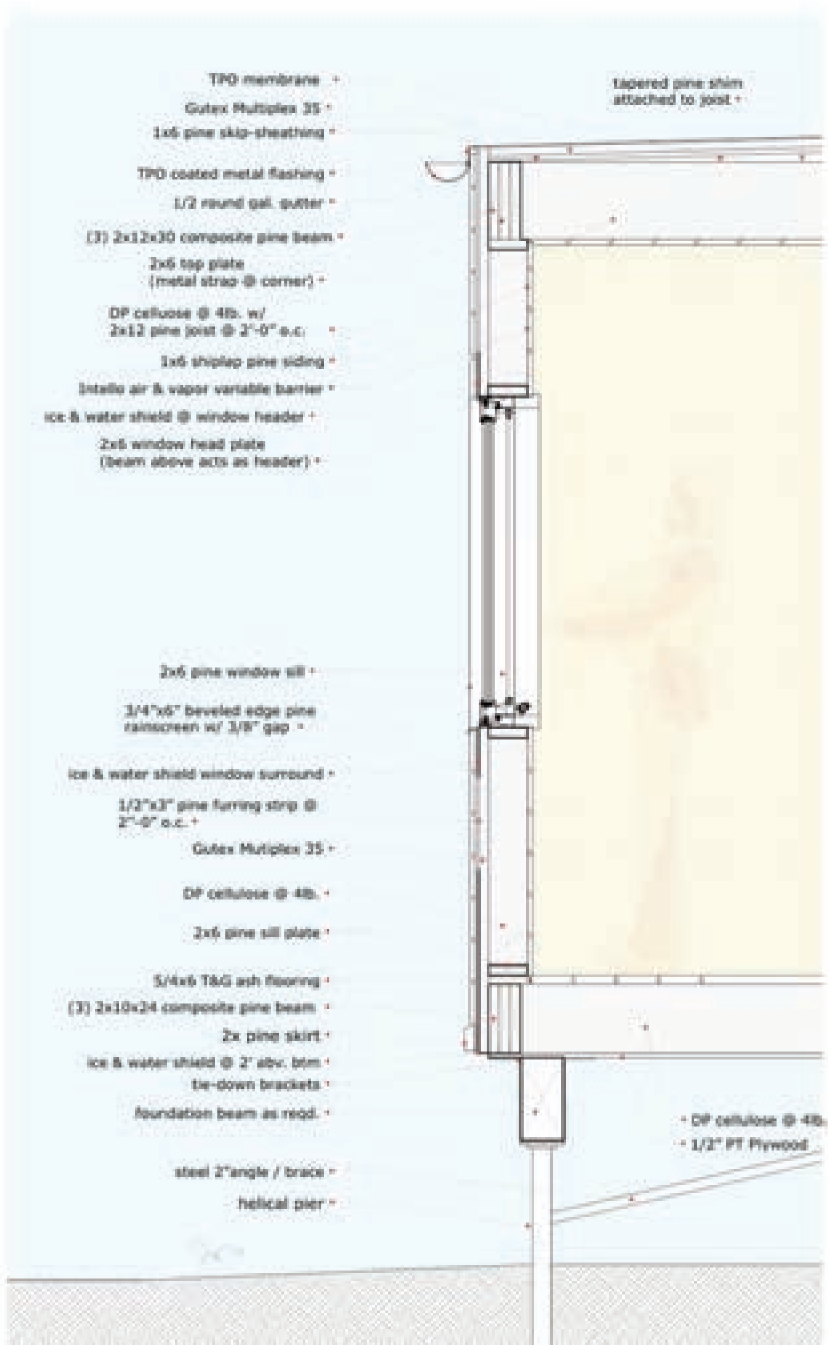
HONESTLY LOCAL, ALMOST

In the case of SU_CASA, the envelope system (Figure 9) consists of an interior sheathing layer of locally harvested, locally milled ship-lap pine boards over a vapor-variable membrane. This membrane is stretched over locally harvested, locally milled, kiln-dried wall studs, floor joists, and roof rafters. Dense packed cellulose fiber fills the stud /joist/roof cavities and is sheathed on the exterior by a 35MM thick composite wood-fiber insulation board. This composite wood-fiber insulation board provides a water-tight, wind-tight exterior layer on the roof and walls without compromising wall cavity breath-ability. The envelope, minus the roof deck, is an air-tight, vapor-open assembly. Meaning, moisture vapor can dry to the inside or outside as needed, but never be trapped in the wall or floor cavity.

Plywood, seen as an integral component in modern wood framing, is absent in the wall and roof sections of the Norwich SU_CASA prototype. The floor layer uses a layer of ½″ pressure treated plywood simply because the design team was unsure of the final location and foundation type of the prototype, and thus decided to install a plywood deck below the floor joists to accommodate a wide variety of site and foundation conditions. Plywood, ubiquitous in the single-family housing industry nationwide, is not a local product in Vermont, and would have accounted for approximately $1300 in the total budget. The use of galvanized metal strap-bracing in lieu of plywood for diaphragm bracing reduces overall cost and increases vapor permeability. The $1300 not spend on plywood wall and roof sheathing went toward purchasing metal strap-bracing and associated metal bracing for approximately $580. Comparative labor costs associated with the installation of plywood sheathing and metal strap bracing were counted as approximately equal, so the elimination of plywood wall and roof sheathing reduced cost.

Using local products and avoiding the use of plywood in the SU_CASA has a purpose beyond saving money, though. One, it reduces the embodied energy in the overall material package of the dwelling while forcing the designers to use locally available products in creative ways. It prompted the question, *"How can we effectively make a wood framed building without plywood?" "How can locally available products take the place of 'imported' plywood?"* This encouraged the student-designers to use products from local sawmills, which kept profits local, rather than sending that profit out of state. Perhaps most importantly though, the designers worked

FIGURE 9. SUCASA Envelope Wall Section / image credit: Lutz



exclusively with local materials for exterior and interior finishes. These local materials are not just from Vermont, they *are* Vermont. As evidenced in projects like those built by Three Tree Home Performance with high-performance vapor-variable membranes, the effort to avoid plywood in wood framed buildings may be gaining traction in Vermont [19].

Gypsum wallboard was another instance where locally grown materials took the place of a ubiquitous material in wood framing. Although gypsum wall board installs quickly, the finishing process can be messy, time consuming, and leave the interior of the dwelling feeling generic. The student design team opted to use kiln dried No. 3A common ship-lap 1 × 6 pine cladding over 1/2″ × 3″ strapping and a vapor-variable airtight membrane to cover the walls and ceiling. Although material costs were a break-even match, labor costs for installing the 1 × 6 ship-lap cladding are estimated to be slightly higher.

It's important to note that the 35MM thick composite exterior wood-fiber continuous insulation board strays from the notion that all products are harvested, processed, and retailed locally. This material, produced in Germany and purchased from a retailer approximately 300 miles away constitutes a relatively severe breach of the design mandates for the SU_CASA. This compromise was made based on the opinion that this material could introduce innovations to the northeast building market, and that perhaps these innovations could eventually lead to this material being manufactured locally. The material was easy to install, provided instant weather protection to the building, does not require an additional layer of house wrap to protect it, and does not need to follow regular stud or strapping spacing to be fastened to the building envelope. When compared to other exterior insulation systems, the upfront cost appears higher, but when considering that the material is a finished layer that doesn't require an additional weather-resistant barrier, the price is comparable to mineral wool or foam. Mechanical systems in the SU_CASA are simple. Heat is provided by two 475W wall mounted electric heaters, one in the bathroom, and one in the main volume. Heat recovery and fresh air and ventilation is provided by a single Lunos eGO unit [20].

HONESTLY LOCAL PRODUCTION

To help further Norwich University's College of Professional Schools' agenda of offering affordable alternatives to the current housing market in Vermont, the university partnered with a local sawmill interested in entering the tiny house market. This arrangement corresponded perfectly with university's objective of mainstreaming smaller, affordable housing alternatives because it vertically integrated the supply chain with the manufacturing process, thus offering more potential for lower retail prices of the SU_CASA. In this arrangement, the sawmill purchased a physical prototype house, including construction documents, from the university and will use the prototype as a floor-model to show prospective buyers. The sawmill is a locally owned, vertically integrated operation that owns timberland, the harvesting equipment, the milling equipment, and has the retailing capability to bring the SU_CASA to a wider audience.

LESSONS FROM SU_CASA

The tiny house is a bottom-up, grassroots example of how an architectural mechanism can gain widespread attention, reach mainstream audiences, and perhaps become an effective tool for teaching the poetics of conservation. It's become an unconventional, unexpected tool for environmental education, and one that has captured the imagination of communities worldwide. With half a dozen reality television programs airing on cable networks, many municipalities adapting local codes to allow for 'accessory' dwelling units, and some banking institutions developing interest in tiny house lending models, the tiny house is making a memorable place in the history of our built environment.

But as a tool for environmental education, is the tiny house a completely positive model of constructive environmentalism? Although it's difficult to establish good, current figures worldwide, the United Nations Compendium of Human Settlement Statistics from 2001 [21] gives an idea of the number of persons per room, per housing unit, as well as the average number of persons per housing unit and the number of persons per room by number of rooms. As one might suspect, more affluent nations have fewer people occupying a greater area than less affluent nations. In most cases we find that North Americans rank highest in terms of occupying the most space per capita [22]. It would seem then that to reduce environmental impact, we would reduce the amount of space required per person, thus reducing the amount of energy needed to condition that space. And while there is certainly a correspondence between the amount of energy required to heat and cool a given area for the number of people occupying that area, the tiny house may not be an entirely wholesome solution to lowering environmental impact given the fact that they have a relatively high skin surface to floor area ratio.

The tiny house can be characterized as essentially a one-bedroom studio apartment, where the kitchen/dining/ living area are one, and are often shared with sleeping quarters. One might imagine then that the tiny house is fundamentally a studio apartment that has been pulled out of a multi-unit complex and placed alone. The issue with this is that as these studio apartments get separated from one another the amount of wall area exposed to exterior condition increases, thus increasing the heating and cooling demands on the interior. As an example, using the Passive House Planning Package [23], we can compare the kBTU/ (ft^2 yr) required for heating a single 247 ft^2 single unit tiny house with combing eight 247 ft^2 tiny houses together into an eight-unit complex. For this example, the author used the same envelope section used in the SU_CASA prototype unit (Figure 9) which models an envelope compliant with the 2015 Vermont Energy Code. This represents the minimum insulation levels allowed to meet State of Vermont energy code. Figures 10 and 11 below show an approximate 216.54% increase in heat energy required to heat the single stand-alone unit over the multi-unit complex. While each unit in the multi-unit complex will have a distinct heating profile, with some greater or lesser than other units, any single unit in the complex will be less than the stand-alone tiny house because the skin-to-floor-area ratio is always greater in the stand-alone unit. So, assuming the stand-alone tiny house uses 11,392 kBTU annually (46.12×247 ft^2) for space heating demands and the multi-units use on average 3599 kBTU annually to accommodate for space heating demands, it becomes clear that the luxury of living in a stand-alone tiny house comes at a real cost.

FIGURE 10. Norwich University SUCASA, Second Prototype House, single unit analysis

Energy Demands with Reference to the Treated Floor Area					
Treated Floor Area:	247	ft²			
	Applied:	Monthly Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	46.12	kBTU/(ft²yr)		4.75 kBTU/(ft²yr)	No
Pressurization Test Result:	1.00	ACH50		0.6 ACH50	No
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	113.5	kBTU/(ft²yr)		38.0 kBTU/(ft²yr)	No
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	88.6	kBTU/(ft²yr)			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	24.9	kBTU/(ft²yr)			
Heating Load:	20.75	BTU/(ft²hr)			
Frequency of Overheating:		%	over	77.0 °F	
Specific Useful Cooling Energy Demand:	0.38	kBTU/(ft²yr)		4.75 kBTU/(ft²yr)	Yes
Cooling Load:	4.80	BTU/(ft²hr)			

FIGURE 11. Norwich University SUCASA, second prototype tiny house assembled as a multi-story apartment complex.

Energy Demands with Reference to the Treated Floor Area					
Treated Floor Area:	1932	ft^2			
	Applied:	Monthly Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	14.57	kBTU/(ft^{2}yr)		4.75 kBTU/(ft^{2}yr)	No
Pressurization Test Result:	1.00	ACH$_{50}$		0.6 ACH$_{50}$	No
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	59.2	kBTU/(ft^{2}yr)		38.0 kBTU/(ft^{2}yr)	No
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	31.7	kBTU/(ft^{2}yr)			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	3.2	kBTU/(ft^{2}yr)			
Heating Load:	6.54	BTU/(ft^{2}hr)			
Frequency of Overheating:		%	over	77.0 °F	
Specific Useful Cooling Energy Demand:		kBTU/(ft^{2}yr)		4.75 kBTU/(ft^{2}yr)	
Cooling Load:	2.35	BTU/(ft^{2}hr)			

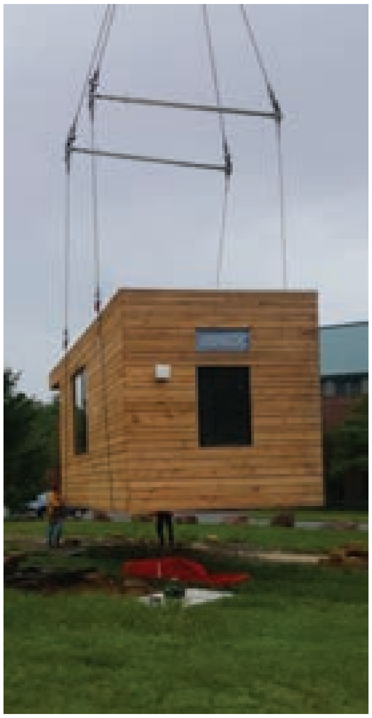
Maybe the value of the tiny house is in the lesson it offers to design educators and design professionals. Perhaps the lesson the tiny house movement is teaching is how *conservation-based design* really begins with tempering our perception of affluence; giving us a glimpse at what we really *can* afford. Perhaps design professionals and design educators should focus as much on tempering and managing the *quantity* of space rather than the technology of the space. Is educating the next generation about photovoltaic arrays, insulation values, and ventilation rates perhaps less important than educating them about what can really be afforded in terms of our environmental budget?

STUDENT PERSPECTIVE

In the design/build program at Norwich University, it's questions like the one above that gets students to craft their own education, and consequently drive their future projects. It's these projects that begin them on their professional trajectory, and where they learn to question the default options we are so often given in the building arts. In the case of the tiny house research projects, students learn to question up-front costs versus lifetime costs. They questioned the appropriateness of a technology in relation to a buildings program. They learned to question (and calculate) their own carbon footprint, and how to compare quality of life to those around the world.

Norwich, the oldest private military college in the United States, was founded on the notion that its students be able to *'to act as well as to think—to execute as well as conceive'*. With this in mind, the tiny house research program at Norwich fits perfectly into a long tradition of experiential learning because it allows students to intimately understand each distinct part of a building and how each part relates to the greater whole. Within the scope of a semester, a student can design and construct each part of a real building, and see that building deployed and operating in real-world circumstances. The quality of education in this scenario is unmatched in the traditional classroom because the students directly witness successes and failures as the result of their own design and craftsmanship. These successes and failures prove and disprove for themselves, eliminating the need for third party (the professor) verification. It's the polar opposite of the classroom scenario where the student relies on the professor to verify results. Blower door tests, cranes lifting structural systems, and the difference between volumes represented on paper, versus how those volumes feel once built are all unforgettable learning opportunities.

FIGURE 12. SU_CASA being craned onto the trailer.



The SU_CASA project yielded many lessons from both a building science and construction perspective, as well as an architectural perspective. Chiefly among the lessons from a construction and building science perspective was the added time and labor associated with air-sealing a tiny space with unskilled labor.

CONCLUSION

One major lesson learned from the SU_CASA project was that architecture and design can only be so effective in solving both housing affordability issues and looming environmental issues. Looking at the quality of life as defined by happiness, rather than as defined by gross domestic product may reveal what is truly important in our homes, and therefore becomes a critical piece of research that could begin to inform how we modify our design behavior to take into account our environmental budget. For example, do boutique kitchen counter-tops and double door refrigerators contribute enough happiness to offset the environmental stress they cause?

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