

Upcycling Embedded Intelligence: Purpose, Process, and [Immediate] Results

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How can distributed manufacturing and the innate intelligence of everyday materials be aligned to transform our built environments? How can increasingly accessible open-source communities and affordable digital manufacturing tools help facilitate such a change [and fast!]?

This paper posits that while accessible digital manufacturing technologies already allow consumers to become prosumers, albeit rarely taking prosumption beyond the scale and complexity of a tea cup or small toy, a powerful, potentially game-changing avenue for the discipline exists in the prosumption of high-performance building products or assemblies by the everyday citizen designer or citizen builder. The upcycling of embedded intelligence holds the potential to immediately impact how we practice and teach, but also how we collectively frame the role and agency of the architect in twenty-first century open-source economies.

The author demonstrated how such an upcycling of embedded intelligence could occur in terms of architectural purpose, process, and results/impact through an exhibition of a series of architectural drawings at the Fall 2019 ACSA conference. The design-as-scholarship projects that were exhibited – two private residences designed by the author’s firm – both utilize a wood-based wall system titled a Timber SmartWall that uses open-source cut files for manufacture. The author also introduces the Radford Train Observation tower by Virginia Tech faculty and students as a case study for the distributed manufacturing of advanced biomaterials, the team having produced their own high-performance building material, hardwood CLT, from local wood. From schematic design to finished building, both projects illustrate in separate ways how the innate intelligence of everyday materials can be utilized in an open-source, distributed manner.

INTRODUCTION

Upcycling is a term often used to describe creative reuse, particularly when the transformation of an entity into an entity of higher social or economic value involves enhancing its environmental value as well. The “upcycling of embedded intelligence” in the context of this paper is intended to describe how expert-level design knowledge can be optimized and packaged for the widespread amateur production of high-performance building products through open-source networks and accessible digital tools. In this context, not only are everyday materials upcycled into more valuable products, but expert knowledge, or ideas, are also upcycled, meaning that their social and economic value is enhanced when they are made available for the general public to utilize; even if the general public does not understand the nuances and complexity of the higher-order idea/knowledge.

The power of upcycling embedded intelligence is evident when, at a grassroots level, the everyday citizen designer or citizen builder can download open-source, higher-order knowledge that is packaged for lower-order use and can create meaningful products from this packaged material. With the right oversight, this form of prosumption, or self-manufacture, by the everyday citizen can lead to a distributed, mass production of building products that enhance the built environment through the way they perform. Such a distributed, grass-roots application of higher-order thinking can create large scale change in a bottom-up manner, a significant benefit of open-source systems.

This paper focuses on the innate intelligence of one everyday material, wood, and through two projects, a Timber SmartWall system and a design-build train tower in Virginia, both led by the author, explores how open-source digital technologies and distributed manufacturing may positively and negatively impact its architectural utilization. While open-source digital technologies such as open-source machining data hold the potential to increase the dissemination of high-level performance information for non-expert production by the everyday citizen-builder, open-source technologies also hold legal and procedural risks via easily accessible data. Additionally, the distributed manufacturing of high-performance wood-based building products also has clear advantages and disadvantages. By increasing the amount of

production facilities for high-performance wood products through distributed manufacturing, a positive increase could occur in the amount of wood used for construction due an increase in the available locations to manufacture products and a potential decrease in cost per product. On the other hand, by creating distributed manufacturing networks for wood-based building products, quality control becomes a primary concern with significant legal and safety implications.

The following paragraphs introduce the benefits of, and limitations to, open-source knowledge and distributed manufacturing while also illustrating through the aforementioned projects how such an upcycling of embedded intelligence could occur. [This paper is supplemented by images of the Timber SmartWall exhibit at the 2019 ACSA Fall conference at Stanford University.]

TOWARDS AND OPEN-SOURCE ARCHITECTURE: FROM CITIZEN-CENTERED DESIGN TO OPEN-SOURCE DESIGN

Citizen-centered design is but one of many societal ideas that gained a new-found relevance for architects following the advent of the “first digital age” (Oxman 2016). Foundational concepts underlying citizen-centered design are intimately related to citizen-centered policy in that peer-to-peer sharing and the transparency of information is believed to deliver services in a more cost-effective way with better societal results. Such transparent, peer-to-peer systems ideally allow for rapid, iterative improvements and benefit from the intelligence of the collective. These paradigms and societal approaches to design stem from research related to societal participation phenomena studied at the turn of the twentieth century and are conceptually framed and articulated in the seminal book “Rise of the Citizen Practitioner: A Phronesis-Based Approach to Citizen Engagement and Social Policy” by Dr. Basil Schaban-Maurer (Schaban-Maurer 2013). Open-source design technologies as discussed in contemporary architectural practice are anchored on the concepts of citizen-centered design research, sharing the terminology and ideologies most directly with the fields of industrial design and design-specific consultancies such as IDEO.

In “Open Source Architecture” by Carlo Ratti and Matthew Claudel, the authors provide perhaps the most explorative framework for open-source technologies in contemporary architectural practice yet published at the time of this writing (Claudel and Ratti 2015). Following the solicitation of Ratti by Domus Magazine in 2011 for an editorial and issue focused on open-source design, the book “Open Source Architecture” was developed in a peer-to-peer manner – along with various digital resources - in a similarly free manner to the shareable, exchangeable architectural material that the book makes the case for in today’s digitally-saturated society. As multiple chapters in the book illustrate, open-source technologies such as the Linux operating system can lead to exceptionally

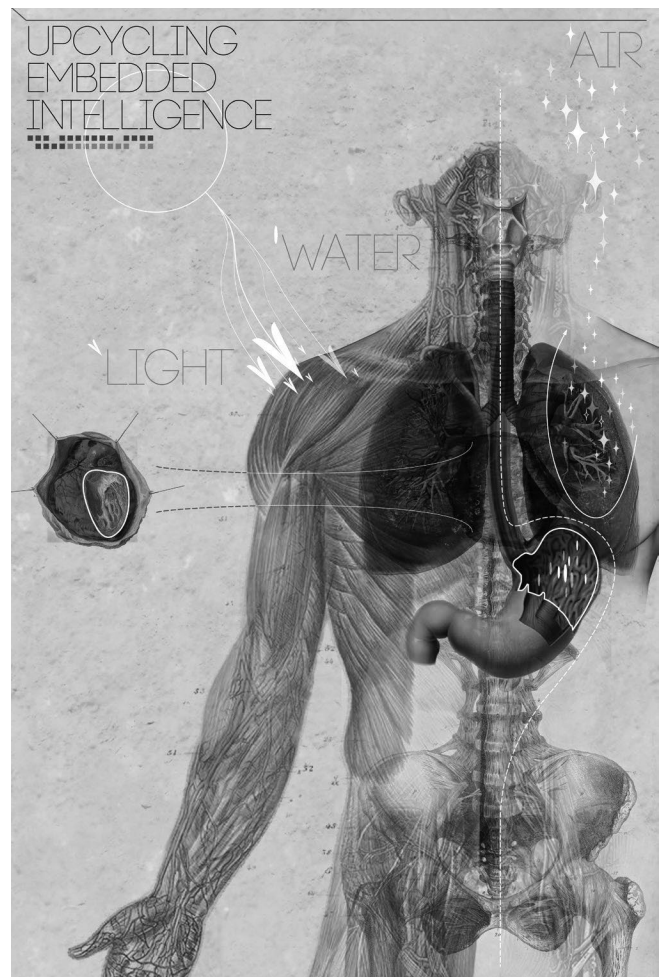


Figure 1: Exhibit Board 1. Stanford Exhibition, Fall 2019

efficient and impactful outcomes due to what Richard Sennett calls “public craft,” or a prime form of collective intelligence through mass edits (Claudel and Ratti 2015, 65). Yet, such open-source technologies or open systems like Linux are naturally predisposed to certain types problems due to their structuring. These problems may include, but are not limited to the following: (1) damaging alterations to code/infrastructure by rogue entities/organizations due to the accessibility of information – this being particularly worrisome for open-source architecture with biomaterials as will be presented in the following section; (2) the lack of oversight control in certain situations of importance – top-down oversight being an efficient means of protection but directly opposed to the ‘open’ mentality; and (3) the ‘live’ nature of the information generally, or in other words, the real possibility that the open-source technology is developed in a direction by the collective that is ultimately not the optimum way forward. Considering that such risks exist and are inherent to the type of peer-to-peer technology being discussed, how can one capitalize on successful aspects open-source technologies in architecture in a Linux-type fashion while mitigating the inherent problems of such open models?

TIMBER SMARTWALL: THE UPCYCLING OF EMBEDDED INTELLIGENCE WITH WOOD

How can distributed manufacturing and the innate intelligence of everyday materials be aligned to transform our built environments? How can increasingly accessible open-source communities and affordable digital manufacturing tools help facilitate such a change [and fast]?

The "Upcycling of Embedded Intelligence" project posits that while accessible digital manufacturing technologies already allow consumers to become prosumers, albeit rarely taking presumption beyond the scale and complexity of a tea cup or small toy, a powerful, potentially game-changing avenue for the discipline exists in the presumption of high-performance building products or assemblies by the everyday citizen designer or citizen builder. Such presumption can be facilitated through the upcycling of intelligence embedded in open-source data - meaning that expert-level design knowledge can be optimized and packaged for widespread amateur production through open-source networks. Such a distributed, grass-roots application of higher-order thinking can create large scale change in a bottom-up manner, a significant benefit of open-source systems. The upcycling of embedded intelligence holds the potential to immediately impact how we practice and teach, but also how we collectively frame the role and agency of the architect in twenty-first century open-source economies.

The Timber SmartWall system under development by the author and introduced on the accompanying boards provides an early-stage roadmap for how one can 'upcycle embedded intelligence' - or design and package expert knowledge for amateur production with basic materials. The Timber SmartWall project uses readily available digital manufacturing tools to strategically manipulate wood for enhanced indoor comfort levels and reduced energy use. The project uses a locally-optimized, CNC wood slicing technique to maximize the wood's latent heat sorption and related hygrothermal performance metrics, thereby using expert wood science knowledge to turn simple timber elements into high-performance indoor architectural products. Two real-world residential projects (the Mountain House and Lake House) currently in design development and construction drawings by the author are displayed on the accompanying boards. The SmartWall wood paneling system is used in each house and the drawings unpack the moisture and heat related design logics that underpin the SmartWall application.

When construction is completed, both projects will demonstrate how high-level knowledge may be translated for distributed manufacturing and how embedding intelligence for amateur production can allow architects to tap into wider swaths of the general population than our discipline typically engages (e.g., if the SmartWall is fabricated at home on one's <\$1,000 Maslow CNC, the SmartWall panels could be installed in the home by a layman for immediate aesthetic and energy-related benefits). This layman's process will be implemented in both residences by the author.

The key material component of the SmartWall system is natural wood. The moisture buffering capacity of natural wood - a hygroscopic material - can play a key role in the reduction of mechanical ventilation rates, thereby providing a reduction in energy usage, carbon emissions from building use, and financial costs for building operation. This raises an important question for architects and homeowners alike, how can natural wood best be used on interiors to maximize its energy reduction benefits? Also, for architects, how can best practices and higher-level wood science be communicated to the layman for a grassroots movement where such a clean tech product can be manufactured easily and cheaply at home? The more households making and using DIY clean tech building products, the greater reduction in carbon emissions can occur.

Despite decades of research on the hygroscopicity of wood, relatively little research has focused on building energy/carbon reduction possibilities if wood's biological properties are maximized on building interiors. This board introduces the design of SmartWall wood panels while subsequent boards (1) provide foundational knowledge underpinning the SmartWall system and (2) examples of its integration in two real-world projects.

Upcycling Embedded Intelligence as a concept is designed to lower carbon emissions from construction through the upcycling of low-value local material resources into high-performance building systems with accessible digital tools. Locally fabricated products using higher-order intelligence embedded in open-source data can have benefits over direct product purchasing.

Locally made based on accessible performance data. Understand making, can understand, fixing.

Building products often can be manufactured locally but usually are shipped from afar.

Carbon footprints of materials are complex and an easy response to know for consumer.

Local low-value material resources upcycled into high value building products with low carbon footprint.

DIY Building Products

Purchased Building Products

Timber SmartWall Key Concepts

- Demonstrates the upcycling of embedded intelligence through a timber wall panel system
- Wall system is composed of small, simple wood elements manufactured at home or locally on low cost digital fabrication tools. Panels are designed for easy install and minimal cut time.
- Wood panels maximize the hygroscopic properties of wood, meaning they are specifically sliced to enhance their ability to absorb water (releasing latent heat during the sorption process)
- The temperature product that is released when water undergoes a phase change can help heat or cool a space if the timber system is designed properly
- Wood panel aesthetics are directly related to performance. Thus the specific arrangement of panels can change both aesthetics AND performance, a key project concept
- The Timber SmartWall system uses such panels in coordination with other heat and moisture factors to enhance the energy efficiency of space while providing other use benefits.

Concepts for an open-source building product app:

- easy to understand carbon savings data
- simple material lists
- open-source material footprint maps
- step-by-step installation instructions with digital scan and AR technology

Carbon footprint of typical building product displayed as map. Percent reduction of carbon by producing product locally displayed (bottom right)

Open-source building product files include placement and usage advice

Digital space scan + AR overlay of installation generates feedback from app. "Correct Installation!"

SmartWall Panel Design

The following selected panel designs are under development for the Mountain House and Lake House projects. The panels are designed to be produced on a low cost Maslow or table top CNC router with basic router bits. The panels are sliced to maximize the wood's hygroscopic properties and generate a patterned aesthetic when aggregated and applied to the residence's high moisture areas such as bathrooms and kitchens. Additional panels could be added to an open-source database and existing panels could be enhanced by qualified editors to further enhance energy saving qualities. Ideally, a layman could download the product file, cut the product with the CNC, and install the product with the app's support without ever knowing the higher-order wood science knowledge underpinning the design or its specific impact on the layman's home. Cost savings and panel beauty when installed can drive demand.

- A - Poplar Veneer. Complexity generated through line cuts. Large modules
- B - Poplar Veneer. Complexity generated through line cuts. Medium modules
- C - Oak board. Triangle cut with curving insert. Medium modules
- D - Oak board. Slice cuts to triangulate. Ball bit cutout. Layered, stacked. Small modules
- E - Veneer. Sliced and peeled up. Layered system. Module variable.
- F - Pine board. Ball bit routed, then sliced an reassembled. Small module
- G - Pine board. Ball bit routed, sliced twice then reassembled. Small module
- H - Variable. Random ball mill pattern. Holes drilled to interior for layering. Module variable

Figure 2: Exhibit Board 2. Stanford Exhibition, Fall 2019

NON-EXPERT PRODUCTION IN PRACTICE

“The central issue with the current mode of neoliberal production is that it is at once too narrow in its sanctioned scope and imperceptibly large in its unconsidered ecological effects. The constitutive materials and energy flows attached to building are so large, and of such confounding complexity, that few architects comprehend or act on them, nor are they trained to do so,” states Jacob Mans in his article “Scaling for Non-expert Production” (Mans 2017, 82). The writing appropriately questions the tangible societal impact of the architect, the relevant scales of architectural design, and the role of non-expert forms of feedback in an age of “wicked problems,” namely human-induced climate change (Boyer and Cook 2013, 142). Mans continues by stating, “to operate at appropriate scales of building requires a post-professional, non-expert disposition. In short, a building can no longer be the sole scale of response to the question of building” (Mans 2017, 82). This is demonstrated by Mans through the design and production of the Littleton Trials, a series of wooden huts built in the U.S. state of Massachusetts. The article efficiently questions how architects can best respond to the global challenges that society faces in a top-down neoliberal global society. While Mans does not directly state the similarity between his positions and the core concepts underlying the open-source movement, Mans proposes a practice of architecture that “repositions the architect as a non-expert” so as to more effectively collaborate with other disciplines to solve larger, more diverse questions about architecture at an environmental scale than the architect could do alone.

TIMBER SMARTWALL

In alignment with Mans’ non-expert perspective on architectural practice, the author of this article launched a design project in June 2018 in an attempt to mitigate numerous negative impacts of the often poorly designed American housing stock. Termed the Timber SmartWall, the project attempts to maximize the hygrothermal benefits of wood as a means to reduce residential energy usage, improve indoor comfort levels, and also provide mental health benefits to inhabitants. The premise of the project is as follows: (1) the U.S. housing stock generally exhibits poor thermal performance and often employs the use of carbon-intensive gypsum board as interior ceiling and wall sheathing; (2) wood naturally stores heat energy via the water that is absorbed by the hygroscopic material and this stored heat energy can be used productively; and (3) the calibrated manipulation of wood can increase the productive hygrothermal benefits of the material and assist in the moderation of indoor comfort levels through the re-release of energy stored as heat in moisture. By replacing carbon-intensive gypsum board with an enhanced wood-panel system, less energy is needed to heat the home due to wood’s hygrothermal benefits, less carbon-intensive gypsum is needed per house, and indoor comfort levels can be improved due to wood’s natural hygroscopic and biophilic properties. Research by Treteknisk, the Norwegian

Institute of Wood Technology, and the collaborative European Wood2New project underpins this design work (Nore 2015).

The author’s exhibit at the 2019 ACSA Fall Conference at Stanford University illustrated how the SmartWall could be integrated into two ongoing residential design projects by the author’s firm. The exhibit introduced the reader to foundational concepts relating to the SmartWall’s hygrothermal performance and then graphically illustrated how the SmartWall’s application could be both performative and aesthetically engaging.

The Timber SmartWall project clearly separates itself from past research through its exploration of potential avenues for large scale fabrication and its aesthetic strategies for the public adoption of both wall and ceiling elements. Unlike the studies by the Wood2New project, the Timber SmartWall system focuses on how to combine performance-enhancing manipulations to wood with attractive aesthetics to increase the public demand for such a product. The SmartWall product would be optimally placed near areas of the home that contain higher than average moisture levels, thereby providing a greater possibility of latent heat sorption. These areas include kitchens, particularly on the walls and ceilings surrounding stove tops, the dishwasher, and sink, as well as bathroom areas. Treteknisk’s research on the hygrothermal potential of bathroom spaces showed a relatively significant national energy reduction in Norway if the common Norwegian home had even a basic uncoated wooden ceiling; this being compared to the typical gypsum, fiberboard, or plastic-based composite ceilings typically used (Nore 2015). Warm water vapor from hot showers would provide excellent latent heat energy to be stored in the panels with the panels naturally functioning to improve indoor comfort as the wood moves closer to an equilibrium moisture content.

A wide variety of commercially available wood products offer diverse opportunities for use in SmartWall applications. Whereas layered, thinly sliced wood veneers would provide a lightweight and high-surface-area solution for ceilings, wood products with greater impact resistance such as hardwood lamellae could be used for wall coverings. Hardwood cross-laminated timber provides a hitherto unexplored SmartWall medium and work has just begun by the author to incorporate CLT into the collection of other SmartWall products under development.

EXPEDITING RESEARCH TO APPLICATION

Innovative biomaterial products like a CLT SmartWall system that could have positive societal benefits should ideally be able to reach the market quickly. The faster the product reaches the commercial market, the faster its energy and carbon-reduction benefits could be realized. Unfortunately a number of hurdles stand in the way of market rollout due to the nature of neoliberal, top-down commercial practices. These include,

TIMBER SMARTWALL: KEY CONCEPTS AND DESIGN TOOLKIT

The Timber SmartWall project exemplifies the 'upcycling of embedded intelligence' concept. To best provide you, the architect, with a 'toolkit' of design strategies for use in your own wood-based open-source projects, key concepts underpinning the author's SmartWall system are described below. Each concept is introduced with basic scientific information followed by potential benefits and/or design strategies the author suggests considering. As described on a prior board, moisture and heat when used as 'design drivers' can have a profound impact on indoor comfort, aesthetics, energy efficiency, and occupant health if used intelligently via hygroscopic building products such as wood. What design strategies interest you and how might your 'embedded intelligence' system using upcycled materials benefit others? Using open-source, low-cost digital fabrication tools, architects have the opportunity to provide the general populace and everyday citizen builder with processes and products to improve lives. While no systems exist without risk, key risks to architects that design wood-based, open-source systems are introduced at the end (lower right corner).

1 Hygroscopicity of wood

How does water enter wood? -Hygroscopicity is the property of wood to attract moisture from (the) surrounding atmosphere and hold it in the form of liquid water or vapor" (1). For example, trees in the forest can vary in moisture content from ~25%~300% depending upon various factors that influence absorption.

Chemical Structure: C₆H₁₀O₅. Cellulose holds water via high-powered hydrogen bonds. Hydroxyl groups, particularly cellulose, attract water.

Storage Locations: Free water (cell wall), bound water cell cavity. Water enters wood 3 ways: capillary tension, vapor through lumens, and molecular diffusion via cell walls.

Wood Swelling: Wood swells when cellulose chains are pushed apart by water. heartwood < sapwood Common moisture storage ratio.

Potential benefits: Wood stores moisture while seeking equilibrium with the ambient air. Negative space in architecture can be thought of as a moisture-laden air volume that can have spatial opportunities if properly paired with natural wood under the right conditions.

Design strategies: The hygroscopic properties of individual wood species are well known and wood behavior can be precalculated to strategically enhance spatial design.

- Optimized indoor comfort levels
- Strategic use of material expansion and shrinkage
- Indoor comfort level manipulation by space or surface
- Heat-dependant jointing
- High strengths, moisture induced hardwood-softwood assemblies
- Wood softening through free water manipulation

2 Moisture Buffer Value (MBV)

Absorption and Release - In 2005, the Nordic Innovation Centre "introduced a new material property, the so-called 'moisture buffer value' which describes the ability of building materials and systems of materials to exchange moisture with the indoor environment" (2).

MBV values: 3x MBV value of wood over concrete and brick; 2x MBV value of wood over gypsum; 20% MBV value of wood over cellulose concrete.

Design strategies: Building products can be arranged according to their MBV and such arrangements have quantifiable benefits that can be pre-calculated.

- Wall systems with high MBVs can considerably reduce indoor humidity swings
- Permeable wall systems cap indoor relative humidity levels as compared to non-permeable systems
- Layered wall systems with hygroscopic materials exposed where needed
- Dynamic assemblies for specific technical and aesthetic performance
- Unique, surprising material assemblies aesthetically. Logical due to performance (ex. layered wood, conc, wood)
- Low-maintenance, indefinite performance
- Multiple rooms designed as a performative assembly to mitigate unwanted humidity swings
- Small elements arranged densely can allow for easy production and installation. End grain exposure ideal
- Penetrations and cavities can impact acoustics as well as MBV

3 Latent heat sorption

Examples of phase change opportunities in building physics - "Latent heat is the sorption energy released or used in the open pores of materials during the exothermic or endothermic process of phase change from vapor to liquid water or vice versa" (3). The sorption of such phase change energy can impact overall energy use in buildings (4).

Heating (2-3%) < Cooling (5-30%)

- Wood-proper HVAC can result in significant direct energy savings from latent heat
- Wood + proper HVAC can maintain stable indoor humidity levels between 43% and 59% while reducing energy usage (4)
- 320 kWh/year saved. By adjusting the heating system 3 degree lower, hygroscopic materials can save significant energy amounts in high moisture rooms vs. non-permeable materials (4)

In a sauna physics, the sensible heat increase is not from the change of humidity but from latent heat energy emitted back into room

Wood surfaces can become substantial heating panels when latent heat is emitted via moisture sorption

Small amounts of moisture located throughout a building also impact cumulative energy use

Design Strategies to Maximize Latent Heat: The moisture buffering capacity of wood reveals an opportunity to maximize the material's latent heat benefits. The following design strategies suggest such possibilities:

- Provide hygroscopic materials in high humidity areas
- Recognize breathing as a warm air moisture release process
- View wood as a moisture 'battery' that heats and cools
- Increase density to increase hygroscopic fuel
- Small impact via small moisture loads is still impact
- Space isolation can lead to more tailored control
- Increase wood's surface area to increase loading capability
- Maximize anisotropic properties through strategic orientation
- End grain to maximize sorption
- Moisture movement designed for latent heat warming
- Climate specific, seasonally flexible moisture buffering
- HVAC always designed in tandem with hygroscopic surfaces

4 Anisotropic Behavior

Orientation Design Opportunities - Wood is made of cells that are often 100 to 200 times longer than they are wide. What properties exist in such a structure and how can such properties be maximized in relation to moisture?

- Sapwood cells offer less restrictions to water movement than heartwood cells
- Early wood is more porous than late wood in tree rings
- Faster growth wood = more porosity for water infiltration, particularly on end grain
- Checking through drying can expose significantly wide and deep surface area to moisture without the need for mechanical intervention
- Wood is orthotropic, changing twice as much in the tangential direction as the radial direction.
- Longitudinal shrinkage is minuscule at only 1-2% maximum.

5 Engineered Wood

Material Properties - Engineered wood is logically more dimensionally stable than natural wood. Veneer-based elements perform differently than mass timber elements but both offer opportunities for sorption when accounting for the glue location, type, and density.

- For panel products, dimensional change is usually proportionally greatest across panel thickness, the dimensional change still being small
- Fiberboard dimensional change is generally viewed as inconsequential
- For panel-based products, edge conditions experience greatest form change
- Checking can occur in engineered products if rapid wetting and drying occurs
- Mass timber elements behave like natural timber in that the water absorption speed is related to size and density

Design Strategies: The primary advantage of using engineered wood for hygrothermal systems is the possibility to take advantage of easily understood and consistent manufacturing processes.

- Softening of panel products through moisture absorption
- Unique hardwood/soft-wood combinations
- Veneers become more pertinent and performative
- Strategic design of fiber product distortion
- Element surfaces can be both ornamental and performative
- Deeper penetration possibilities for more exposed hygroscopic surface area

Architectural Risks

Open-source environments hold the possibility for a grassroots, widespread distribution of advanced, high-performance building products designed by experts and optimized for local, non-skilled fabrication with accessible digital tools. Such risks are well-documented relative to the open-source movement at large. For this specific project using upcycled, hygroscopic raw materials, risks to 'expert' building product designers (architects) include, but are not limited to, the following:

- Liability for faulty fabrication, liability for improper performance, misapplication leading to rot and decay, poor material stock selection, degree to which products can be customized for specific application, design ownership rights, payment as it relates to contracts, viral misappropriation of product, hacking of data, products with unverified performance reducing exposure of verified high-performance products, degradation of architectural discipline if services are free or lack verification of quality, etc.

(1) Hygroscopicity of wood. Mendelova Univerzita v Brne. Accessed Sep. 3 2019
 (2) Kranjčič D, Nore K. Latent Heat Phenomena in Buildings and Potential Integration into Energy Balance. International Conference on Sustainable Synergies from Buildings to the Urban Scale, SBE16, Procedia Environmental Sciences 38 (2017) 364-371.
 (3) Nore K, Kranjčič D, Bruckner C. The Principals of Sauna Physics. 6th Intl. Building Physics Conf. IBPC 2015. Energy Procedia 78 (2015) 1907-1912.
 (4) Charyntala O, Simonson C. Moisture buffering capacity of hygroscopic building materials: Experimental facilities and energy impact. Energy and Buildings 2006; 38:1270-82.

Figure 3: Exhibit Board 3. Stanford Exhibition, Fall 2019

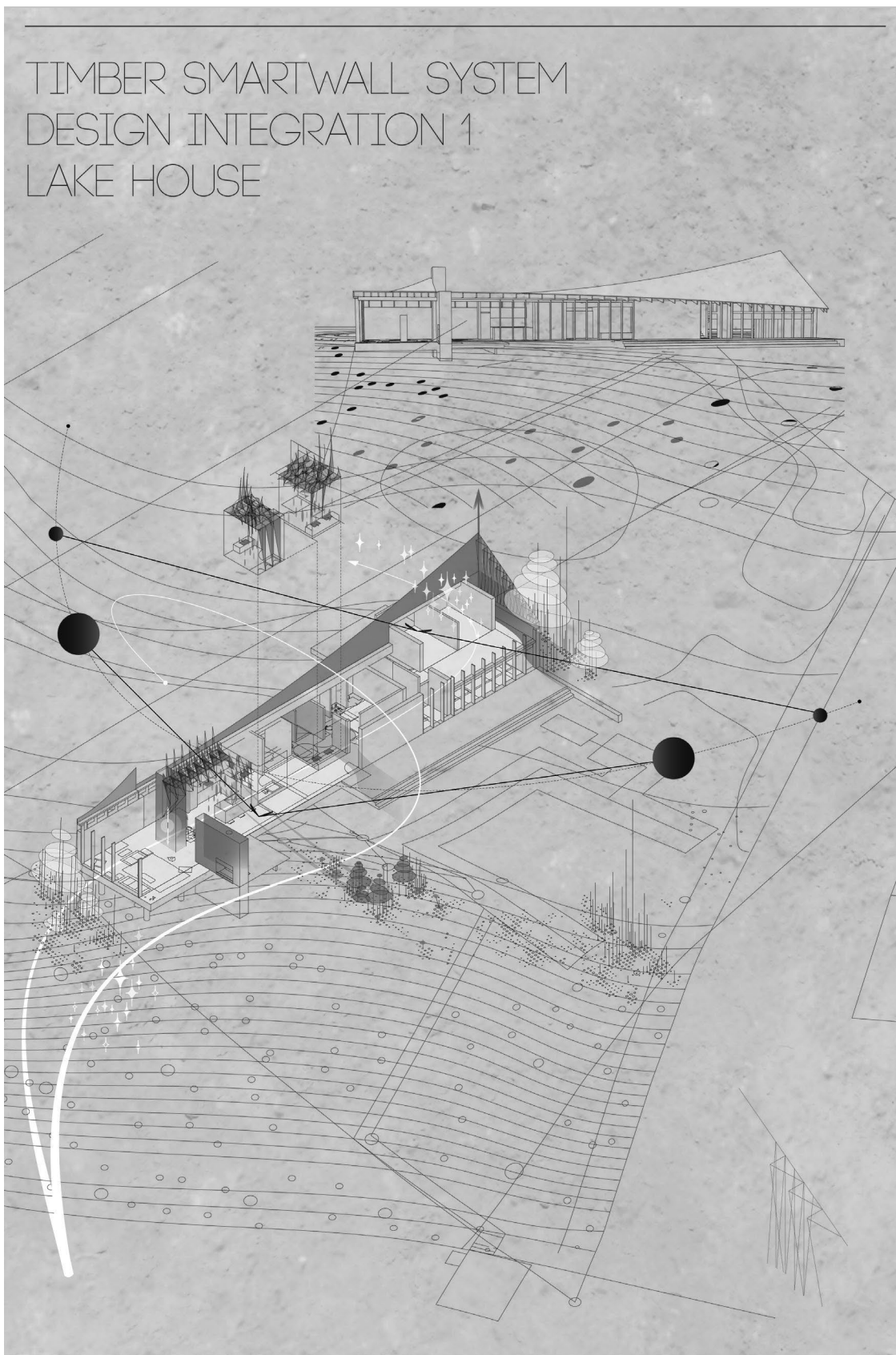


Figure 4: Exhibit Board 4. Stanford Exhibition, Fall 2019

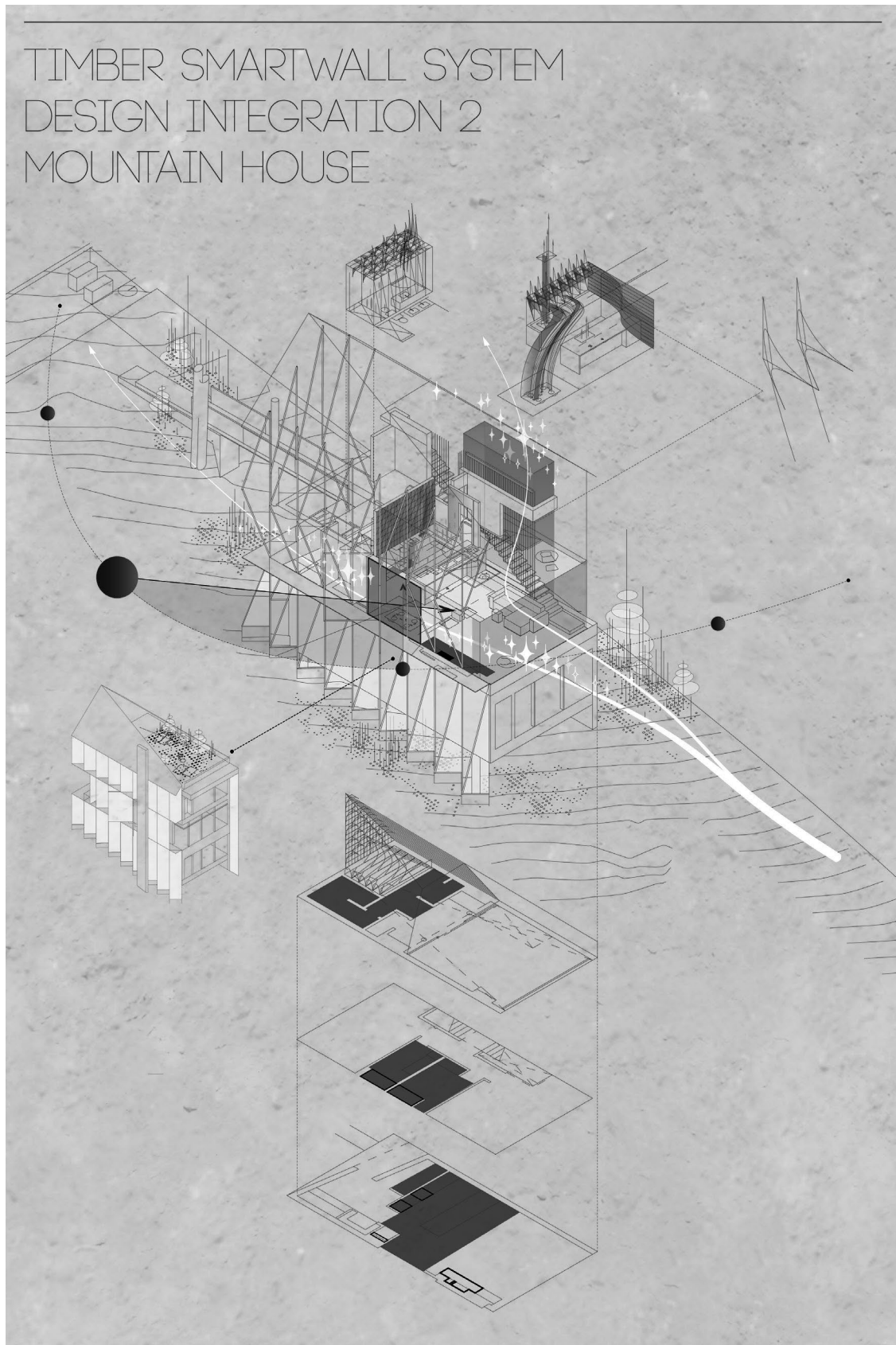


Figure 5: Exhibit Board 5. Stanford Exhibition, Fall 2019



Figure 6: Radford Train Observation Tower, project co-led by author

but are not limited to, one, market studies needed to prove market potential – this takes time to test and demonstrate – and two, outdated perceptions and long-standing cultural norms that may cause the novel product to be viewed as too risky for investment. Relative to the aforementioned hurdles, the CLT Timber SmartWall system raises a number of important points about the market rollout of innovative biomaterial systems in general. How can such building products overcome market hurdles in order to be introduced to markets quickly? How can such products be distributed on a mass scale without significant industry backing, a process that normally requires time and a concerted investment effort? And lastly, once introduced to the market, how can the products adapt most rapidly to changing aesthetic preferences while still retaining optimum performance levels - levels that require higher-order knowledge of wood science to achieve? Such market questions relate to nearly every new product to some degree including the bio-based materials that are most important to addressing pressing global issues like climate change. Bioplastics can be seen as risky in a relative sense to fossil-fuel-based plastics due to decades of experience that society has with plastic made from non-renewable sources. CLT can also be seen as risky due to a general lack of demonstrated successes as compared to the pervasive use of concrete and steel in

construction, for example. In common terminology, ‘if it isn’t broken why fix it,’ the challenge being to illustrate to the general public that in fact there are serious consequences to standard plastics and energy-intensive construction methods, for example. They are in-fact ‘broken.’ The risks of common practice may be far greater than the perceived risks associated with new material solutions. Based upon this perspective, how novel bio-based products reach markets quickly and at a scale that is meaningful?

OPEN-SOURCE TECHNOLOGIES TO OVERCOME MARKET HURDLES

The SmartWall project is being designed by the author to maximize the benefits of open-source technologies as a means to overcome the market hurdles listed above. As related to the multi-faceted affordances and limitations of open-source technologies illustrated by the Linux operating system, the use of open-source technologies as a means to fabricate and also distribute SmartWall panels including those made of CLT offers a number of advantages. Low-cost machines such as a Maslow CNC can be used to manipulate the surface of CLT to enhance hygrothermal performance. Maslow CNC machines can be purchased for less than 1,000 USD and link to common software packages for a variety of design-to-production

possibilities. Due to their low cost and high-performance advantages, Maslow CNCs can be purchased by a significant percentage of society allowing the individual to produce their own high-performance CLT SmartWall panels at home. If this is infeasible due to a variety of condition-specific situations, like urban inhabitants living in micro homes without the space to fabricate, low-cost digital tools such as the Maslow support the development of ‘maker cultures’ or Fab Labs that operate as independent businesses with small overhead costs to service this need. Wood-science and design experts can create custom cut files per type of wood product and upload the data to open-source networks. Everyday citizens then have the opportunity to download the cut files, perhaps paying a small royalty, and fabricate high-performance SmartWall products in a distributed manner. This design for non-expert production through the concept of embedded intelligence allows a grassroots form of distributed manufacturing to occur and allows the SmartWall product to be iteratively prototyped by the general public. If the SmartWall product is attractive aesthetically and can lower a household’s energy bills, then the cost of a Maslow CNC, the stock product to be cut, and the free or low-cost embedded-intelligence data are collectively positioned to help the design product overcome some of the most challenging market hurdles.

OPEN-SOURCE DISTRIBUTED MANUFACTURING IN CONTEXT

It is important to note that the SmartWall project previously mentioned is but one of a plethora of open-source projects intended for distributed manufacturing by the architecture and design industries. The project is unique in that it is both an architectural building product and an infrastructural concept of how to produce the product. The process of production and the questions that arise from it are part of a much larger open-source design movement. “Digital Property: Open-source Architecture” edited by Antoine Picon and Wendy Fok curates emerging discourses and practices of the open-source movement and raises critical questions in regard to ownership, collaboration, and safety. Speaking about the open-source movement, Picon and Fok state that the way this notion has become a “key theme for so many contemporary design practices is truly striking” (Fok and Picon 2015, 11) “While the design process has been accelerated, the results, generally in digital format, can be indefinitely circulated. In theory, its physical translations, from prefabricated parts to entire buildings, can now be replicated with great fidelity or customized at will to adapt to specific needs,” the authors state (Fok and Picon 2015, 7).

Certain dilemmas that emerge from such networked design and manufacturing processes include the issues of ownership and control. What is a fair method of retribution when objects and systems are designed and/or produced by a multiplying conglomeration of contributors? How can additional authors be added to the chain and who gets credit for production

(Fok and Picon 2015, 11). If the SmartWall is fabricated at home, does the original designer get credit or the fabricator who actually produced the project with their machine? Francis Bitonti directly addresses the potential for distributed manufacturing to lower carbon emissions and advocates for the idea of “social manufacturing” where users actively participate in design (Bitonti 2016, 105). This perspective is particularly apt for the CLT SmartWall project where everyday users of the open-source data could collectively contribute to the affective qualities of the elements while the wood-science experts select and test which aesthetic options can maintain the product’s high-performance metrics. Such an ecosystem could easily spur the development of use metrics, social media ranking systems, and need for oversight to remove underperforming design options.

ARCHITECTURAL PRODUCT CERTIFICATION

For the construction industry specifically, new methods to facilitate oversight may require an altering of the disciplinary roles of building-product certification boards, one example being ANSI that certifies CLT products for use at a national level. If CLT is being produced at a local level and manipulated at a local level, the certification and approval processes could respond by becoming more distributed, providing technical certification training or other supporting information to localities that oversee building code compliance and other construction approval processes. No matter what type of construction material is produced through open-source data and distributed fabrication technologies, local authorities could screen products before construction is allowed to commence.

HARDWOOD CROSS-LAMINATED TIMBER CASE STUDY

The need for such oversight can be demonstrated by the Radford Train Observation Tower project designed by the author and collaborating faculty and students at Virginia Tech. The design-build project utilized custom fabricated hardwood CLT due to the lack of locally-available softwood CLT and the availability of low-cost, locally-sourced Yellow Poplar wood. As hardwood CLT is not ANSI-APA PRG-320 certified, the team used hardwood CLT performance research developed by Virginia Tech and pursued a non-standard building code path for building permit and construction approval. The hardwood CLT was used in two structural building enclosure elements, one of which was built a factory setting, shipped to the site, and craned into place. Construction for the full structure was completed in September 2019.

The CLT was produced with low-cost plywood pressing technology that could be replicated across the United States or Europe in a distributed manner. By using low-cost tools with higher-order production information, this example of custom-fabricated CLT illustrates that grass-roots efforts to fabricate high-performance biomaterials can be achieved in a cost-competitive manner. The CLT production occurred in a

historic warehouse operated by the Southern Virginia Higher Education Center. The former tobacco processing facility had been repurposed with digital fabrication tools and the process of production provided unique market benefits due to low-overhead costs. While the hardwood CLT produced for this project meets and exceeded ANSI performance standards, there is currently no system in place in the United States to comprehensively verify performance data of structural building products produced in a distributed manner. Verification is critical to maintain public health and safety, and perhaps a precedent-based building approval process in the United States could be more beneficial for such grassroots production methods. This case study illustrates how an innovative maker culture for open-source building products could stem from the pairing of low-cost tools and low-overhead facilities. Such full-scale, real-world projects that upcycle embedded intelligence for the distributed manufacturing of high-performance building products provides valuable insight into the benefits and limitations of such systems. Further demonstration of such open-source systems would be useful.

ANALYSIS AND DISCUSSION

The included case study projects illustrate how open-source technologies and distributed manufacturing networks can alter the landscape of top-down design-to-production processes and raise a number of provocative disciplinary questions relative to the embedment of higher-order knowledge in open-source production. In regard to advanced biomaterials such as CLT, the example projects assist in the exploration of the positive and negative impacts open-source technologies provide for its architectural utilization. Large-scale studies that attempt to introduce newfound biomaterial construction systems to industry through an open-source, distributed process would be of particular utility. The issues of oversight, control, and quality that have been previously introduced could be tested in a quantitative manner and may provide valuable data for future open-source projects. Grass-roots efforts to produce smart materials and iteratively develop their performance following a Linux-based model also hold promise. The research is timely due to the pressing need to reduce energy use in buildings and carbon emissions from building construction and utilization. Emerging technologies offer newfound benefits and avenues for practice beyond traditional processes, yet the current impact of such open-source technologies is relatively nascent on global markets. If architects follow the lead of other professions in adopting open-source technologies for non-expert production and networked manufacturing on a large scale, how will this impact the utilization of intelligent everyday materials such as wood, and ultimately how will this alter the design of architectural space?



Figure 7: Radford Train Observation Tower, project co-led by author

ENDNOTES

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