[Local] Materials Matter

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This research explores three design-research projects led by the author that transformed locally sourced, underutilized biomaterials into high-performance building products tailored to their regional contexts. They are intended to expose barriers related to product development, permitting, code compliance, and application, each key limitations for the widespread acceptance and utilization of novel low-carbon construction materials. One case-study project, the New River Train Observation Tower, involved the utilization of low-grade timber products for the development of local-species CLT. The low-grade "trash" wood for the structural product was sourced, milled, pressed, and utilized locally, thus significantly reducing carbon emissions from construction, benefitting the local economy, and resisting region-specific pests/fungi. The thirty-foot-tall, publicly accessible tower was the first hardwood CLT building in the United States to receive a building permit and to be constructed with local-species wood. Another practice-based research project by the author titled "Lake House" employs local alternatives for non-renewable building products. The project involves the utilization of thermally modified wood and highlights key hurdles to locally sourced, bio-based material utilization. Each project exemplifies a material-based carbon management strategy and is affiliated with the author's research at the Center for Low-Carbon Structures and Systems at Virginia Tech, a multidisciplinary research unit focused on the development and implementation of novel bio-based building systems. Both case study projects and their related low-carbon products/systems align with the AIA Framework for Design Excellence, specifically Designing for Resources and Designing for Economy.

INTRODUCTION

The hegemony of Fordist thinking and industrial practice during the 20th-century provided manufactured goods and related services to the masses at a global scale. Economic expansion and technological progress were generally considered comprehensive end goals in and of themselves with the natural resources and environments supporting such material and consumption cultures being viewed as more of an opportunity for further economic advancement than the precious sustenance for life itself. This research document supports a reconceptualization of such priorities by aligning environmental concerns with economic progress in the architectural, engineering, and construction (AEC) industries through bio-based materials.

With an increased global focus on the protection and conservation of natural resources and environments in the 21st century, and a recognition that non-renewable materials are both limited in availability and their production downright dangerous for the planet's health, the AEC industries are actively seeking solutions to minimize environmental impact through the physical constructions for which they are responsible. As greenhouse-gas-driven climate change is widely recognized as the preeminent environmental concern, AEC professional organizations such as the American Institute of Architects (AIA) have assumed leading roles for both the education of professionals and the policy-driven code requirements that mandate progressive change in practice.

According to the AIA's Materials Matter Program - one of many climate-related initiatives - the utilization of locally-sourced building materials and products is widely considered a 'best practice' and a key avenue to lowering carbon emissions from construction, particularly if the materials are bio-based. That said, this document collectively explores multiple design-research projects led by the author that transform underutilized biomaterials into high performance building products tailored to their regional contexts, a distinct emphasis being placed on local extraction, upcycling, and utilization. This design-as-scholarship research is intended to serve as a procedural roadmap for the development and application bio-based building materials for structural and finish applications, as well as a case study document through which one can consider their architectural potential.

INTELLECTUAL CONTEXT

The case study projects presented in this document each utilize 'advanced biomaterials,' or low-value bio-based materials that have been upcycled into higher performance, and thus higher value, products. Whereas a majority of biomaterial research in the field of architecture focuses on a specific biomaterial product regarding its technical performance, development and application, and/or architectural impact

Figure 1. Lake House (under construction) using locally-sourced, thermally modified wood.

from a socio-cultural or historical position, this paper explicitly considers the collective, or a portfolio of projects, and through the collective provides insight for the architectural tailoring of local materials to their local context. Through this collective lens, the design-as-scholarship projects - some of which are still in progress - can be understood as part of a larger pattern of practice and impact, the body of work being the research rather than any individual artifact. The collection of projects also highlight various macro and micro factors impacting the widespread development and utilization of new bio-based building materials.

Project Background

Each project exemplifies a material-based carbon management strategy and is affiliated with the author's research at the Center for Low-Carbon Structures and Systems at Virginia Tech, a multidisciplinary research unit focused on the development and implementation of novel bio-based building systems. Each design-as-scholarship project and its related low-carbon products/systems align with the AIA Framework for Design Excellence, specifically Designing for Resources and Designing for Economy.

The three projects are as follows (e.g., project, location, industry affiliation): (1) Lake House, Tennessee (USA), VOR (professional practice); (2) Mountain House, Virginia (USA), VOR (professional practice); (3) New River Train Observation Tower, Virginia (USA), Virginia Tech (academic).

Each project utilizes a bio-based material from the Appalachian region that has been upcycled into higher-performance and higher-value building product with the specific product either being utilized as a structural or finish product. The project/product list is as follows: (1) Lake House/Thermally-modified wood; (2) Mountain House/Thermally-modified wood; (3) New River Train Observation Tower/Hardwood cross-laminated timber (CLT).

The author led or co-led the design for each project. Thus, the research document stems from first-hand material development, prototyping, and full-scale construction experience. Various institutional and industry partners were directly engaged the various projects' design and construction processes, and thus the case studies themselves are the result of multi-disciplinary teams.

PROJECT INFORMATION

Buildings are composed of thousands - or even millions - of unique parts made from a variety of materials. As illustrated in the book "Empire, State & Building" by Kiel Moe, contemporary buildings are composed of parts that comprise a global material landscape when collectively considered, despite widespread acknowledgement that locally-sourced materials are preferable (Moe 2017). Such relevant preferences for practice stand in stark contrast to dominant global supply networks where, for example, Austrian cross-laminated timber (CLT) is being imported into timber-rich Georgia to build houses in Atlanta, and vast quantities of Chinese steel and Danish brick are being used to build Manhattan skyscrapers, despite plentiful local material availability. These are just but a few examples of expansive global supply networks being prioritized over local, low-carbon opportunities. Considering that each global region has a unique material-climate DNA - often exemplified by vernacular construction methods - how can building design and construction be tailored to these context-specific factors in the twenty-first century to both reduce building-related carbon emissions from construction and operation, while also increasing building quality and performance?

The following pilot projects from the Appalachian region of the United States draw from the wealth of local natural resources - namely hardwood timber - not only for their own construction, but also for their use as pilot projects for the nearly 150 million East-Coast-dwelling Americans that live within a three-hour driving radius of Appalachian hardwood forests. By

Figure 2. Mountain House (under permitting) using locally-sourced, thermally modified wood.

increasing sustainable, bio-based material production in the Appalachian region, East Coast urban areas can have lower-carbon material options for construction while the utilization of such products can provide economic benefit to rural areas. Each of the following bio-based materials will be presented relative to selected macro and micro factors that impact its utilization, the author focusing on one factor per material to illustrate diversity.

Thermally Modified Wood

Macro scale political decisions involving tariffs can either rapidly accelerate a push for local material innovation or can stifle it. The Trump administration tariffs on US hardwood exports to China in 2018-2019 significantly impacted the American timber industry with financial losses to China alone averaging $200 million per quarter (AHEC 2019). As AHEC data indicates, not only were lumber exports significantly reduced, but other countries increased trade with China to fill the gap and account for the loss of the American market share. Such tariff impacts on Appalachian hardwood distributors in particular have decreased the cost per board foot of lumber due to a lack of market availability and have generated a substantial immediate need for new internal market outlets. While on one hand this economic condition has very negatively impacted the US hardwood industry financially, it also has also accelerated the need for new biomaterial products and the willingness of industry to test prototypes.

That said, thermally modified (T.M.) wood made with locally-sourced Ash and Yellow Poplar may prove such a market outlet considering its low-carbon sustainability metrics, local availability in the Appalachian region, and high durability. Unlike in Europe where non-renewable building materials are more heavily regulated and public perception of fossil-fuel based products is generally lower, the United States is dominated by building products that are petroleum-based such as the ubiquitous Trex decking and plethora of vinyl siding products. Without regulations that financially incentivize renewable product purchasing to a sufficient degree, AEC professionals are often left with few low-carbon options.

Enter T.M. wood. Commonplace in Europe where non-renewable products are heavily regulated, thermally modified wood, often referred to as T.M. wood, is a dimensionally stable, non-toxic, insect-resistant, high-performance product. Wood is baked in a high temperature, oxygen-free oven to naturally remove organic compounds at a cellular level. Thus, the wood attains high-performance characteristics, albeit while becoming slightly brittle in nature, while completely avoiding fossil fuel reliance. The characteristic chocolate brown color after heating weathers to a soft gray if left unoiled over time.

Two projects led by the author, the Lake House (Fig. 1) and Mountain House(Fig. 2) in Tennessee and Virginia respectively, utilize T.M wood for finish work on both the facade and decking. Key to the architectural intent of the Lake House is a seamless interior to exterior connection with floor-to-ceiling windows and outdoor spaces that draw the eye through the project. Architecturally, the project employs a minimal material palette with pre-weathered T.M. wood as a facade element, both

Figure 3. Custom-developed hardwood CLT from local forests before assembly.

for its sustainable properties and consistent aesthetic. While the material application would be considered commonplace through its tongue and groove system, local contractors are uncomfortable with the material due to their unfamiliarity, despite its clear environmental benefits. Associatively, the Mountain House uses T.M. wood for its entry facade and roof deck, but concerns have been raised among the project team about the product's durability and aesthetic over time despite the material's proven results on other select projects. Project team members have even encouraged non-renewable products to be used in the place of T.M. wood, such as wood-plastic composite decking, as it is seen as a "safe" alternative. Both residential projects are expected to be completed in 2021 with one currently under construction and the other in permitting.

The projects illustrate multiple key hurdles for new, bio-based materials to overcome in practice: (1) an incorrect perception that they are less durable; (2) use decisions that do not consider the environmental damage of non-renewable products; (3) the competitor, non-renewable product's environmental damage not be accounted for in project cost; and (4) the general preference for AEC professionals to specify the same products that they have used before and are comfortable with using.

Hardwood CLT

Cross-laminated timber (CLT) is a panelized mass timber product widely known for its low-carbon benefits, as well as the construction speed and related cost savings that can be achieved through its use. Unlike much of Europe where CLT products are available within a carbon-reasonable shipping distance, the United States' size and nascent mass timber industry require that certain portions of the country such as the Southwest, Southeast, and Midwest import CLT from great distances, namely the Pacific Northwest, Canada, and Europe. CLT panels are not currently produced in the Appalachian region as the forests are comprised of hardwoods, not the softwoods used to make CLTs. In essence, fossil fuels are being spent to import wood into forested regions because, supposedly, the wrong wood species exist locally to make CLTs. This is occurring despite the aforementioned $500 million, tariff-related decline in US hardwood exports, and a related 19% oversupply of low-value hardwoods like Yellow Poplar in forested regions of the American East(AHEC 2019). As foresters well know, an oversupply of low-value timber increases forest fire risk, negatively impacts forest health, and dilutes US timber markets for high-quality timber as low-value wood is oversupplied.

Figure 4. New River Train Observation Tower constructed with locally-sourced, custom-developed hardwood CLT.

Low-value, fast growing and oversupplied hardwoods like Yellow Poplar offer an opportunity for hardwood CLTs to be developed that use locally harvested wood, manufactured by local industry, and utilized in local buildings in the Eastern United States to reduce carbon emissions, a holistic product process that can improve both rural and urban economies alike. On the contrary to concerns that harvesting hardwoods is unsustainable, American hardwood forests are sustainably managed and Yellow Poplar is even considered invasive in some regions as it crowds out slower growth, higher value hardwoods like White Oak. Why import wood into forested regions when overlooked, low-value, local timber can be upcycled into a high-performance, high-value building product like CLT? The development of Yellow-Poplar CLTs can provide a key source of sustainable, structural building material to high-population areas located in the hardwood-dominant eastern half of the United States, the aforementioned construction market of approximately 150 million people, and serve as a local-species CLT model for hardwood regions globally.

From 2017-2020, the author co-led a research team at Virginia Tech consisting of faculty and graduate students to develop and utilize full-scale hardwood CLT (HCLT) for the construction of a 30-foot high, 75-foot long publicly accessible train-viewing tower in Radford, Virginia. Building upon five years of developmental experience by faculty in the Department of Sustainable Biomaterials at Virginia Tech (sources), the faculty-student team in the School of Architecture+Design designed and built the first permanent, permitted building in the United States with a structural hardwood CLT product. The hardwood lumber industry was intimately involved in the process through the donation of lumber, to project-team-advisement relative to thermal and UV concerns, to the public dissemination of research finding.

The project exemplified multiple key limitations to the development and utilization of novel, locally-sourced and bio-based materials in practice. While the project team was able to acquire locally-sourced timber for the HCLT panels, its actual utilization in key structural components needed to be building code compliant - only softwood CLT from certified manufacturers is currently code compliant. Despite lab research illustrating the excellent performance of the product during lab testing - the HCLT even exceeding the performance of softwood CLT on multiple key comparative tests (source) - the HCLT product had not been successfully produced at full scale before in the United States, nor were there methods in place to establish the quality control of production in a non-industrialized facility, of which there were none regionally available. This meant that the team could not prove how the novel building system performed at full-scale under the full impact of environmental conditions, and they also could not demonstrate to code officials that the full-scale panel production would be controlled enough for the panel to behave as lab tests had indicated. These project hurdles are only a small subset of limitations the locally-spruced and produced building material faced, but serve to illustrate the catch-22 of needing a full-scale demonstration project to prove the safety and performance of the new building product, but not being allowed to - or in some cases having the means to - build the full-scale pilot test because the new material does not have any prior demonstrated successes in practice.

For the Virginia Tech project team, local code officials were willing to approve the construction of the tower with a non-code-compliant structural material based upon the research data provided by faculty from the Department of Sustainable Biomaterials, namely Dr. Dan Hindman. The lab research results, paired with local trust in Virginia Tech as an reputable institution allowed the project to move forward. The local building code inspector relied upon pre-occupancy structural inspections by licensed, independent engineers to verify structural integrity before final approval. Now that the structure is complete, long-term testing can be conducted on the building material, providing a research path for HCLT made with Appalachian hardwoods to reach potential code compliance, and then more widespread use. Without code compliance, the material cannot reach a scale of carbon impact that would make a meaningful difference, and at worst, if a failure were to occur, the non-code compliant material may be seen in a negative light by the general public, thus hurting its future potential for impact, as well as the impact of other related material products and systems. In the case of the New River Train Observation Tower, the project was conducted successfully, completing construction in Spring 2020, and the full-scale demonstration of the locally-sourced and locally-upcycled building product/system can serve as an case study for other related projects/products.

ENDNOTES

1. Kiel Moe, *Empire, State & Building* (Actar, 2017).
2. AHEC. 2019. https://www.ahec.org/sites/default/files/statistic_report/download/AHEC%20Jan-June%202019%20Hardwood%20Export%20Report.pdf
3. Milad Mohamadzadeh and Daniel Hindman], "Mechanical Performance of Yellow-Poplar Cross Laminated Timber," Virginia Tech Report No. CE/VPI-ST-15-13 (December, 2015).