Collaborative Materiality:

A New Outdoor Lab to Study Iridescent Nanocellulose

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Abstract

Design of structures at the nanoscale can render new materialities and experiences at the architectural scale. In particular, structural color—the interference and scattering of light due to the geometric organization of tiny surfaces to render dynamic and iridescent color, a property exhibited by many birds, insects, and plants—can be manufactured by tailoring wood pulp and other cellulosic resources. Cellulose nanocrystals (CNCs) are a biogenic source material with potential biodegradability and recyclability features that can be cast into a thin film that possesses this optical behavior as well as mechanical and electrical advantages, posing many promising applications in building components. This case study examines the cross-disciplinary design-build and material research process for a novel outdoor teaching lab to study exterior architectural CNC applications.

"Materiality is a rubric that tends to horizontalize the relations between humans, biota, and abiota. It draws human attention sideways, away from an ontologically ranked Great Chain of Being and toward a greater appreciation of the complex entanglements of humans and nonhumans." *Jane Bennett*[1]

NEW MATERIALITY

Architecture has long drawn inspiration from structures observed in the natural world to derive forms, surface patterns, or organizational diagrams at the scale of a building. Intrinsic properties at a smaller scale govern the behavior of materials at a larger scale, and thus materials have always been selected and manipulated to achieve a desired performance or effect in architectural projects. Emerging understanding of structures at the mind-bendingly tiny nanoscale (10-9 (one nanometer is therefore one-billionth of a meter)) further expands the spectrum of material manipulation and reframes the relationship between architects and collaborators in the sciences. The pursuit of aesthetic experience and iterative development fundamental to architectural design can entangle with lab-based research work.

There are many potential uses for nano-structured materials in buildings; current deployments include performance additives for concrete and exterior coatings to promote insulative or self-cleaning properties. Simultaneously, a wide range of innovations in wood products are rapidly being adopted in architecture from the scale of building structure with mass timber technology to the scale of material fibers with acetylated wood, for example. Structural color—the interference and scattering of light due to the geometric organization of tiny surfaces to render dynamic and iridescent color, a property exhibited by many birds, insects, and plants (Fig. 1)—can be manufactured by tailoring wood pulp and

Fig. 1. Examples of structural color: bird feather, beetle shell, fish scales, CNC material sample

other cellulosic resources. The Structural Colour Studio at Aalto University has tested such a colorant at the scale of architecture and furniture with their Shimmering Wood Collection[2], while designers and researchers at Chalmers University of Technology in Sweden and the Wallenberg Wood Science Center have experimented with 3D printing nanocellulose hydrogel with the addition of alginate[3]. All the possibilities and properties of structural color derived from nanocellulose are not yet known.

This paper focuses on a cross-disciplinary design-build and material research case study that created an outdoor teaching lab to study exterior architectural nanocellulose applications. In this project for Biltmore Hall at NC State University, architecture students worked in the machine shop, on site, and across disciplines in the material science lab with researchers to pursue new materiality.

BILTMORE HALL: DESIGN-BUILD CASE STUDY

This project began as a request from the University Facilities Team to brainstorm ideas to improve an uninviting and underused courtyard at the heart of the College of Natural Resources. The design team of architecture students, led by the co-authors, worked with University Facilities, the University Architect's Office, and the College Administrative Council to iteratively develop the project criteria and designs, direct material research, create prototypes, develop a project budget, seek funding, manage subcontractors, and ultimately fabricate and install the project. The project offered immersive, applied learning opportunities usually absent in our typical architectural curriculum including material research and development and design-build exposure.

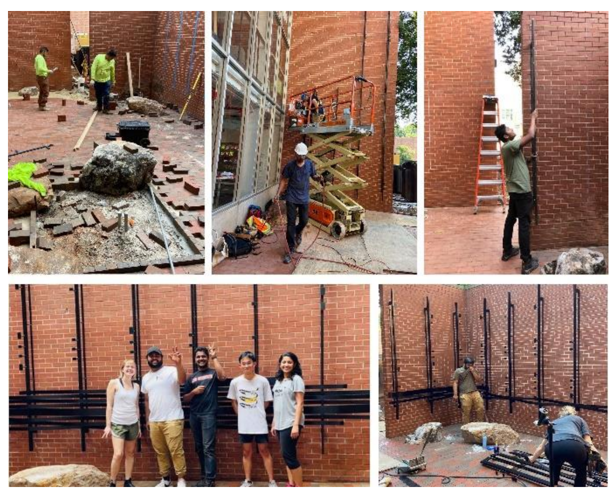

Fig. 2. Students leading the design-build process


Fig. 3 and Fig. 4. Biltmore Hall Courtyard: renderings for outdoor lab to study exterior applications of iridescent nanocellulose

During initial design iterations, students collected information about the wide range of faculty-led research taking place within the College of Natural Resources, during which time they learned about work within the Pulp and Paper Science Laboratories testing temporary surface applications of CNC to produce iridescent coatings on fabric. Naively, the students asked, *"Could we use that material outside to capture the changing sunlight?*" which prompted months of cross disciplinary exploration into novel ways to encapsulate CNC and extend its resilience towards UV and moisture.

The resulting design that emerged from this collaboration was conceived of as part liminal shade garden and part research lab. The revived courtyard centers around an arching native dogwood tree surrounded by sitting boulders, all embraced by a woven network of black anodized aluminum ribbons (Fig. 3 and 4). This woven network is mounted to the existing masonry walls to become the armature for the ongoing material research on cast nanocellulose membranes—a novel techno-bark of sorts. The design team eventually arrived at a flexible clip system that allows researchers to evaluate and swap out samples over time, thereby creating a living, ever changing lab display. This wall serves both as a captivating art installation, featuring the CNC's brilliant iridescence and providing a visually dynamic rhythm which engages users moving through the space, and a material testing site where myriad CNC mixtures and diverse encapsulation techniques are subjected to variable exterior conditions (temperature, humidity, precipitation, wind, direct and indirect solar exposure, etc.) to gather initial data on CNC viability in architectural applications.

What is CNC?

Cellulose nanocrystals (CNCs) are nanosized, rod-like crystalline particles derived from natural cellulose sources by a controlled chemical process (Fig. 6). They are characterized by an aspect ratio (length/diameter) >5, with lengths up to a few micrometers (e.g., in the case of tunicates) and widths between 3-10 nm (Fig. 5).[4] The use of concentrated (64 wt%) sulfuric acid for CNC production is a common procedure that has successfully been scaled up over the past ten years for large-scale production of aqueous suspensions of CNCs (at 3-6 wt%)[5]. Under continuous stirring, mild temperatures (around 60-65 C), and for durations spanning from 45 min to 2-3 hours depending on the selected biomass, an aqueous suspension of CNCs can be produced: the acid aims to dissolve the amorphous region of cellulose - the

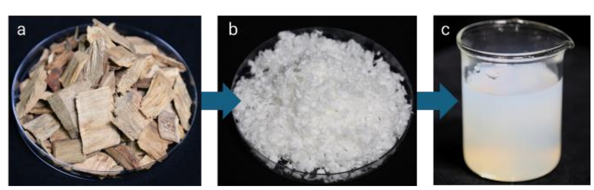

Fig. 5. From wood chips (a) to pulp (b) to cellulose nanocrystal suspensions (c)

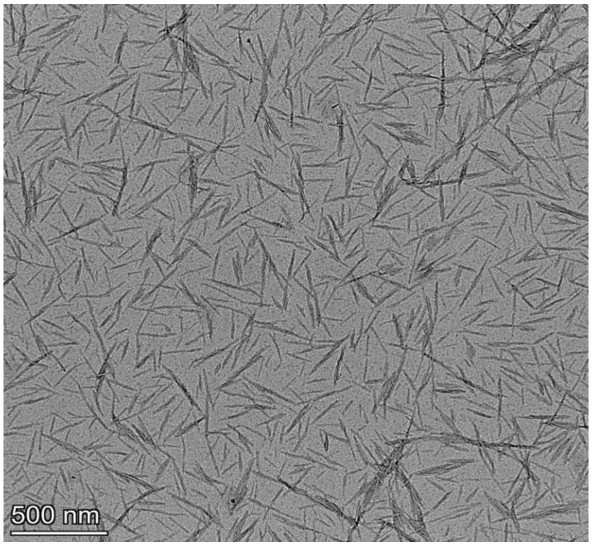

Fig. 6. Transmission Electron Microscopy (TEM) image of cellulose nanocrystals extracted from microcrystalline cellulose (28500x)

main constituent of CNCs - leaving intact its crystalline regions. Fine-tuned control of this hydrolysis step is crucial to meticulously remove the amorphous cellulose, without damaging or disintegrating into sugars the crystalline cellulose regions[6]. The hydrolysis is quenched with cold water to stop the reaction. The suspension of hydrolyzed biomass is then washed several times to remove the excess of acid and redisperse in water. Through application of sulfuric acid, the surface chemistry of cellulose is slightly changed, endowing the CNCs with a high colloidal stability: meaning the particles can be safely dispersed in water without aggregating. Both the surface chemistry and the nanoscale dimensions of CNCs have an impact on their ability to self-assemble in water and in turn, produce visible iridescent colors.

CNCs present many advantages for a diversity of applications, as they combine the benefits of synthetic nanotechnology to sustainability features, such as biodegradability and biocompatibility. Their high crystallinity, high surface area-to-volume ratio and nanoscale dimensions make them as strong as Kevlar, highly versatile for enhanced compatibility with a diversity of polymeric matrices and functionalization for advanced materials development. CNCs for instance have demonstrated their potential as mechanical reinforcement of polymers and their ability in reducing microcracks in cement. The optical properties of CNCs make them unique renewable particles. Unlike other renewable nanomaterials, CNCs can self-assemble in water to form ordered helical structures similar to that of DNA, which can be preserved upon drying to generate visible iridescent colors[7]. Challenges yet remain as to controlling and fine-tuning the generated colors to meet end-users' demands. Additionally, CNCs remain water-loving particles and their direct use in applications/products that require water and moisture resistance as well as water-repellency can be challenging.

Material Research & Development

Thin films of cellulose nanocrystals can simply be obtained by casting the aqueous suspensions of CNCs in a Petri dish and allowing them to dry in ambient or controlled conditions (e.g., using oven drying). In this project the filmmaking process was scaled up using larger, deeper molds like baking dishes to enable the production of larger sheets of CNCs. An aqueous suspension of CNCs, as produced from the sulfuric acid hydrolysis process, will result in blue iridescent colors. Different colors can however be obtained by changing the colloidal stability and the interaction of the CNCs in water. In this work, we combined CNCs with another water-soluble polymer, polyethylene glycol (PEG), in different solid weight ratios (from 10 to 50 wt%). Addition of PEG to the CNC suspensions not only resulted in different colorations but also endowed the large sheets with flexibility for further processing.

Architecture students collaborated with the co-author's lab in the Department of Forest Biomaterials to create a diversity of CNC-PEG sheets with different iridescent colors (fig. 8).

Fig. 7. Architecture student testing CNC suspensions

Fig. 8. Examples of iridescent colors obtained by combining CNCs and additives such as PEG.

Because of the water-loving nature of CNCs and PEG, additional strategies to make the composite films water- and weather-resistant were crucial prior to their applications outdoors on the woven metallic network, and in general, for their use in exposed conditions. A form of encapsulation was desired that was clear, low-gloss (non-reflective), UV-stabilized (due to extended solar exposure), waterproof (preventing any moisture from wicking in from the edges and faces), and could be implemented easily through heat-lamination at low temperatures or pressure-activation. Furthermore, to attach the composite films to the aluminum ribbons substrate, the encapsulation system had to also work as or be compatible with other adhesives. Solar encapsulant films, heat-set laminating films, polyester and polyethylene pouches with pressure-sensitive acrylic adhesive, and liquid coatings including a non-toxic water-based lacquer substitute were all attempted.

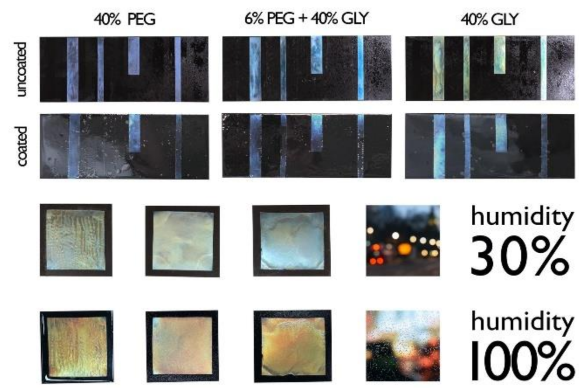

Fig. 9. CNC material and encapsulation test in variable humidity

Ultimately it proved most feasible to separate the encapsulation strategy from the connection strategy to the aluminum. The team determined that a combination of thermal and pressure lamination using a clear, low gloss, 5 ml, UV stable plastic manufactured by Jackson Hirsh Laminating worked best using a thermal hydraulic press where the CNC sample was placed between two 5 ml sheets of laminating plastic and then placed between high temperature silicone sheets to squeeze out all air bubbles. Students then derived a custom bent-wire clip system that held the laminated samples to the aluminum ribbons and promoted the desired flexibility to move and swap out composite film samples over time, thus feeding into the goal of using the installation as a research lab of sorts.

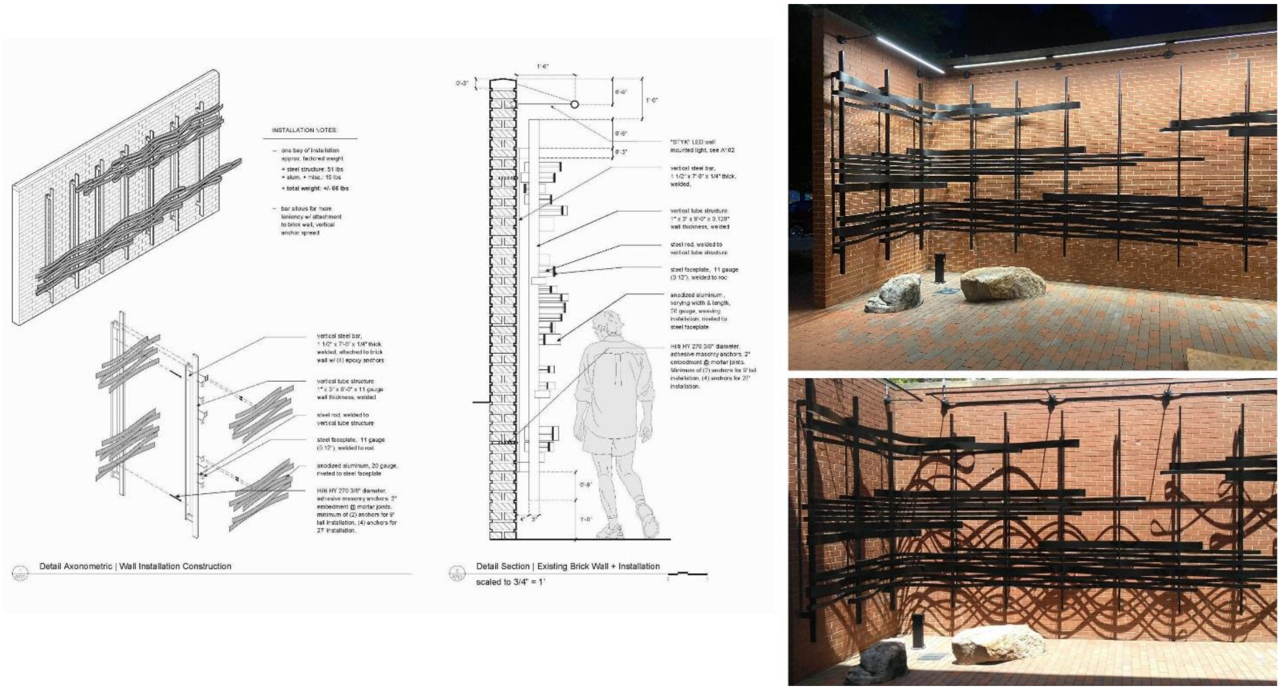

Fig. 10. Woven wall construction details

CNC Material Opportunities for Future Research

Beyond dazzling visual effects, cellulose nanocrystals offer insulative and reflectivity values that suggest it could be useful as an interlayer in glass assemblies or as a coating or coloration in lieu of paints, dyes or other toxic substances. CNC films are highly versatile materials: in addition to providing thermal insulation and selected reflectivity, they can be designed with different haze and transparency, and they can be functionalized to enable smart applications and incorporation, for instance, of electronic components.

CNCs have already demonstrated their potential as mechanical reinforcement of composite materials[8], as biocompatible particles for biomedical scaffolds or in wound dressings[9], as Pickering stabilizer of emulsions[10] in cosmetics, foods or paints, as electronic inks for 3D printing[11], among other applications. We have only scratched the surface. Exploitation of CNCs in design and architecture, especially, remains at its infancy. One can imagine incorporating these particles for structural integrity enhancement, soundproofing, insulation, optical performance or biomimicry of nature's colors and functions.

Conclusion

"Today, the structural basis of scientific understanding makes possible the design and invention of new materials rather than their accidental discovery. And while these new materials are ordinarily conceived with a specific application in mind, it may be that their impact upon society will engender unanticipated results. … An excess of purpose menaces us, and that is why the spontaneity of aesthetic inquiry must continue to precede the heavy-footed logic of scientific law and order."
Hilde Hein[12]

Architectural practice increasingly demands cross-disciplinary, collaborative approaches based in research—the Biltmore Hall Courtyard and Outdoor Lab Design-Build Project engaged across programs and university constituents amounting to a complex, practice-like experience for students, instructors, and researchers. It was ambitious to attempt to realize a built project on campus during short spurts of availability—of time, labor, facilities, funding—over multiple semesters, let alone incorporate a novel material research component. Scientific and design pursuits need extended space for implementation, iteration, and observation. Process is paramount to both, but yet, a high-quality, documentable product is also necessary, especially in the case of a permanently installed project such as this. We encountered difficulties in continuity, we were limited by our knowledge and methods—architects are not material scientists—and yet our charge to connect big-picture and detailed thinking into one-off real-world applications can help in part contribute to scientific exploration. Therefore, concerns of material science, such as the biodegradation of material, push us to be more mindful of the performance and ecological balance of our works. The cross-disciplinary, collaborative partnership that this project fostered and will further facilitate is representative of new modes of practice that are research- and open inquiry-based, ecologically focused, and holistic.

Notes:

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