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**Sugarcane cellulose fibers**

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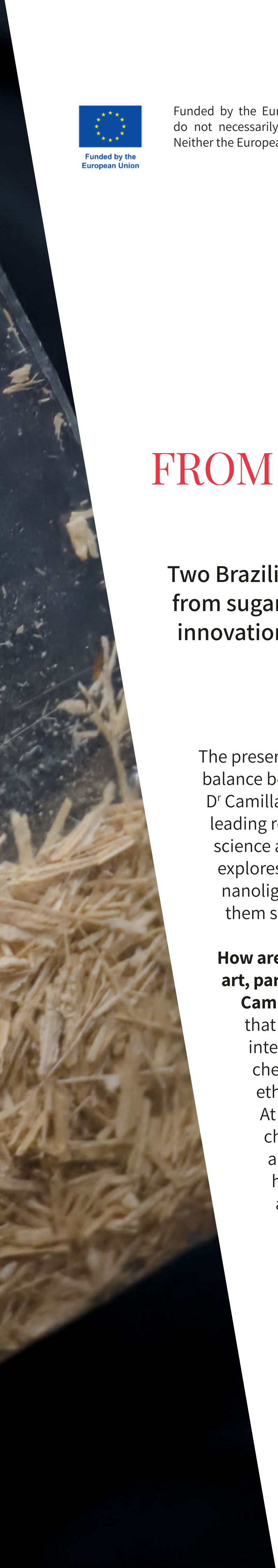

# FROM SUGARCANE TO SAFEGUARDING ART

**Two Brazilian researchers are pioneering the use of nanocellulose and nanolignin from sugarcane to revolutionise heritage conservation, combining scientific innovation, sustainability and respect for cultural treasures.**

The preservation of cultural heritage demands a delicate balance between scientific precision and artistic sensitivity. Dr Camilla Camargos and Professor Camila Rezende are two leading researchers whose work bridges chemistry, materials science and cultural heritage preservation. Their collaboration explores how green technologies, such as nanocellulose and nanolignin, can transform conservation practices, making them safer, more sustainable and more inclusive.

**How are you related to the intersection between science and art, particularly in the conservation of cultural heritage?**

**Camilla Camargos**: Our work is rooted in understanding that cultural heritage's conservation is a highly interdisciplinary field. It draws on knowledge from chemistry, materials science, art, history, microbiology, ethics, restoration theory and conservation practice. At this intersection, we explore how science and green chemistry can contribute to the development of safer and more sustainable methods. This convergence has shaped my academic and professional journey, as I come from a background in both Conservation and Chemistry. I earned a bachelor's degree in Conservation and Restoration of Movable Cultural Heritage and a Master's in Chemistry at the Universidade Federal de Minas Gerais (UFMG). Under the supervision of Prof. Camila Rezende, I completed my PHD at the Institute of Chemistry of the Universidade Estadual de Campinas (UNICAMP), where I worked on nanocellulose and nanolignin coatings for paper, wood and textiles. Since 2023, I have coordinated research and teaching at UFMG and founded the research group NANOCOR (Nanotechnologies and Advanced Materials for the Conservation and Restoration of Cultural Heritage). In close collaboration with Prof. Rezende's research group at UNICAMP, we have been actively involved in developing novel green conservation materials within the framework of the GREENART project.

**Camila Rezende**: My background is in Chemistry, Physical Chemistry and Materials Chemistry, but I have always been fascinated by art-dance, music and visual arts. Being able to apply my classical chemistry background to the field of conservation and restoration is both a privilege and a great source of motivation. I studied at UNICAMP and worked with polymer nanocomposites, coatings, surface characterisation and wetting/dewetting phenomena during my graduate and postdoctoral years. Since 2012, I have coordinated the Laboratory of Chemistry and Biomass Morphology (LaQuiMoBio) at UNICAMP. This laboratory specialises in extracting plant-based components, including cellulose and lignin, for use in films,

*— Nahir Fuente*

cosmetics, gels and aerogels. In 2017, I was introduced to conservation and restoration by Camilla Camargos, who joined my research group to conduct her PHD project. Since then, we have been working together in a complementary way.

**What does "eco-friendly conservation" mean to you?**

**C.R.**: It focuses on preserving cultural heritage while minimising the environmental impact of conservation and restoration practices. It is a comprehensive approach that includes using natural-sourced and more sustainable materials throughout the various steps of the restoration process, reducing the use of harmful chemicals and solvents, conserving energy, minimising waste, ensuring proper disposal of materials and adopting practices to protect the artwork, the environment and conservators.

**How does your background in chemistry influence your approaches to preserving and restoring art?**

**C.C.**: Chemistry allows me to approach conservation challenges at both phenomenological and molecular levels. On one hand, it helps me interpret visible deterioration phenomena, such as discolouration, embrittlement, or surface alterations, and relate them to underlying chemical and physical processes. On the other hand, it enables me to investigate the molecular mechanisms that drive degradation and to understand the interactions between historical substrates and conservation materials. This dual perspective is essential for evaluating risks, designing preventive strategies and developing treatments that are effective and removable if necessary. Chemistry also guides the selection and modification of materials, supporting responsible solutions that respond to the specific needs of cultural heritage. Ultimately, it strengthens my ability to bridge technical conservation practice with evidence-based innovation.

**C.R.**: I enjoy thinking of chemistry as a fascinating science that allows us to understand systems and materials at the molecular level. In the gels, for example, we modify the base polymers, cross-linkers, formulations and preparation methods to achieve the desired performance in terms of cleaning efficiency, flexibility and other properties. These characteristics are achieved by playing with the compounds at the molecular level. The same applies to nanocomposite coating films, where the final macroscopic properties, such as transparency or UV protection, are controlled at the molecular or nanometric scale. This bottom-up approach is particularly helpful in designing materials that meet the specific needs of the application.

**Your workshop at GREENART [see p.104] involves nanocellulose and nanolignin coatings as well as hydrogels. How do these green materials compare to traditional conservation techniques?**

**C.C.**: While not all traditional conservation techniques necessarily result in high environmental impact, certain materials raise concerns regarding toxicity and sustainability, such as synthetic copolymer-based coatings. That said, some conventional coatings, especially many cleaning gels already in use, are relatively low-impact. However, thinking about sustainability today requires a broader perspective — one that goes beyond environmental concerns to include economic and social dimensions as well. We focus on developing materials derived from abundant agro-industrial residues, such as sugarcane bagasse in Brazil, to produce nanocellulose and nanolignin, which are then applied in cleaning hydrogels and protective coatings. These green nanomaterials not only present a reduced environmental impact, as they are mainly biodegradable and non-persistent, posing minor health risks for conservators, but they also have the potential to be more accessible in Brazil and across South America. We aim to contribute to a more inclusive and locally viable model of sustainable conservation.

**What are the challenges you have faced in cellulosic substrates in books and artworks?**

**C.C.**: One of the challenges lies in developing conservation solutions that are effective and respectful of the material, historical and structural characteristics of cellulosic substrates. Books and paper-based artefacts often present complex layers of meaning and construction, including inks, adhesives, bindings and supports, that require careful, case-by-case assessment before any intervention. Particularly challenging scenarios include works of art on heavily degraded wood-pulp paper, documents on vegetal parchment and collections affected by environmental disasters such as flooding. Insect-damaged graphic documents present another recurring and delicate challenge. In 1943, Monsenhor Joaquim Nabuco published a book titled *Bibliófilos versus bibliófagos* (*Bibliophiles versus book-worms*), a landmark work in which he denounced the widespread damage caused by insect activity in Brazilian collections. Nearly a century later, this concern remains highly relevant and pressing, as many of these objects are too fragile to undergo mechanical or large-scale interventions without risking further loss. In 2023, for example, I supervised an undergraduate thesis focused on the conservation of a 19$^{th}$-century wood-pulp book


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that had belonged to a historically significant figure in the city of Pelotas, Brazil. The book exhibited numerous small lacunae (paper losses) resulting from insect attack. Manual reintegration using nanocellulose enabled precise filling with minimal interference to the original substrate and bookbinding. While projects like this highlight the need for adaptable, low-impact and material-compatible methods, I maintain a deep appreciation and respect for traditional conservation techniques, which I continuously study, apply and pass on to my students. These methods remain essential in practice and form the foundation upon which new materials and approaches must be evaluated and integrated.

**How do composites and natural nanoparticles help reduce the chemical footprint in the art world?**

**C.R.**: Natural polymers, like cellulose, lignin and their nanoparticles, have been investigated due to their compelling properties and the potential to reduce the chemical footprint of traditional methods. To begin with, both cellulose and lignin are bio-sourced feedstocks, which already minimises the environmental impact of using fossil-fuel-based polymers and particles. Furthermore, extracting these components from agro-industrial waste, such as sugarcane, is an approach that not only reduces the amount of accumulated waste at processing plants but also adds value and gives this waste a more noble purpose. We also pay special attention to the processes for extracting cellulose nanoparticles (nanocrystals and nanofibrils) and preparing lignin nanoparticles, seeking to use milder reagents at low concentrations and aiming for routes that minimise energy consumption and waste generation. Another interesting aspect of cellulose and lignin nanoparticles is that they are dispersible in water. While macromolecules of cellulose and lignin are not water-soluble, their nanoparticles possess a negative surface charge, which allows these particles to remain stable in aqueous dispersions, significantly contributing to low toxicity. Both components are non-toxic and biodegradable, which is especially important in the case of cleaning gels. Another key point is that cellulose nanocrystals and nanofibrils naturally form gels depending on their concentration in the dispersion. Although these are soft gels that require crosslinkers to become suitable for cleaning applications, their predisposition to gelation facilitates the entire preparation process. The nanoparticles are also compatible with other natural polymers such as alginate, gelatin and gluten, allowing for fine-tuned modulation of the properties needed for cleaning gels. Finally, lignin is a multifunctional compound with antimicrobial, antioxidant and UV-absorbing properties, which is highly beneficial, for example, in film preparation. One single component can provide the functionality of several ingredients in a formulation, minimising the total number of components required. The protective films developed, for instance, contained only three elements: nanolignin, cellulose nanocrystals, and cellulose nanofibrils. Considering all the beneficial properties, natural polymers and their nanoparticles are promising for applications in the art world.

**How feasible is it to implement these eco-solutions in museums and archives globally?**

**C.R.**: We are not yet at a stage of large-scale implementation in museums and archives worldwide. Many of the eco-friendly materials we work with are still under development and several aspects must advance before broad adoption becomes feasible, including production processes, testing protocols and long-term performance evaluations. That said, we are actively working toward scalability. Currently, we can produce nanocellulose at pilot scale using an ultrafine friction grinder, which allows us to generate sufficient quantities for experimentation and pre-application studies. Coatings based on nanocellulose and nanolignin are the most promising candidates for short-term scalability, as they are easier to produce, apply and integrate into existing workflows. Gels, on the other hand, remain more challenging. Currently, we can produce cleaning hydrogels in sheets approximately 10 × 10 cm in size, which takes up to 48 hours to be ready for use. Scaling up gel production is one of our current priorities and we are working to optimise formulations to make this possible.

**What role do eco-friendly technologies play in the future of art conservation?**

**C.C.**: They are fundamental in shaping the future of art conservation, not only from an environmental perspective, but also through the broader lens of sustainability, including social and economic dimensions. These technologies aim to reduce the use of highly toxic solvents, non-renewable materials and waste-generating processes, thus minimising harm to both conservation professionals and the ecosystems around them. Economically, they represent an opportunity to develop more accessible solutions, especially in regions where high-cost imported products are not viable. By working with renewable raw materials, such as lignocellulosic agro-industrial residues, we can create locally sourced alternatives that reduce dependence on international supply chains and better align with the financial realities of many institutions in South America and Africa. Socially, sustainable innovation in conservation promotes inclusion by creating knowledge and tools that are adaptable to diverse contexts and available to a broader range of professionals and communities. It also reinforces ethical commitments to future generations by ensuring that our interventions are responsible, considered and attuned to long-term impact. Eco-friendly technologies are not just alternatives; they are part of a necessary transformation of conservation practice, grounded in innovation, responsibility and regional protagonism.

**How do you balance the scientific rigour with the artistic sensitivity required when working with cultural artefacts?**

**C.C.**: Conservation and restoration are, by definition, a transdisciplinary field. It draws from the humanities, social and natural sciences, and arts. Scientific rigour is essential to understanding the materials, mechanisms of deterioration and effectiveness of interventions. At the same time, artistic sensitivity is crucial to respecting the formal, symbolic and cultural values embedded in each cultural object. Rather than seeing scientific contribution and artistic interpretation as opposing forces, I approach them as complementary ways of knowledge. Understanding the historical context of an artefact, its original techniques and its meaning to different communities is as important as identifying the molecular aspects involved in its degradation and the material interactions related to its conservation. In practice, balancing both dimensions often means listening closely to the object. In my teaching and research, I emphasise that sensitivity and precision are not mutually exclusive. Meaningful conservation approaches require a deep engagement across disciplinary frontiers.

**Camila Rezende and Camilla Camargos**

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