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## The CNRS/MC Notre-Dame scientific worksite: an extraordinary interdisciplinary adventure



Historical monuments, and particularly the great religious monuments of the Middle Ages, have been the subject of scientific study for several decades. From art history to archaeology engineering, their material and immaterial realities, including digital approaches, have been studied from a variety of angles by teams of researchers from different institutions across Europe. The tackled issues are highly varied: architectural, building site supplies, craftsmen's technical gestures, decorative programs, conservation, this latter including various approaches as seismic risk, acoustics, aesthetics, ethnologic, digitization, etc. Research programs funded by calls for projects existed through various European research support organizations. A large number of articles have been published on this research, notably in *Journal of Cultural Heritage*.

But with the fire at Notre-Dame de Paris on April 15, 2019, and above all the formidable restoration work that quickly followed the tragedy, it is, to our knowledge, the first time in the world that so many scientific forces, so many different and complementary disciplines, have come together to study an heritage monument, and this, largely financed by two institutions such as the CNRS on the one hand and the French Ministry of Culture on the other. This institutional impetus for public research is part of the emotion that gripped France and the whole world following the threatened loss of an emblematic world heritage monument. An heritage emotion that has also been the subject of study in recent years. The result is a scientific project which, since 2019, has brought together more than a hundred researchers and research support staff from various French and international research institutions (CNRS, Ministry of Culture, Universities, CEA, etc.). Within this framework, 12 PhDs have been financed and developed around the various aspects of Notre-Dame research. The strength of this scientific project lies in its holistic aspect, expressed through the nine working groups that have been set up (wood, stone, glass, metal, structure, monumental decor, acoustics, digital data, emotion and mobilization). These groups do not work in parallel and separately. They are constantly exchanging ideas, through regular working meetings and events such as the Marseille workshop on March 28 and 29, 2022. The scientific project also works in close interaction with other entities of the French Ministry of Culture (Direction Régionale des Affaires Culturelles, Etablissement Public pour la restauration de Notre-Dame de Paris, Architectes en chef des Monuments Historiques) and of France (INRAP, BRGM,...). In this all-encompassing spirit, the project has created a rare dynamic momentum, and is helping to maintain it. This momentum has also benefited from the benevolent welcome of both the Architects

and the Etablissement Public pour la restauration de Notre-Dame de Paris, who have opened the doors of an exceptional worksite to scientists, enabling this safeguarding of knowledge about a monument paradoxically little studied in view of its place in the history of construction and in world heritage. Since its creation, the EPND had been run by General Jean-Louis Georgelin, who sadly passed away accidentally at the end of August 2023. His Contribution at the beginning of this special issue bears witness to his commitment to this monument, for which we are eternally grateful. As part of this project, Notre-Dame de Paris made it possible to benefit from the methodologies put in place during the community's previous research, but also to develop new ones (for digitization, for example), which we will be presented throughout this special issue.

This special issue of the *Journal of Cultural Heritage* reflects both the interdisciplinary dynamic and the work of the working groups. It begins with a paper by **Zimmer et al.** [1] dealing with the crucial issues of safeguarding the remains from the very first days after the fire. Thousands of remains not only had to be saved, but also inventoried and stored, so that they could and will be studied in the future. This stage determines the feasibility of many future scientific studies. Next come the respective contributions of the working groups, introduced by each coordinator.

Diving into the foundational elements, the **Wood Working Group** undertakes an expedition into the cathedral's age-old timberwork, with **Dufraisse A.** [2] initiating the discourse. They illuminate the historical significance and environmental narratives of Notre-Dame's timber. **Clara Penagos et al.** [3] combine archaeological and historical data to identify and date the timbers of Notre-Dame's "forest." The piece by **Thibaut et al.** [4] highlights the challenges and advantages of using oak beams in medieval constructions. Lastly, **Daux et al.** [5] provide insights into the medieval climate through wood analysis and its influence on the cathedral's construction and preservation.

Parallel to this exploration, the **Stone and Mortar Working Group** brings to light the enduring materials that form the bedrock of Notre-Dame's majestic stature. **Gallet Y.'s** [6] foundational insights merge seamlessly with Gothic vault-building techniques. **Moulis et al.** [7] offer insights into the cathedral's construction through an archaeological analysis of the collapsed arch's voussoirs focusing on its original construction techniques. **Mechling et al.** [8] focus on the mortars, detailing their physicochemical properties. Lastly, **Baillieul et al.** [9] provide a deeper understanding of Gothic vault-building techniques.

Building upon these elements, the **Metal Working Group** casts light on the intricate nuances of metals embedded within the cathedral's architectural tapestry. Spearheaded by **L'Héritier M. [10]**, the journey spans the roles of iron and lead. Further spotlighting the iron elements, **L'Héritier et al. [11]** detail the methodological challenges and discoveries concerning the cathedral's iron framework. **Syvilay et al. [12]** transition the focus towards the role of lead, exploring its historical casting, joining, and recycling practices spanning centuries. Concluding the metal exploration, **Briard et al. [13]** raise awareness regarding lead pollution in historical landmarks, drawing enlightening comparisons between Notre-Dame de Paris and Sainte-Chapelle.

This material narrative is complemented by the **Stained Glass Working Group**, which delves into the Notre-Dame's windows. With **Loisel C. [14]** guiding the way, the narrative spotlights scientific challenges and methodological approaches. **Boulanger et al. [15]** discuss the complexities faced after calamities, sharing insights into the methodologies developed in response to disasters. **Pillet et al. [16]** concentrate on the challenges of studying and restoring the stained glass of a historically listed, damaged building like Notre-Dame, offering solutions to monumental restoration.

Moving from material essence to the behavior of the edifice, the **Structures Working Group** examines Notre-Dame's post-fire architectural integrity. Under **Morel S.'s [17]** expert eye, the discourse melds tradition with innovation, painting a picture of the cathedral's rebirth. **Parent et al. [18]** present a comprehensive structural analysis of the cathedral's vaults, by merging complementary approaches. Lastly, **Guibaud et al. [19]** use Notre-Dame as a crucial case study, aiming to enhance fire safety models in historic buildings.

This structural exploration finds its acoustic counterpart in the insights of the **Acoustics Working Group**. Led by **Pardoen M. [20]**, the group embarks on a sonic journey through the epochs, studying the sound environment of the cathedral's construction site. **Canfield-Dafilou et al. [21]** transport readers to a time when the voices of choirboys resonated within Notre-Dame's walls, focusing on the Late Middle Ages and the Modern Period. Lastly, **De Muynke et al. [22]** embark on a journey to recapture the cathedral's acoustic memories before the fire of 2019, providing a sonic perspective on its history.

Amidst the tangible and intangible, the profound emotional heartbeats resonating from Notre-Dame are charted by the **Heritage Emotions Working Group**. **Voisenat C. [23]** ventures deep into the emotional, societal, and cultural connections binding humanity to the cathedral. In the following discourse, **Monferran et al. [24]** navigate the sacred territory between the tangible architectural marvel and the intangible sanctity of Notre-Dame. **Sagnes S. [25]** then explores the experience of the cathedral from various lenses – mediators, users, and narratives – painting a vivid picture of the interactions and stories that have been interwoven within its walls. Concluding this introspective journey, **Isnard C. [26]** presents a broader social perspective on heritage catastrophes, juxtaposing the mourning phase with the hope-filled path towards reconstruction and envisioning the future.

Completing this kaleidoscopic journey, the **Digital Data Working Group**, steered by **De Luca L. [27]**, weaves the threads of history with digital innovation, ensuring that the multidisciplinary endeavour on Notre-Dame remains vividly accessible and enduringly safeguarded. Venturing further into technological advances, **Néroulidis et al. [28]** introduce a digital platform designed for the collaborative work and the integration of diverse scientific data related to Notre-Dame. **Mouaddib et al. [29]** present dedicated techniques in 2D/3D data fusion designed for the comparative analysis of Notre-Dame's vaults pre- and post-fire. Finally, **Jacquot et al. [30]** tackle the vast challenge of collecting, assimilating, and inter-

preting a broad range of data for the virtual reconstruction of the cathedral's "forest".

Together, these diverse explorations, spanning from material foundations to digital realms and from sonic imprints to emotional landscapes, collectively champion the undying legacy of Notre-Dame de Paris as common denominator of dozen of disciplinary fields belonging to heritage science. They constitute an exceptional reservoir of knowledge that can be mobilized for future research and restoration projects.

This special issue takes a programmatic look at all these aspects, providing a good overview of the challenges and initial results of the CNRS/MC scientific project.

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