Main Story:

Scientists at the bedside of Notre Dame

By Nathaniel Herzberg

Since the fire, in an effort to understand the scope of the damage and the possible ways to restore the cathedral, a vast scientific operation is underway in the rubble of Notre-Dame. The debris also offers a wealth of insight into over eight centuries of the architectural history of the edifice and the surrounding city. A visit to an extraordinary site.

On Tuesday, July 2, a large group of visitors walks through the charred aisles of Notre-Dame. Bishop Patrick Chauvet, the rector of the cathedral, and Philippe Villeneuve, chief architect for Historical Monuments in charge of the cathedral, introduce the convalescent old dame to the billionaire François Pinault. The businessman and his cohorts have been exempted from wearing the obligatory airtight bodysuits and the masks protecting them against lead contamination. Nor do they have to soak their shoes in the disinfecting foot bath. A donation of 100 million euros is well worth a little preferential treatment.

The real event on this day, however, is taking place elsewhere. The dozens of employees who are constantly working on the site have their heads turned upwards. Crane operators and rope technicians are installing the first of 23 wooden scaffolds designed to support the flying buttresses of the cathedral. After extinguishing the fire, this is the second essential step towards rescuing Notre-Dame de Paris, ravaged by flames on April 15.

The images made their way across the world: the first plumes of smoke; the uncontrollable fire devouring the cathedral; the collapsing spire; the tireless firemen battling the flames, all under the eyes of the unbelieving then shocked Parisian onlookers. Two and a half months after the disaster, the firefighters have left the site which is now out of bounds behind fences topped with barbed wire. Tourists watch from a distance, surprised by the apparent good health of the venerable old lady. Little do they know that her equilibrium is still precarious.

"Ah! I'm going to faint," exclaims Philippe Villeneuve, who having finished his social duties, is now observing the manoeuvres underway. About 40 meters above ground an 8-ton wooden frame suspended from a crane threatens to bump into the pinnacle. But then it passes through, descends along the arches, and comes to rest under the flying buttress. "When this phase is completed in a few days, we can all breathe a little easier," says Pascal Prunet, one of three chief architects who have come to lend a helping hand to their colleague at this crucial moment.

Prunet was specifically asked to collaborate with the researchers dispatched to the church. It's a full-time job, considering the scientific challenge of this extraordinary construction site. From the first night onwards, art-historians, archaeologists, and curators have assisted the firefighters trying to save as much of the cathedral as possible. But it was on the next day, once the real extent of the damage was discovered, that the work really started. "I was relieved, everything was still there. But we had to act quickly," says Marie-Helene Didier, regional curator at the department of Historical Monuments, and the person in charge of Notre-Dame's art work and furniture.

The specialists understood that with the collapse of the frame and a part of the vault of the cathedral, the structure had lost its legendary stability against heat and humidity. **"**We went from 50% to 90% of humidity in the following days,**"** remarks Didier, **"**and during the heat wave, the temperature reached 39˚C (102°F) on the ground and 52˚ C (125°F) under the vault.**"**

All the paintings have been removed. Only the three very large ones remain, including the famous Visitation (1716) by Jean Jouvenet. **"**It would be impossible to transport them across the nave », Didier explains. Instead, scientists from the research laboratory for historical monuments (LRMH) have equipped the paintings with temperature and humidity sensors. **"**And here I am, watching the data bouncing like a yo-yo », she says.

"Usually, researchers at the LRMH respond to specific requests,**"** says architect Pascal Prunet. **"**Here, the demand is global. All of their specialists are contributing simultaneously.**"** Stone, wood, stained glass, paint, metal: 20 of the 23 specialists working in this laboratory located in Champs-sur-Marne on the outskirts of Paris take turns working on the site. **"**It's exhilarating and exhausting at the same time,**"** comments Thierry Zimmer, Deputy Director of the team. **"**We were not given additional staff, and all of our other projects are virtually at a standstill. »

The geologists Véronique Vergès-Belmin and Lise Leroux are classifying the stones that robots extracted a few days ago from the pile of rubble under the crossing of the transept. Whole arrays of vault materials are lined up on the shelves: all sizes, all forms, very damaged or still intact. **"**First, we have to try and conserve a maximum amount of elements tracing the building's construction,**"** explains Véronique Vergès-Belmin through the anti-pollution face mask, which she never takes off. **"**If we lose this information, we will not be able to find it again. The position of each object on the ground has been documented. But these stones also bear witness to the behavior of the fire. It's our second mission to extract this knowledge. The architects would like to reuse as many of the original parts as possible for the restoration process. Does their condition allow this? That is our third role: to precisely characterize this material.**"**

Appearance of Fungi

Underneath a large tent, twenty blocks wait to be transported to the laboratory. There is for example a stone smashed into two parts, which will be studied for the possibility of repair. Another one, scorched by the fire, will need to have its strength measured. One block is completely covered with lead and will be used to test the process of decontamination. Further on lies an element of the ridge, with its mortar still attached.

"The research carried out in the laboratory will help us to test the porosity and mechanical strength of the stones before we advise architects about whether it will be necessary to replace certain parts,**"** says Lise Leroux. **"**There is a principle guiding the compatibility of material, aesthetic and physical. If you place a stone in the middle of others, if it is too hard or too soft, you risk weakening the whole structure.**"** A larger problem involves the tons of water flooded into the building to fight the fire. **"**How long will it take for the stones to dry completely: 5 years, 10 years, or even longer? This is what the scientists will tell us,**"** emphasizes Pascal Prunet.

This forced humidification of the building has also brought microbiology specialists from LRMH to work on the site. With the high temperatures that followed the fire, unwelcome fungus has started to appear, notably behind the small organ. Didier dreads what is happening under the wooden stalls, on each side of the choir. **"**But no one can access these parts,**"** she says regretfully, **"**Except the robots.**"** Both the machines, claws and buckets aloft, have proved perfect for delicately removing the debris. They have recovered 700 pallets of material from the crossing of the transept and should address, before mid-July, the pile of stones and charred beams amassed under the nave. But it is useless to instruct the robots to specifically disassemble the pew seats and platforms and transport them back. **"**I have to wait, it's a bit frustrating,**"** Didier confesses.

She is also rueful about the Saint-Guillaume chapel, in the northern part of the building. **"**I had fully restored the little chapel, and it was inaugurated in November 2018. I did the same for the small altar in February, and the three statues commissioned by Louis XIII, in December. Fortunately, this gives us a starting point to examine lead pollution, compare it to other parts of the church, and see what came from the fire and what was there before.**"** She smiled: **"**I will not have cleaned up for nothing.**"**

Healing the patient, reaching correct diagnosis through a series of tests and experiments, deciding on the most efficient treatment allowing a quick recovery: this is the primary role of the scientists working on the site of the cathedral. For others, however, Notre Dame is above all an exceptional experimental terrain. In May, the Centre national de la recherche scientifique (CNRS) launched an out of the ordinary "scientific project ». Six of its ten institutes were to participate together in a rare initiative for a milieu that generally operates in isolated fields. Two coordinators will supervise the proceedings: the Biomolecular archaeologist, Martine Regert, and a Chemist specializing in ancient materials, Philippe Dillmann.

« In fact, this cathedral had hardly been studied", says the chemist. **"**There are multiple reasons, but it has been particularly difficult to carry out tests while the church was continually open to the public. Now we have a unique chance to explore the cathedral**'**s hidden parts, but also to extract intangible information that was inaccessible before. There is a real sense of urgency here, because this information can disappear very quickly.**"**

Martine Regert adds: **"**We can date a beam to the closest year of its age. Normally, it is necessary to take samples from the frame. In the beginning of the 90s, a team had been allowed to extract about fifty samples which gave interesting, but partial results. Now, everything is on the floor. We will have a unique amount of data, which we will treat statistically.**"**

"Make the debris talk"

The study of wood, stone, glass, metal, sound, or even emotion and digital data: seven working groups have been asked to learn as much as possible from this disaster. For Maxime L'Héritier, Associate professor in History at the University of Paris VIII and coordinator for the **"**metal**"** group, the rivers of lead that flowed from the fire will provide valuable lessons. **"**Thanks to isotopic analyses, we will be able to study the material**'**s sources, but also the recycling that happened over time,**"** says L'Héritier. **"**Where does the 19th century lead come from? This historical knowledge is valuable, but it will also inform our current practices. What is the origin of the lead found in the Seine, in the air, and in our bodies ?**"**

Another curiosity is the iron, which has proved more present than expected in the rubble. Have we underestimated its use by the builders in the 12th and 13th centuries? "We are now able to date Iron. Or rather, the carbon present in traces of the steel contained in the iron. We should be able to make the debris talk," explains L'Héritier.

This data will be collated through a very particular type of 3D cartography, that Livio De Luca, architect, computer scientist, and project manager calls, "a digital double of the cathedral." Many scientific institutions or private companies have worked in recent years on laser or photogram-metrical surveys of the building: Vassar College in the United States, the German University of Bamberg, and the French company, Graphic Art and Heritage, that have previously digitized the cathedral's framework.

"We are in the process of negotiating agreements. At the same time, we are already developing a prototype," says Livio De Luca. " In a series of phases, we will successively design programs, which we will then implement and enrich with one clear objective in sight : the documentation of Notre-Dame in Time and in Space. This strategy is groundbreaking, and we should be able to apply it to other monuments. The main challenge is the extremely diverse nature of the data. »

If there is an enormous amount of information that is visual and textual in nature, there is also the data on sound. Mylène Pardoen is waiting for permission to enter the building so she can conduct the first readings with acoustician Brian Katz. "We have heard a lot about the big organ, which is apparently intact," says the 'archeologist of soundscapes', a term that she has coined for herself.
« But the registers of the organ were designed in keeping with the original acoustics of the cathedral's volume. And this, obviously, has changed. The stained glass windows have disappeared, but this is not the only point. In 2013, Brian Katz had made a series of recordings. We will thus be able to advise the architects restoring the monument. And also, we will be able to go back in time, search all sources available in text or in image regarding urban infrastructure, the presence of animals, the congregations attending the services... All of this will help us create a soundscape of the past. »

Diving into the past to study matter. Or immersing oneself in the present to observe human behavior. This is pretty much the approach adopted by anthropologist Claudie Voisenat from the Interdisciplinary Institute for Contemporary Anthropology, and the 20 researchers from diverse laboratories that she will coordinate. Her specialty? “The emotions related to heritage", she simply says. With a slightly embarrassed smile, she goes on. “It is awful to say so, but for us, the Notre-Dame fire is the terrain of our dreams, an incredible opportunity.” On Thursday, the 4th of July her group, dubbed "Emotion-Mobilization," organized a one-day workshop aimed at the examination of the primary results collected. Be it the sentiment of attachement felt by residents and worshippers, the distress of those who witnessed the disaster, the controversy surrounding the restoration effort, or the feeling of what the anthropologist has chosen to call « Sedition » the whole range of human emotion is represented. When asked about this last term, sedition, Voisenat answers: « Remember the placards brandished by the Yellow Vests ? ‘All for Notre-Dame, nothing for Quasimodo’.[1] This is what we want to study. The role of the unanimous political response in the aftermath of the drama, or the unrivaled immensity of the donations when compared to the fire at the Museum of Rio, for example[2]. There are also the opportunities that have suddenly appeared for a whole range of highly specialized workers, artisans, and scientists.”

A monument thus offers a generation of researchers its scars as well as its wrinkles, to paraphrase Victor Hugo. This is probably the last miracle of “this old queen of our cathedrals.”

Box 1: **Burnt Wood, a window to the past**

Like everyone else, Catherine Lavier was in shock on April the 15th. **“**I was overwhelmed by my emotions,**”** the specialist of heritage woods, from the Research and Restoration Center of the Museums of France (C2RMF), tells us. **“**I did not even think about the cathedral as such, but about the framework, only the framework. And then suddenly, I started thinking like an archaeologist. For us, everything that is destroyed is a gift. It is a sad thing to say, but with this fire, a whole mine of information has opened up for us."

Already, no less than 850 fragments have been labeled and installed on shelves, under the large white tents that now occupy the square in front of Notre-Dame. **“**When I have classed those that are in the big bags there, on the sides, we will have more than 1,000,**”** she evaluated. **“**But this is only what the robots have removed from under the cross of the transept.**”**

The remains of the spire designed by Viollet-le-Duc, the famous wooden parts made from the forest of 1,300 trees -- a legend that Catherine Lavier hopes to verify -- either rest under the nave or still hang suspended from the air. Robots should start to sort through the Mikado-like jumble on the ground by mid-July. The rope technicians will then start their tightrope maneuvers and come back to her with their presents.

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[1] Some ‘yellow-vest” protestors in France believe the money for Notre Dame’s restoration could be better spent elsewhere.

[2] In september 2018.

“I thought that I had done it all, she says. Climbing, digging, diving to go after objects.But to stay put, and wait for something to happen, that’s a first. But everything is exceptional here. Look at the tents, they will soon be full of fragments. I don’t know where we will put all of this. What I do know is that a lot of people will learn a lot of things from this wood.**”**
Lavier goes closer to a fallen beam. The surface is severely burnt and covered in lead particles. But the heart seems intact, which is the case for quite a few other samples. **“**The species of the wood is obvious. It's oak, of course, but there are also these saw marks. From them, we can understand how the wood was cut, how it was assembled. Elsewhere, we can find specific traces of craftsmen’s work, somewhat like a signature. It becomes possible to identify the carpenter, his company, or the carrier. A beam that has been worked upon is like a book. But a book written in Esperanto, in a mix of many different cultures and languages.**”**
This type of information on the work of simple craftsmen is often lost. So now is the last opportunity to study traces of it. It’s also the last chance to collect data regarding the life of the trees involved. The number of rings allows researchers to identify the age of a specimen at the time of its felling. Their width enables scientists to understand the period it was cut down in. These scars left by time are like barcodes. They become precious mines of information when the data collected on them is compared to already existing information. . It becomes possible to identify the region in which the tree was grown, and through the addition of the characteristics of the knots, the nodes and the shape of the trunks, researchers can even evaluate the density of the original forest, and whether it grew in the plains or in the mountains.

But after the flames have been put out, what remains of this information? **“**Almost everything,**”** answers Alexa Dufraisse, an archeo-botanist who specializes in charred wood and coordinator of the **“**Wood**”** group. **“**We know how to evaluate the shrinking of wood because of fire,**”** she explains. **“**We also know the chemical changes that fire causes. We are thus able to provide information about the character of the fire, about what we call the **‘**intensity of carbonisation**’** which stems from a combination of the temperature reached and the duration of the fire. »

Even more impressively, burnt wood stores environmental data, specifically climatic information. The isotopic analyses of oxygen and carbon in the dark circles enables researchers to follow information including the temperature and rainfall of the period concerned, almost as if they were present at the time. The trees of what is called the **‘**forest**’** of Notre-Dame (the framework of the nave and the choir), grew somewhere between the 11th and 13th centuries, during what is called maximum medieval climate. Hot in terms of temperature, and opulent with regard to Society.

« Climate change deniers regularly use this to challenge the scientific consensus,**”** says Dufraisse. « Getting details about summer temperatures at that time or the intensity of draughts could help climatologists to precise what is a warming period without human involvement. » And therefore to better characterize our Anthropocene.

All this from a few charred pieces of wood? Lavier relishes this idea. **“**You will never see stakes or beams in museums, even if they hold together Venice and the arenas of Nimes. We have always been the poor cousin of archaeology. But now, we are the ones who have access to information. It will even influence the choice of the stones which can be reused. I find that pretty satisfying. » The triumphant return of forgotten old wood.

Box 2: **250 researchers to rescue the Cathedral**

Among scientists, spontaneous generation does not have a good reputation. And to be fair, this association was not born out of nothing. It appeared three days after the terrible fire that ravaged the cathedral. However, the speed of its constitution and its development is almost a miracle. The ashes were still warm when three researchers decided to launch Scientists for Notre-Dame. Arnaud Ybert is Associate professor of Art History at the Pierre-Jakez-Hélias University in Brittany. Maxime L'Héritier is an archaeologist and metallographer at Paris VIII University. As for Olivier de Châlus, he works with the Arcadis design office, which employs him as a construction engineer. Even before the fire, he has been on a sabbatical to write a thesis on the history of medieval construction techniques, on the site of Notre-Dame.

The scientists' love for the cathedral goes beyond strict professional interest. Châlus, for example, has been running the guide service for four years, after seven years of volunteer work. "I was present when the fire started," he says. "I had to start responding to the first technical issues. During this time, the three of us exchanged ideas. In only three days, we had incorporated the legal status of the association. I became the spokesperson."

From the outset, the objective was twofold : to bring together scientists and collect knowledge from texts, maps, and records accumulated for centuries. But it was also to offer a point of contact for civil society. "We cannot blame politicians and journalists for not working with good data if we do not place it at their disposal," argues Châlus. For example, in the early hours following the fire websites amplified by social networks mourned the disappearance of the "millenary forest" of Notre-Dame. The group corrected the error, citing a study from 1995. The oaks used in the 13th century were in fact less than a hundred years old.

A LARGE BODY OF INFORMATION

In one week, 70 researchers had joined the group, 200 at the end of the month. 250 members have now registered: historians, art historians and archaeologists of course, but also curators and archivists, anthropologists, sociologists and theologians, physicists, chemists, paleo-climatologists, and musicologists. Researchers come from everywhere : France, Europe, America, the North as well as the South, Japan, Australia... "The community, usually dispersed, came together around this global emotion," says Châlus.

On the group's website, they contributed reference articles, but most importantly, they published what they call « notes ». From the dating of the vaults to the nature of the stones, the iron frames to the wooden framework, the identification of medieval stained-glass windows, to the rules of restoration imposed by the Venice Charter and the "feedback" from previous fires, the notes offer a large body of information to whoever wants to take it. "We have the knowledge. Our duty is to share it, especially in a moment like this," insists Châlus. And so what if, for the occasion, he has deprived his thesis of an important discovery on the dating of vaults.

Journalists consult with them, politicians as well. When representative Cédric Villani wanted to set up a panel for a conference in Parliament, he called on the Scientists of Notre-Dame. For the moment, the association relies only on the goodwill of its members. The National Institute of Art History (INHA) will soon provide it with offices, and the CNRS (French national center for scientific research) has clearly associated the group with its scientific project. "I must admit that 80% of our members have one foot inside it," Châlus says smiling.

Will this already pleasingly plump baby be able to grow and thrive ? “I know, it's a pretty big job,” Châlus says. “But if nothing else, we will have helped nurture and structure the initial momentum.”