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# A Geophysical Survey in Notre-Dame de Paris Cathedral: Revealing the Buried Past After the Disaster

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## Highlights:

- *Geophysical survey in Notre-Dame de Paris Cathedral.*
- *Ground-Penetrating Radar and electrostatic survey for urban archaeology.*
- *Geophysical survey for archaeology in a complex and polluted environment*

**Keywords:** complex environment, electrostatic survey, GPR survey, Notre Dame de Paris Cathedral, urban archaeology.

## INTRODUCTION

On April 15, 2019, Notre-Dame de Paris cathedral was engulfed in flames, this event touched the hearts of the French population as a whole and far beyond. However, this emotion has to be followed up by reflection and action to save and restore the monument. The involvement of scientists has been a necessity to understand this masterpiece of Gothic architecture and to restore it as best as possible and in the quickest way possible. The analyses of the origin of the building materials, dendrochronological dating of the wooden framework, study of paintings, stained-glass windows, metallic artefacts, 3D laser-scanner... are essential steps in the restoration process of this monument.

Very early on, the Inrap teams were called upon to intervene in this considerable undertaking. The first team took part in the clearing and inventorying of the charred beams and stones, then carried out archaeological excavations before the setting up of the highest crane in Europe and the equipment beside the cathedral.

In July 2019, the Ministry of Culture requested the Inrap geophysics team to carry out a geophysical study of the cathedral's floor. The objective of such a survey was two-fold. Firstly, to take advantage of an empty cathedral so as to understand what was beneath the soil. Secondly, to anticipate possible restoration works affecting the near subsoil and the probable archaeological remains.

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## A DEDICATED METHODOLOGY

In this context, three complementary intervention methodologies were implemented:

- A very high resolution GPR survey with a 3D-Radar step frequency multi-antenna radar (DXG1812 antenna; Fig. 1). This was carried out on the whole area to have a very detailed map of the near surface (70 cm – 1 m depth of investigation).
- A GPR survey with a GSSI 350 MHz HS antenna to investigate deeper anomalies. In some places, the depth of investigation reached up to 2.5 meters, especially in the side-aisles.
- An electrostatic survey for measuring electrical resistivity and dielectric permittivity of the soil. A MP3 prototype (Fig. 2; Flageul *et al.*, 2013) from UMR METIS (Sorbonne Université, Paris) was used with a V-shaped geometry and three different pole spacings (0.70/1.14/2 m).

This technique gives information about the clay content of the soil and is a useful complement to GPR.

This geophysical survey was carried out in a very particular context requiring adapted safety rules. First, a very high level of pollution from the hundreds of tons of incinerated lead in the roof and the spire had to be taken into account in the implementation of the survey, for the protection of personnel and equipment. Also, a large part of the cathedral (the nave and the transept) was totally restricted due to possible falling building materials from the roof. All of these particular conditions required that the geophysical devices be adapted on a remote-controlled machine to perform the survey (Fig. 1). To provide a centimetric precision of the location, all the geophysical data was located in real time by a robotic total station.

This survey was part of the emergency restoration program with an extremely tight schedule and many important safety measures. After months of preparation, the fieldwork took place during the autumn of 2020, in the midst of a sanitary crisis. Ten days inside the cathedral enabled all the accessible areas to be surveyed.

## RESULTS AND CONCLUSION

The different geophysical techniques revealed numerous anomalies (Fig. 3). This multi-device approach offered a global view of the cathedral's ground with a very good correlation. The various heating systems since the 19th century and onwards were found, as well as several sets of anomalies whose origin is undoubtedly related to the previous phases



Figure 1. 3D-Radar survey with remote-controlled machine in the nave.

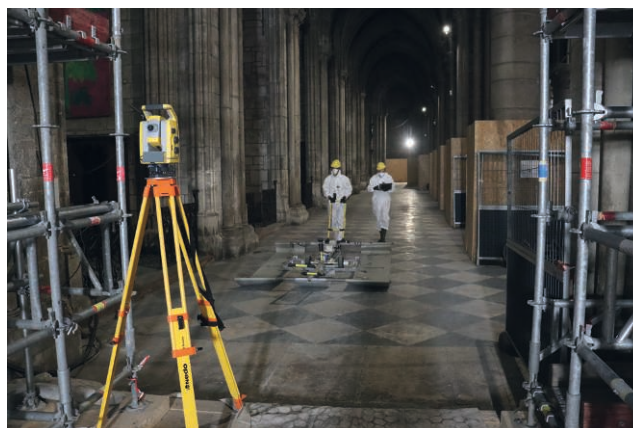


Figure 2. Electrostatic survey in the south side-aisle.

of the building. Some of them can be clearly linked to previous excavations and an archaeological/historical analysis has begun.

With this challenging survey in a complex and polluted environment, the combination of GPR and electrostatic surveys has been successful. This geophysical project has allowed us to recognise a poorly known service network and has revealed totally unknown remains, which has successfully enhanced the knowledge of this emblematic monument.

## References

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Figure 3. 3D-Radar and electrostatic maps (CAD: AGP/Inrap).