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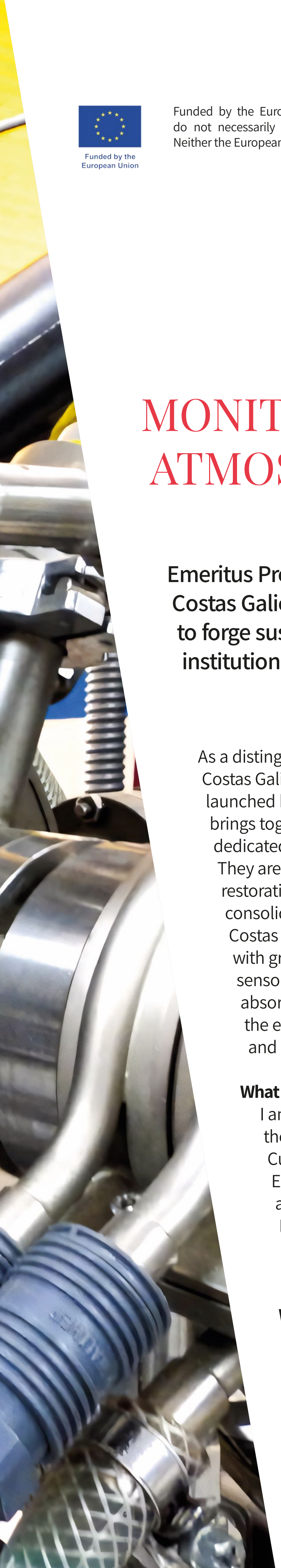

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GREENART

MONITORING THE IMPACT OF ATMOSPHERIC CONDITIONS ON ART

Emeritus Professor of Chemical Engineering at the University of Patras in Greece, Costas Galiotis is delving into nanotechnologies and materials science to forge sustainable conservation solutions for cultural heritage institutions as part of the European GREENART project.

As a distinguished chemist, Greek researcher and academic Costas Galiotis is involved in GREENART, an international initiative launched by the European Union in October 2022. This project brings together scientists, conservators, and cultural institutions dedicated to the conservation and restoration of artworks. They are collaborating to develop new, green, and sustainable restoration products such as cleaners, protective varnishes, consolidants, and monitoring technologies. Within GREENART, Costas Galiotis's mission is to harness technologies associated with graphene and other two-dimensional materials such as sensors, harmful gas and moisture absorbers, and ultraviolet absorption membranes. This initiative aims to create tools for the end-users of the programme, namely cultural institutions and conservation professionals, to preserve artworks.

What is your professional background?

I am a chemist with a PhD in materials science from the Engineering Faculty at the University of London. Currently, I am a professor in the Department of Chemical Engineering at the University of Patras (since 2014) and a collaborating member of the Institute of Chemical Engineering Sciences (ICE-HT), one of eight university research institutes of the Foundation for Research and Technology-Hellas (FORTH).

What is your current role at the Foundation for Research and Technology — Hellas (FORTH) and in the within the GREENART project?GREENART project?

My present role at the Foundation involves studying graphene-related materials (GRM), 2D materials (production and properties), composites and polymers (structural, mechanical, and spectroscopic characterisation of polymers and composites) and non-destructive testing of materials (a world leader in applying Raman laser spectroscopy for strain or deformation measurements in fibres and composites). My role in GREENART is to facilitate the end-use of technologies developed related to graphene and other two-dimensional materials such as sensors, harmful gas and moisture absorbers, ultraviolet absorption membranes, etc., by the end-users of the programme, who are the cultural heritage institutions (museums, galleries, academies, etc.).

We understand that you will be developing green technological solutions to monitor environmental conditions affecting cultural heritage. Could you tell us more about this?

It is well-known that atmospheric conditions can impact or even alter the materials used by artists, thereby damaging cultural heritage items. These atmospheric factors include changes in humidity and temperature or emissions from the items themselves due to their prolonged stay in enclosed spaces such as

— Antonio Mirabile

display cases or storage boxes. For the latter, there is an increase in the concentration of various harmful gaseous pollutants, due to the gradual decomposition of the items, which further accelerates the degradation process. One of our main goals in the GREENART project is to develop green solutions to effectively monitor these essential environmental parameters. The proposed solutions include the development of sensors to record relative humidity, temperature, and pollutants such as acetic and formic acids. Subsequently, the developed sensors will be integrated into electronic and communication solutions for real-time monitoring of environmental variations. While this concept is not new, the innovation in our case lies in the use of green materials and sustainable methods to develop both the sensors and some of the electronic components necessary for their interconnection and communication.

Which other research institutes are collaborating with you within the GREENART project?

We have a close collaboration with various institutions from many European countries, boasting a wide range of knowledge and experience in the field of sensors. This includes material developers, electronics experts, and end-users. At FORTH (Greece), we have well-established expertise in nanomaterials, particularly graphene-related materials (GRM). We are working in collaboration with the Centre for Colloid and Surface Science (CSGI, Italy) and two institutes from the National Research Council (CNR, Italy): the Institute of Polymers, Composites, and Biomaterials (IPCB) and the Institute of Nanostructured Materials (ISMN). Together, we are developing various sensing materials through green approaches. Additionally, in the development of sensor electrodes, the Tyndall National Institute at University College Cork (T-UCC, Ireland) is working with CNR-IPCB and CSGI to develop new polymer formulations suitable for creating porous electrodes. These electrodes are used by both FORTH and T-UCC in the final assembly of new green sensors. Another activity at T-UCC includes the integration of the developed sensors with electronic and communication solutions using an NFC antenna designed and developed specifically for GREENART. Finally, the produced sensors are validated and tested both in simulated environments at the University of Ljubljana (UL, Slovenia) and the University of West Attica (UNIWA, Greece), as well as in practical settings like at the Peggy Guggenheim Collection in Venice (Italy) or the Hungarian National Museum (HNM, Hungary).

What materials are these sensors related to?

Several innovative materials are being examined and utilised in the development of the sensors, which are either produced through green methods from natural raw materials or sourced from recycled materials and waste. However, graphene and its derivatives undoubtedly dominate all types of sensors. GRM are utilised in various parts of the sensor design, starting with the electrodes, which are produced through the laser graphitisation of biopolymers or natural materials, through to the detection layer where green graphene oxide (GO) is used for monitoring relative humidity. In addition to electrode development, biopolymers and natural materials such as cork are also employed in the development of substrates for sensors and NFC antennas. Furthermore, other 2D materials as well as metal oxides and chlorides have been tested for sensors detecting volatile organic compounds (VOCs) and temperature.

Are they already used in other fields?

Relative humidity and temperature fluctuations are among the primary environmental factors that are monitored and recorded daily in various application fields. In other words, these types of sensors can find applications in many areas outside GREENART, ranging from electronics to buildings, transportation, and industry. Regarding VOC sensors, we target specific pollutants that are harmful to heritage materials. However, they can also be produced from many other sources and some of them are extremely hazardous to living organisms and humans. Therefore, we believe our VOC sensors could find broad usage in a range of application fields.

How do they work?

Although the sensors differ from one another as they respond to various physical or chemical stimulus changes, they share common operational characteristics. The basic principle in all cases involves detecting changes or variations in a particular physical parameter, which are then converted into an electrical signal. Humidity sensors, for example, are designed to function like capacitors. Fluctuations in relative humidity cause the adsorption or desorption of water molecules in the detection area, thereby altering the sensor's capacitance. The measured capacitance change is then converted into relative humidity *via* a calibration curve. On the other hand, VOC and temperature sensors function like resistances. Indeed, when target molecules are detected by the detection area, the conductivity of the sensor changes, so that the recorded electrical signal can be converted into VOC concentration values. It should also be noted that a change in temperature leads to a change in the concentration of charge carriers in the graphene network, which results in a change in conductivity, which can then be converted into temperature.

Humidity sensors on ZFB archive box for museums

Photo Costas Galiotis

> Graphene and its derivatives undoubtedly dominate all types of sensors. GRM are utilised in various parts of sensor design, which are produced through the laser graphitisation of biopolymers or natural materials. — *Costas Galiotis*

How is it innovative compared to existing materials?

The use of nanomaterials such as graphene and its derivatives and many of the methods used to develop the sensors (e.g., laser writing) can be characterised as cutting-edge technology. However, in our approach, the environmentally friendly development of the sensors, which includes all green materials and sustainable methods for their production, constitutes the main innovation compared to existing materials. The materials used for the sensors are either raw biomaterials (e.g., biopolymers) or recovered from recycled materials and waste, while the methods used for their production are either eco-friendly or lead to significant reductions in harmful chemicals, water, and energy waste.

Regarding sustainability, how can you monitor that the new materials are more eco-friendly?

For GREENART, we follow an integrated approach in terms of production methods and material development. Moreover, we provide all necessary information for the ongoing assessment of processes to project partners, such as the University of Venice, which handles safety and lifecycle sustainability evaluations. Additionally, we employ environmentally friendly production methods and use recycled materials/waste as ecologically compatible reactants to achieve our goals of developing green technological solutions for monitoring cultural heritage.

Are these sensors suitable for all types of environmental conditions and compatible with all types of cultural heritage materials?

Depending on the type of sensor, they are suitable for recording a wide range of measured parameters. For instance, humidity sensors can monitor the entire relative humidity range from 0 to 100% and can operate from 0 to 40°C. Similarly, temperature sensors have been evaluated from 0 to 100°C. As you can see, these ranges are much higher compared to the environmental conditions under which cultural heritage materials are stored or displayed. However, there are certain environments where the sensors are not rated to operate (e.g., a wider temperature range) or cannot function primarily due to the materials from which they are made. For example, most biopolymers are destroyed at high temperatures. Finally, regarding the range of heritage materials, I must say that the operation and performance of all types of sensors are not affected by the nature of these materials. The only issue that could arise would be the requirement to record harmful pollutants other than those for which the sensor is designed to measure.

How do you work with cultural heritage institutions to assess and validate the new sensors?

For the validation of the green sensors, we work closely with two museums, the Peggy Guggenheim Collection and the Hungarian National Museum. Furthermore, all other cultural heritage institutions that partnered with GREENART are welcome to participate in the evaluation process. Additionally, we make efforts to disseminate our findings to cultural heritage institutions beyond members of the GREENART project; we are also in discussions with the Museum of Science and Technology at the University of Patras to evaluate the green sensors in their facilities.

Do you think they will be ready for production and sale at the end of the project?

Among the three different types of sensors, the GO-based humidity sensors are at the highest level of evaluation, as their validation in real environmental conditions has already begun. Although several other tests need to be carried out before the end of the project, we are optimistic about achieving all the set goals. On the other hand, the discussion regarding the production and sale of the sensors goes beyond these objectives. We have considered this, and it could be done, perhaps not at the end of the project, as there are additional steps required beyond sensor performance, but in the near future, it is something we would like to advance. The cost of the sensors is an additional advantage in this direction, where due to the use of the materials and methods I have mentioned above, it is significantly lower compared to competing sensors typically developed from non-recyclable and expensive metals such as platinum, gold, and silver.

Costas Galiotis

Courtesy Nanotechnology and Advanced Materials Laboratories

Costas Galiotis's team at Foundation for Research and Technology-Hellas

Courtesy FORTH