INNOVATOR **AGH**

Scientific achievements

We are proud to present an overview of some of the most interesting academic achievements of our outstanding AGH UST scientists. Although necessarily selective, this publication demonstrates a collection of the most expansively researched fields and disciplines at our university – not only in the sphere of ideas, studies, and discoveries, but also in terms of implementations in industry and economy.

In the world of science, success is marked not only by the fact of implementing research results, but also by the launch of projects, facilitated by receiving specific funding or by becoming a member of a team carrying out a particular activity. The money granted by such prestigious Polish institutions as the National Science Centre (NCN), the National Centre for Research and Development (NCBR), the Ministry of Education and Science (MEiN), or the funding from the Initiative for Excellence – Research University (IDUB) programme testify to the potential of the projects originating at the AGH UST.

The specific feature of our university's profile means that the research carried out here must be both theoretical and practical in nature. Therefore, we have attempted to present it on a broader scale and to embed its idiosyncrasies and application potential within the surrounding reality. This leads to the conclusion that the research projects conducted by our employees, doctoral students, and students respond to the multifarious challenges of the modern world – from the digitalisation of practically all aspects of life, through issues related to the exploitation of natural resources and the energy transformation, to social problems and civilisational diseases.

I hope that this publication and the achievements in materials science, biomedical engineering, or computer science presented herein will be an incentive for scientists and entrepreneurs who want to establish cooperation with our university, as well as a source of inspiration for young people who wish to enter this fascinating world of science.

Professor Marek Gorgoń
Vice-Rector for Science

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AI to help animals. New generation of intelligent tools for veterinary diagnostics

Today, artificial intelligence algorithms find applications in multiple areas. One of such fields is veterinary medicine. Similarly to people, animals also suffer from all kinds of inflammations and cancers. It is precisely these afflictions that have been targeted by the AI and veterinary experts from the CyfroVet project.

The chief objective of the project, carried out by the AGH UST Academic Computer Centre CYFRONET, is to reduce the time of cytology tests, which are the first step in diagnosing neoplastic lesions in animals. Currently, waiting for results can take from several days to two weeks. The price of the test is also quite considerable. Moreover, sending samples to laboratories comes with additional costs.

There is a possibility of accelerating the moment of receiving preliminary results by using an automated system that takes a picture of the sample of cytological material and analyses it with the use of artificial intelligence algorithms, making it possible to detect the pathological changes therein. Based on such preliminary tests, doctors will be able to make initial decisions about further diagnosis and treatment.

Developing a system like this presents quite a challenge. Firstly, and quite significantly, scientists need to collect a sufficient number of photos of multifarious samples, which will allow them to train the artificial intelligence algorithms in recognising neoplastic lesions.

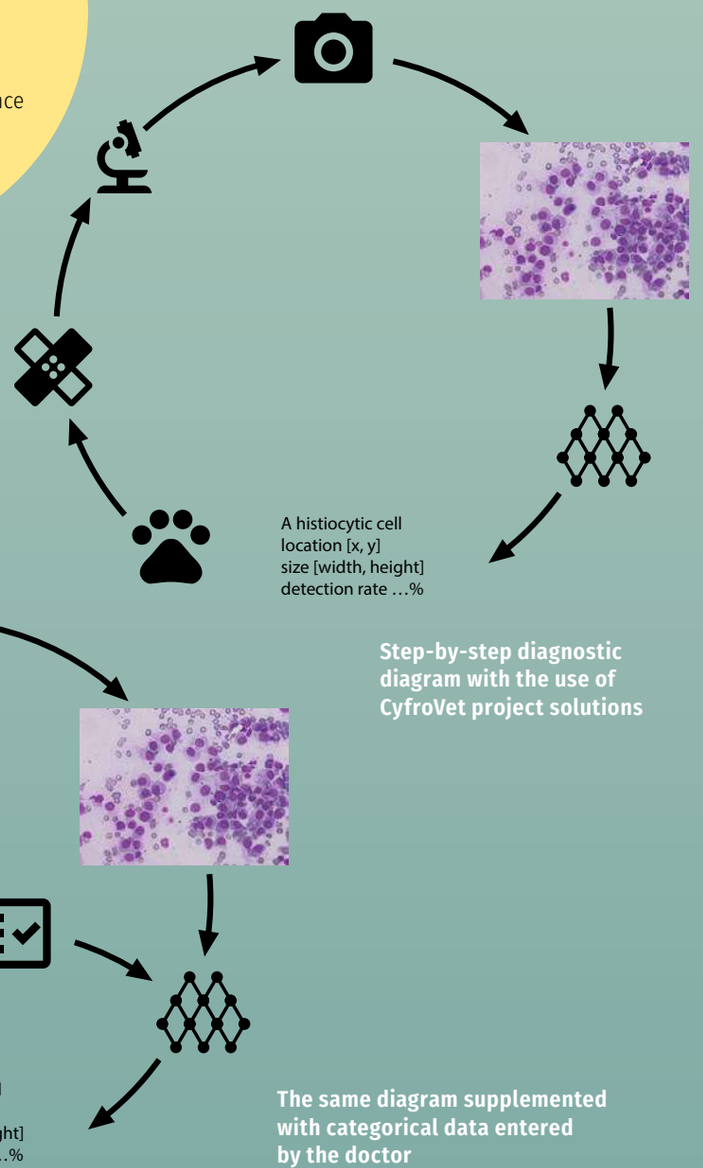
In the macroscale, a cytology sample is non-homogeneous: some spots show a higher diagnostic potential than the others. A specialist is able to pre-identify and analyse them for changes. A system for cytology diagnosis should be able to carry out such analysis too. Only selecting specific fragments of the analysed photos, which contain questionable pathologies, will facilitate precise diagnosis.

Another time-consuming process is related to training data labelling, which requires an expert to mark any pathologies by hand, which are then verified by a certified pathologist. This stage ensures a high quality of the artificial intelligence system. As part of the project, the scientists have already created a solution that allows them to classify selected pathological changes using neural networks. They have also developed network architectures, which allow them to precisely detect and semantically segment individual cancer cells, facilitating a detailed analysis of pathological changes. This has set the classification accuracy rate at high 96%. The system works for three selected neoplastic lesions: mastocytoma, histiocytoma, and lymphoma. Based on the YOLOv3 detection algorithm, the model developed by the scientists allows them to isolate within the image of the cytology sample the so-called 'field of interest'. At the same time, scientists are working on a model based on semantic segmentation, which allows them to isolate areas of pathological changes with an accuracy of one pixel.

The team is also investigating ways to develop a holistic veterinary diagnostic system, which will take into account not only microscope screenings of photographed cytology samples, but also the information collected by the vet during anamnesis. The medical history allows the doctor to evaluate the patient's condition by analysing its age, past diseases, location of skin lesions, as well as any additional information the doctor can obtain from the owner. These constitute categorical data, which can significantly affect the diagnostic decision made by the veterinarian. Accounting for this data in the artificial intelligence algorithm will allow the scientists to improve its efficiency and generalise the results. In machine learning, this phenomenon is known as the use of multiple modalities for building models.

The project is carried out by a team of specialists comprising Prof. Kazimierz Wiatr[a, b], AGH UST Prof. Paweł Russek[a, b], Dr hab. (Eng.) Maciej Wielgosz[a, b], Dr (Eng.) Rafał Frączek[a, b], Michał Karwatowski, MSc Eng.[a, b], Jakub Caputa[a], and Daria Łukasik[a] ([a] – CYFRONET, [b] – Faculty of Computer Science, Electronics, and Telecommunications).

CyfroVet project led by
Dr hab. (Eng.) Maciej Wielgosz
Academic Computer Centre
CYFRONET
Laboratory of Acceleration of
Computing and Artificial Intelligence



Step-by-step diagnostic diagram with the use of CyfroVet project solutions

The same diagram supplemented with categorical data entered by the doctor

Air purification installation to protect work stations from viruses

A stream of pure air envelopes the person standing in a room, removes the exhaled air, and creates a barrier against the outside air. This is how the prototype installation works. An installation to protect people who might be exposed to viruses, including SARS-CoV-2.

To limit the spread of COVID-19, in addition to the work that aims to develop effective treatments and vaccines, we must take appropriate preventive measures. In this case, proper ventilation of rooms is crucial. This is because the infectious SARS-CoV-2 virus spreads, for example, through aerosols, that is, a mixture of air, fine solid particles, and liquid droplets that everyone emits when they breathe and speak, not to mention coughing or sneezing. Such a cloud containing pathogens can move about and linger in air for extended periods in crowded and poorly-ventilated rooms.

The engineers from the Ventilation and Air-conditioning of Facilities Team at the Faculty of Civil Engineering and Resource Management have decided to tackle this challenge innovatively. They are currently working on an air purification system which, in comparison to those applied in general ventilation and air-conditioning systems, is intended for a single person.

'The idea originated as a result of our observations and the needs of industry, where people have to work in close contact or where they are confined in small spaces, as in mining, for example. Constructing this type of ventilation will facilitate the minimisation of human exposure to the virus in the aforementioned situations', explains AGH UST Prof. Marek Borowski, the leader of the project titled *Air purification system for work stations exposed to the COVID-19 virus*.

The tested solution is made of a ventilation fan, an electrostatic air filter that captures and neutralises microbes, a ventilation installation, and a ceiling diffuser made of an elastic and easily disinfected PET-G material. The diffuser is meant to create a stream of air that will remove the exhaled air from the user-occupied zone, while simultaneously blocking the flow of air from the outside.

During research work, the AGH UST scientists have examined the impact of the plenum box entry on the velocity profile of the air stream. *'The plenum box decompresses the air stream and causes a decrease in its velocity before it reaches the fan, where it is profiled accordingly by the arrangement of vanes and other elements. Moreover, when the air velocity decreases, the noise level is also reduced',* explains Prof. Marek Borowski. *'This is why research on the shape of the box, the direction of the air entry, or its velocity is so important and has been carried out for many years. We're still trying to reach the optimal shape, because when you mount the installation, it's sometimes impossible to apply an ideal solution.'*

The challenge that the designers and producers of HVAC systems (heating, ventilation, and air-conditioning) face is to provide optimal functionality of their devices, while simultaneously bearing in mind the maximum comfort of the user. The latter factor is influenced by temperature, humidity, purity, and velocity of the air flowing from the system. The last parameter is decisive when it comes to feeling unpleasant draughts in the room. The PIV (Particle Image Velocimetry) and CFD (Computational Fluid Dynamics) analyses have shown that the way the stub pipe is connected to the box has a significant impact on the distribution of air from the fan. Although, taking space limits into consideration, the producers of such devices use side-entry plenum boxes, the air stream profile in this configuration is less symmetrical than in the case of a top entry. The researchers indicate that a partial solution to this problem might be the installation of perforated panels inside the box. However, this can come at the cost of dropping pressure and increasing the noise level.

The solution developed by the AGH UST researchers can be redesigned by using a different type of fan, so that the installation, instead of creating a protective barrier around a single person, would shield an entire group of people.

Smoke test used to visualise the propagation of air around the dummy

Team led by **AGH UST Professor Marek Borowski**
Faculty of Civil Engineering and Resource Management

Project funded by a university grant within the IDUB programme

Amino acids to extend the life of medical implants

Implant production uses a variety of materials which, within a specified time, should perform predetermined functions: have defined mechanical properties (strength, abrasion resistance, etc.), be biocompatible with the human organism, and show corrosion resistance. The most frequently used materials include metals and their alloys, such as titanium and stainless steel. Unfortunately, the interaction of metal implants with bodily fluids causes various chemical reactions on the metallic surface, leading to their deterioration.

'As a result, toxic compounds are released into the organism, which can lead to the development of various infections or cancers. On the other hand, replacing damaged implants is expensive and requires complex and cumbersome medical procedures', says Dr Dominika Święch from the Faculty of Foundry Engineering, leader of the project titled *Spectroscopic studies in micro- and nanoscale of the corrosion process and its inhibition of the modified metallic surfaces applied in implantology*, carried out by the consortium comprising the Faculty of Foundry Engineering, the Academic Centre of Materials and Nanotechnology (ACMiN), and the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN).

An effective way to hinder corrosion is to modify the surface of materials used in implantology with inhibitors. The tested materials are modified with gold and copper nanoparticles, which possess potential anticorrosive and antibacterial properties. Moreover, they strengthen the spectroscopic signal during the examination of processes occurring on the studied surfaces. The application of the particles is supervised by Dr Kamila Kollbek from the ACMiN which provides access to necessary equipment.

The scientists pay special attention to amino acids, which occur naturally in the human body and perform numerous biological functions. As previously shown, they can play the role of corrosion inhibitors; additionally, they are non-toxic and relatively inexpensive. Until now, Dr Święch has been examining tryptophan (Trp). In our bodies, it constitutes a precursor of various metabolites, including serotonin (a.k.a. 'the happiness hormone') and melatonin (in control of the sleep-wake cycle), influences the health of our skeletal system, and its residues form peptides that play a vital role in the immune system. To find out whether Trp is also a corrosion inhibitor, electrochemical studies of stainless steel have been conducted. The scientist simulated an adverse environment that influences the process of implant corrosion in the human body (namely, the presence of chloride and phosphate ions). The results indicated that Trp, in controlled conditions, adsorbs onto the surface of the corroded stainless steel, resulting in improved corrosion resistance.

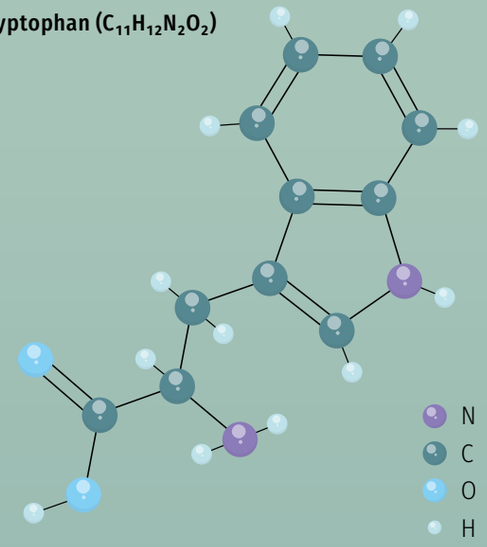
'Research on the inhibition process uses surface-enhanced infrared absorption (SEIRA) and surface-enhanced Raman spectroscopy (SERS) techniques, which are useful tools for monitoring the process in the microscale; techniques that combine the advantages of atomic force microscopy and spectroscopy (e.g. AFM-IR), which facilitate imaging the process in the nanoscale, are also used. Using primarily the methods of oscillatory spectroscopy in my research, with particular use of nano-spectroscopic imaging, is a novel approach to the investigation of the corrosion process and its inhibition. Research carried out with the use of these techniques has multiple advantages, namely, the measurements are fast and the sample remains intact, and it does not require special preparation', explains Dr Święch.

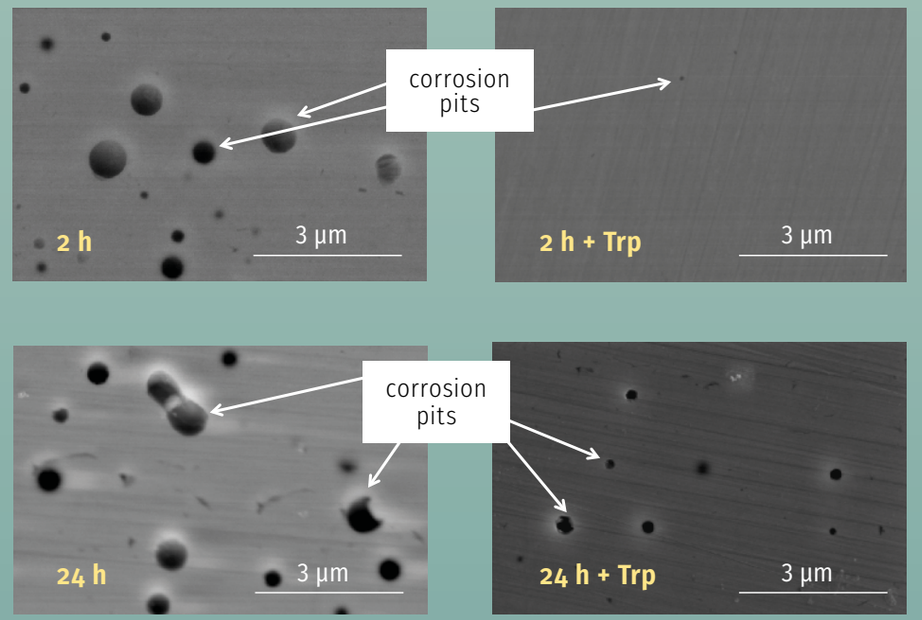
Using spectroscopic methods facilitates the identification of the products of corrosion and makes it possible to investigate the corrosion inhibition process *in-situ* and *ex-situ* in micro- and nanoscale (e.g. determining structural changes occurring as a result of interactions between potential inhibitors and the metallic surface with simultaneous surface morphology control).

Team led by **Dr Dominika Święch**
Faculty of Foundry Engineering
Department of Chemistry and Corrosion of Metals

Project implemented within SONATA 15/NCN

Tryptophan ($C_{11}H_{12}N_2O_2$)





SEM images (taken with a scanning electron microscope) of the 316L stainless steel surface after electrochemical corrosion tests in inflammation conditions (Phosphate-buffered saline [PBS], pH=3, temp.=37°C) with and without Trp present, in various time exposures

Artificial brains vs. von Neumann bottlenecks – research on synthetic intelligence

An artificial brain instead of a traditional computer? This can be our future. A team led by Professor Konrad Szaciłowski is working on improving memristors that constitute a synthetic equivalent of synapses. Their huge advantage is that they combine the properties of a memory and a CPU, which considerably increases the computing efficiency of the system, simultaneously reducing its energy requirements. This opens the path to overcoming the von Neumann bottleneck, which significantly limits the capabilities of modern computers.

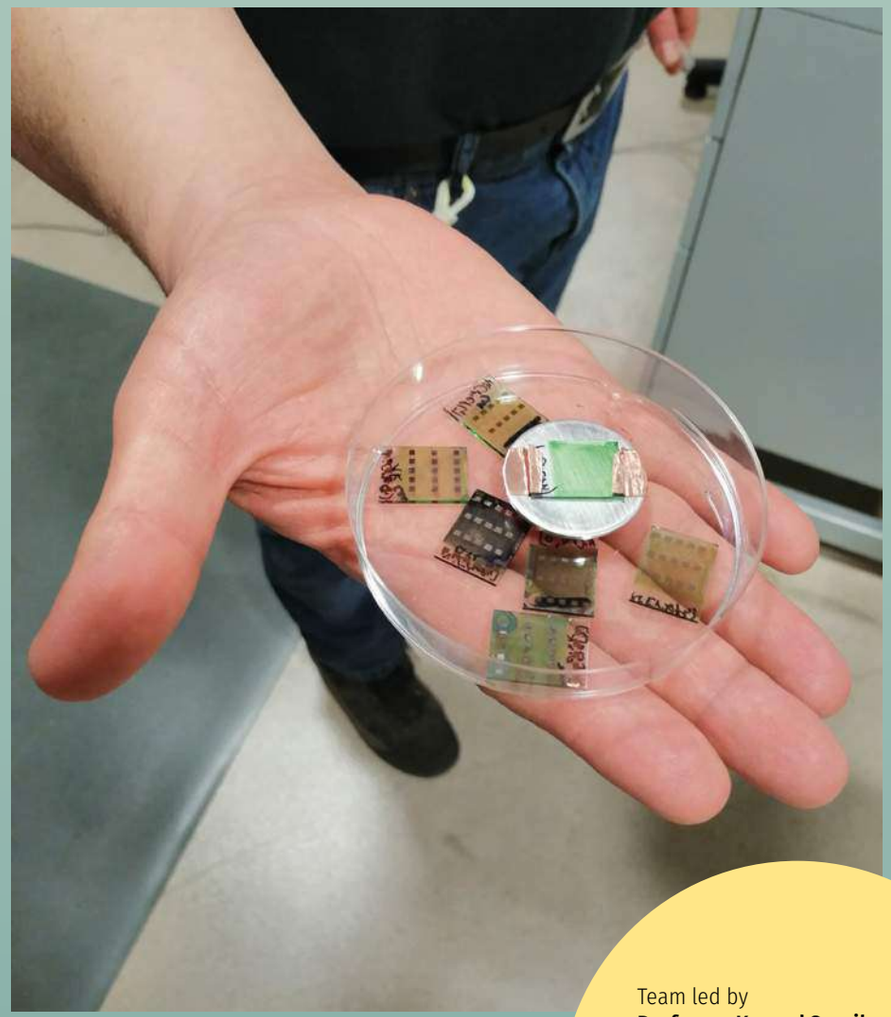
They are made of a CPU (Central Processing Unit) and a memory, between which data travel. This solution has one fundamental drawback: the data bandwidth between the two units is limited, which makes the CPU inert before it receives information. This problem does not apply to the human brain, which can also be viewed as a computing machine. The reason for that is cells that combine the functions of memory and a CPU. Research has shown that synapses can store information and process them at the same time. It happens because they memorise the flow of electrons; therefore, they operate on the basis of a local memory, which does not rest on classic, but on fuzzy or many-valued logic. The question boils down to how to mimic this clever natural contraption and how to create a new-generation computer that mimics the nervous system.

A prospect for a leap in computer technology is the so-called 'memristor' (a portmanteau of *memory resistor*), which can be seen as an artificial counterpart of a synapse. Its resistance increases when electrons travel in one direction and decreases when they go the opposite way. Each memristor remembers its state even when the power is off, and retains its most recent resistance without power supply. This makes it a perfect candidate for a component that can one day serve as a building block for a network which will mimic the functioning of the brain.

Building a memristor is quite a challenge. We need innovative solutions, which are investigated at the AGH UST Academic Centre of Materials and Nanotechnology. Using interdisciplinary knowledge, the researchers try to build a memory resistor that can operate in home conditions. They construct systems made of nanoparticles and light-sensitive post-perovskite materials.

'A memristor is a non-linear circuit called a sythetic synapse, because you can force it to retain a kind of primitive memory – it'll remember whether an electrical impulse has flown through it or not. Whereas an artificial neuron is the usual name given to an electrochemical cell that generates electrical impulses under the influence of light. The case is now to merge these two different elements to create a completely synthetic system that will process data analogously to the processing that occurs in a biological nervous system', the project leader says. *'Memristors based on perovskites have been studied for 6 to 8 years. In this specific case, we're talking about the lead perovskites, that is, complex compounds containing lead, iodine, and an organic cation. These compounds show good electrical conductivity and are commonly applied to solar cells. However, memristors made of them have one basic flaw: they are extremely air- and humidity-sensitive. This is why we are looking for entirely new materials that will have properties similar to those of perovskites, i.e. show the so-called "memristance", while simultaneously being not as sensitive to environmental factors. We need memristors that we can mass produce on a larger scale in the future.'*

When scientists manage to develop individual components, they will begin to construct neural networks, capable of performing specific tasks. *'We want to make a bucketful of jelly with which we'll be able to play chess',* jests Professor Szaciłowski. In other words, the goal is to create a physical synthetic intelligence that could be used to construct hardware.



Team led by
Professor Konrad Szaciłowski
Academic Centre for Materials and Nanotechnology

The *Post-perovskite memristive materials for hardware networks* project funded by a university grant within the IDUB programme

Black glasses as a solution to the problem of high-temperature corrosion

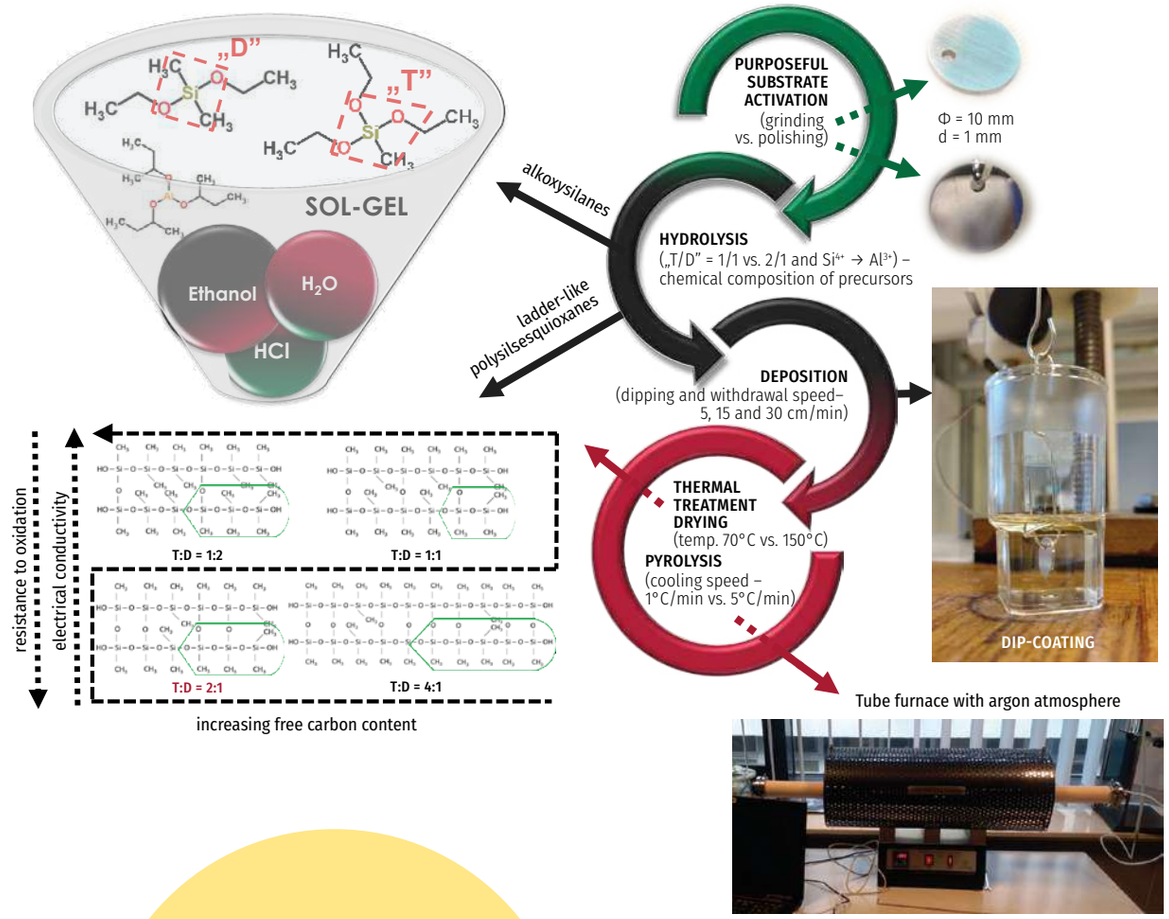
Corrosion is a gradual process of material degradation stemming from its interaction with the work environment. The commonly known phenomenon of metallic element rusting, resulting from the flow of electric charges between the degraded material and the electrolyte that contains aggressive ions – for instance, Cl^- or OH^- – is an example of electrochemical corrosion. An example of chemical corrosion might be the degradation of metallic materials under the influence of hot, gaseous work environments (more than 400÷500°C).

The problem of high-temperature corrosion affects many branches of the economy because higher temperatures often translate into an increase in process efficiency, such as fuel combustion in aircraft engines. It also affects the energy industry and low-emission SOFC (Solid Oxide Fuel Cells) technology that requires high operational temperatures (ca. 800°C). This requirement results from the need to provide an appropriate level of ion conductivity of the electrolyte made of zirconium dioxide (ZrO_2) stabilised with yttrium oxide (Y_2O_3). Unfortunately, such high temperatures mean the acceleration of degradation of individual elements of the fuel cell, including the so-called 'interconnects' – the "backbone" of the cell that facilitates the connection of individual cells in larger stacks.

A way of counteracting these problems is to use protective coatings. As far as interconnects in SOFC are concerned, the task is even more difficult due to strict material requirements for potential interconnect materials that encompass not only resistance to oxidation in high temperatures, but also a high level of electric conductivity. Dr (Eng.) Maciej Bik, who works in a research team led by Professor Maciej Sitarz from the Faculty of Materials Science and Ceramics, has been trying to solve the problem. He optimises the process of obtaining protective coatings based on the so-called 'black glasses'.

Black glasses are materials with the structure of amorphous silica, which belong to the so-called 'polymer-derived ceramics' (PDC). The key element that determines the interesting properties of black glasses is carbon, which can be found in the material in two variants. The first one constitutes carbon atoms bonded with silicon atoms by strong, Si-C covalent bonding, which contributes to a high thermomechanical resistance of the material. The other variant is the so-called 'free carbon phase', which occurs when a certain threshold of carbon content in the glassy matrix is exceeded. This phase is responsible for electrical conductivity and black colour of the material. After many years of research, Dr Maciej Bik was able to discover the optimal ratio of both these phases and develop a process of obtaininig tight and homogeneous black glass-based coatings from "pure" silicon oxycarbide (SiOC) and aluminium cations silicon oxycarbide (SiAlOC). During high-temperature tests (800°C) of steel samples dedicated for interconnects and modified with the use of black glass-based coatings, promising results were obtained as the uncontrolled diffusion processes were impeded, which translated into a significant reduction in material degradation rate with simultaneous maintenance of satisfactory levels of electrical conductivity. This was the first such an attempt in the world to use silicon oxycarbide-based coatings in this way, which have a working mechanism completely divergent from the most commonly used layers based on spinel- or perovskite-structured compounds.

One of the greatest advantages of this coating material is the wide scope of possible applications, which include not only metallic substrates (ferritic steels, intermetallic alloys), but also work in various atmospheres (oxidation, reducing). Black glass-based coatings have been successfully used on the substrate of TiAl alloy, intended for low-pressure turbine vanes for aircraft engines (750°C; air and air with steam) as well as substrate of pure chromium (950 and 1050°C; air).



Team led by **Professor Maciej Sitarz**
Faculty of Materials Science and Ceramics
Department of Silicate Chemistry and Macromolecular Compounds

Project funded by a university grant within the IDUB programme

Experimental plan of production optimisation of black glass-based coatings

Collective intelligence and the electronic republic. The Internet and social participation

In what way can the Internet increase the participation of citizens in the public domain? Will collective intelligence help us implement a new model of participation in public debates? A research group for ICT applications (Information and Communication Technologies) in the public domain, established at the Faculty of Humanities, tries to answer these questions.

In ancient Greece, making decisions affecting the entire community happened during meetings on the agora, where people debated the future of the Greek city-states. In our times, the Internet was to become such a place: people wished to create a space in which citizens could talk to one another and collectively decide on the fate of their countries. This idea has been referred to as the electronic republic by the leader of the research group, Dr Rafał Olszowski.

Currently, the most common model of social participation is representative democracy, in which, as the name suggests, citizens choose their representatives to govern and make decisions about the state in their name. The less popular model is direct democracy, where citizens themselves make choices by voting, which gives them a significant influence on governing their country. The latter manifests itself in electronic democracy, which aims to engage all citizens in public matters through the use of information and communication technologies, allowing for Internet referenda. There is one major general objection against direct democracy, namely that, in reality, it means the mob rule, whereas the expert rule would be much better. Is that the case, though?

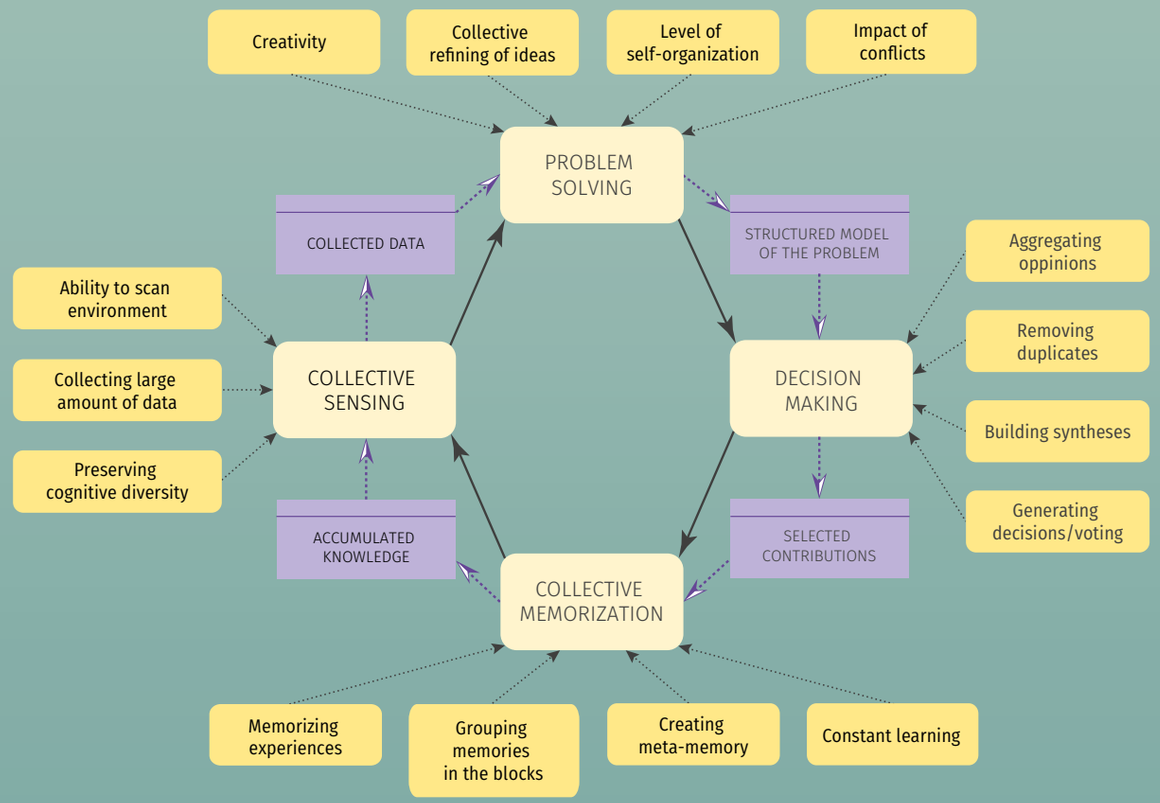
Scientists who study collective wisdom analyse the transfer processes of a considerable amount of data, which they try to dissect in search of regularities. For instance, organising large-scale Internet traffic and behaviours, they prove that an averaged response of a mass of anonymous Internet users is sometimes even better than an expert opinion. For collective wisdom to occur, certain conditions must first be met. Initially, cognitive diversity plays a rather important role. This is a situation when the mass present differing points of view. Secondly, it is important that the answers are autonomous, i.e. independent. Thirdly, the structure and quality of arguments matter, as well as the model of debate – deliberative or agonistic.

The AGH UST scholars analyse collective intelligence studying smaller groups first – local and city communities. They also focus on large-scale public debate, especially the one on Twitter. Due to the integration of the API Twitter software and IT tools prepared in the R language (Piotr Pięta, MSc was responsible for the programming work), massive response collections are gathered and analysed in terms of group interrelations, sentiment, polarisation of opinions, and debate balance.

'*Studies have shown that if a group has to make a collective decision, different thinking styles of this community members, that is, the cognitive diversity, translates often to better results. However, it's best when they represent some common values and goals, and have a sense of group identity*', Dr Olszowski claims. Based on conclusions from observing social initiatives carried out online – such as the participatory budget of Krakow – the team describes cognitive processes influencing collective intelligence. The group is also considering which political model suits best a system in which the citizen takes active part in creating the electronic republic. '*We are analysing current initiatives and wonder what is their impact on creating public politics, and the adopted model of citizenship. In other words, we are trying to answer the question who a citizen is in the electronic republic – is he/she truly a co-creator of the public sphere or rather a consumer, as in the liberal model, where they get certain services for which they must pay taxes*', explains Dr Olszowski and summarises: '*Small ICT-aided communities can be a strong element of the public domain. They should balance government institutions operating on the premises of bureaucracy, as well as large media corporations which impact the Internet increasingly stronger.*'

Team led by **Dr Rafał Olszowski**
Faculty of Humanities

The *Collective intelligence on the Internet: applications in the public sphere, research methods, and social participation models* project implemented within SONATINA 2/NCN



Computer science to aid detectives. LINK2 – forensic analysis support system

The process of forensic analysis is complex and often based on a massive amount of data. The goal of a forensic scientist is to obtain information inaccessible at first glance but revealed only after a detailed investigation of all available data from various angles. Considering the laboriousness of analytical processes and the limited perception capabilities of humans, scientists have come to the conclusion that the process can be simplified using computer tools.

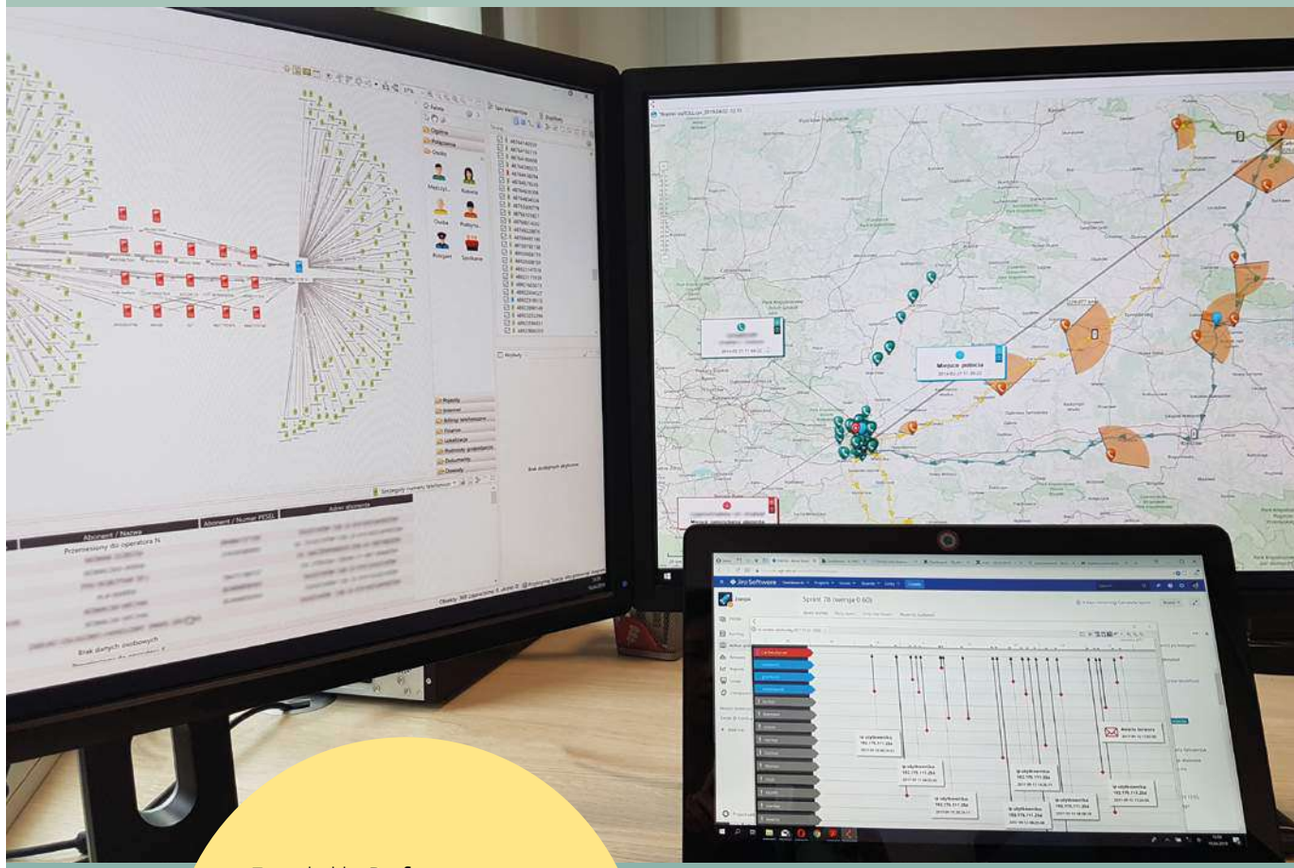
Developing and implementing tools to answer the real needs of state security institutions requires an experienced, interdisciplinary team made up of scientists, programmers, testers, and analysts, such as the team from the AGH UST Forensic Software Lab that has created the LINK2 environment – a comprehensive IT solution designed to support the work of criminal analysts. The software is tailored to the needs of Polish public security services and field experts. It provides a set of tools for integration, pre-processing, and the visualisation of data from various sources.

One of the first steps in data analysis is the preparation thereof. Based on experience and expert opinions, there is certainly no standard format of data. Therefore, LINK2 has been equipped with the crucial and extended set of tools supporting data import. It is in the form of a graphic creator that guides the user, step by step, through the entire process. During data import, the software evaluates its correctness and completeness in the context of selected domains.

The objective of the analysis is to put forward and verify hypotheses, which usually occurs through revealing relevant relationships between objects on the basis of large amounts of interconnected data. To aid this process, it is helpful to use multifarious algorithms and heuristics. An example of such tools might be the search of potential meetings, uncovering and recognising patterns, or multicriterial filtering and data search. These tools allow the analyst to focus on relevant data (from a specific point of view). The user can also review the statistics that present consolidated information on the data collections under analysis, for example, a list of objects that interact with each other most often, their activity, and time profiles.

Another important quality of LINK2 is the methods of visualisation that allow the analyst to discover and edit data, and prepare final reports intended for further proceedings. The environment has three graphic editors. The pattern editor provides tools supporting the visualisation of objects (as graph knots) and relationships between them (as edges of graphs). This allows the software to distribute the graph elements clearly, conditionally mark the elements, and recognise and combine similar knots. The map editor is to improve analyses carried out on the basis of geographical data. In addition to the possibility of importing it from heterogeneous sources, the scientists developed visualisation methods of routes, various types of occurrences, address information, or telecommunication facilities. The editor is also equipped with a tool facilitating the filtering of objects in terms of the time of occurrences related thereto. The time editor shows the chronological order of events on a timeline and presents relationships between objects (e.g. a meeting, phone call, financial transaction), which proves particularly useful in event sequence analysis and correlation analysis between events related to different objects (typical in investigating economic crimes).

Due to the cooperation with officers of public security institutions, the scientists have been able to determine specific requirements for the application and implement a fully functional version, which has been positively verified in practice (a hundred and several dozen licence agreements signed with public security institutions all over Poland; the number of active users amounts to several thousand). This fact is corroborated by multiple distinctions awarded by the police and the Polish border guard.



Team led by **Professor Marek Kisiel-Dorohinicki**,
Dr (Eng.) Jacek Dajda,
and Dr (Eng.) Kamil Piętak
Faculty of Computer Science, Electronics, and Telecommunications
Institute of Computer Science

Projects funded by the NCBR

Electronic zero waste? Developing methods for complete photovoltaic panel recycling

Photovoltaics is becoming a more and more popular “green” alternative to produce energy, and its market in EU countries is growing rapidly. Estimates say that by 2025, in Poland alone, more than 420,000 tonnes of solar panels will have been installed. Considering that their average life cycle spans 20–30 years, in the coming years, in Poland alone, people will face the challenge of managing more than 100 tonnes of exploited photovoltaic installations. What can we do to make sure it is not just e-waste?

Even now, photovoltaic panels can be used to resource aluminium, silicon, or glass. However, for now, these methods are usually incomplete, inefficient, or expensive. Therefore, the AGH UST launched a project aimed to develop a technology to almost completely recycle worn out PV modules, carried out in a consortium with the research and technology company 2loop Tech. The partners estimate that the methods of recycling PV panels will not only be fully environmentally friendly, but also economically effective, facilitating the reclamation of almost 100% of elements necessary to produce such devices, including precious metals, such as silver. The AGH UST will carry out laboratory tests and develop a method of recycling the panels, whereas the implementation and launch of a prototype technological line will lie with 2loop Tech.

Devising methods for reclaiming precious metals and other valuable elements from electronic devices rests in the hands of a research team led by Dr (Eng.) Krzysztof Broda from the Faculty of Civil Engineering and Resource Management. To do this, the scientists use a variety of separation techniques. Some are simple and known from chemistry classes – the gravitational method, based on varying densities of materials. The others, however, are more complex and require a laboratory. This is the case with thermal and chemical separation. One of the most popular and effective techniques includes the electromagnetic method. ‘*In low-intensity magnetic separators, we can separate iron, and in the stronger ones, copper and aluminium, which show weak magnetic properties*‘, says Prof. Barbara Tora, member of the research team.

A photovoltaic panel has layers. PV modules are manufactured from individual solar cells that, after being wired to one another, are encapsulated and put into an aluminium frame. Therefore, the recycling process must begin with the separation of individual types of material. What exactly does it look like? Currently, the process starts with thermal treatment and grinding of the worn out equipment. Due to economic and ecological reasons, big furnaces are becoming a thing of the past in favour of the grinding method, which uses machines that crush the panels or vibration mills. After that, the product is separated on a line during optical sorting or granulometric separation (sieving). Mechanically separated glass can be later reused to make new panels or transported to a facility that produces bottles. Copper and aluminium that make up the wiring are also easily separable and meltable. Whereas silicon from solar cells can be successfully reclaimed with the use of a fascinating technique developed… more than 100 years ago. ‘*It’s the so-called “Czochralski method”, a Polish chemist who invented the method of making cells from silicon. You can say that these cells are grown – I’m sure everyone learned at school about the method of crystallisation, when you put a string into a glass with dissolved salt, which then swarms with small crystals. In this case, it’s exactly the same. However, when salt dissolves in water at room temperature, silicon, in turn, needs a solvent heated to 1414°C*‘, explains Prof. Tora.

The recycling process of photovoltaic panels will focus on mono- and polycrystalline silicon cells that were introduced into the market first, constituting its largest percentage, and being the first to become e-waste in a matter of the next five years. The recycling technology and research thereon will develop to encompass subsequent generations of PV cells when they finally become recyclable.

A photovoltaic panel prepared for recycling (with crushed glass layer)

Team led by
Dr (Eng.) Krzysztof Broda
Faculty of Civil Engineering and Resource Management
Department of Environmental Engineering

EVA encapsulant separated from the panel using thermal methods (heated up to 60%)

Fog as a nature-inspired source of water. New applications for polymer nanofibres

Limited access to drinking water is one of the most serious problems of the 21st century. Several regions in the world have experienced this issue, and sourcing water needs more and more unconventional methods. One of such can be harvesting water drops from fog using meshes made of electrospun polymer nano- and microfibres.

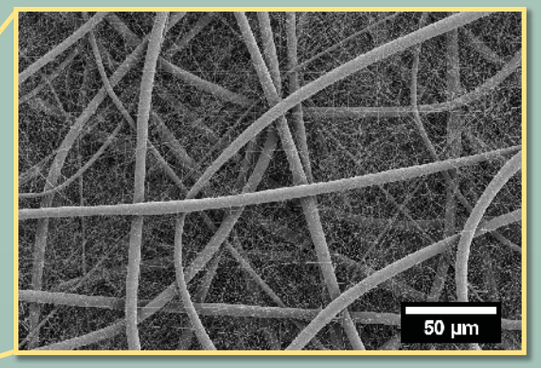
The first commercially available fog water collectors (FWCs) were created in the 1990s. They are made of meshes mounted onto metal stands with a specifically designed weave, which are used to catch droplets from the passing fog and gradually filter down the water to a container. However, existing collectors require modifications to improve their efficiency. The discovery of a method to more effectively harvest water from fog is something that researchers around the world are trying to do. A project focusing on this issue is also carried out by a team led by AGH UST Prof. Urszula Stachewicz from the Faculty of Metals Engineering and Industrial Computer Science.

'*We often draw inspiration from nature*', says team member Dr (Eng.) Joanna Knapczyk-Korczak. '*Looking at the world around us, we can find out what ways nature did devise to acquire water in places with limited resources.*' A perfect example is the *Stenocara gracilipes* beetle, which lives in desert areas and, therefore, in conditions without access to water from traditional sources. Its survival strategy is based on collecting water from the fog that forms in the early morning. Due to its hardened wings, which combine hydrophilic and hydrophobic properties, it is capable of catching droplets carried by wind, which then filter down directly into its mouth. Another inspiration came from spider webs, which, despite their hydrophobic properties, can collect water drops from rain or fog. It turned out that by copying nature, scientists can create biomimetic meshes capable of collecting water from fog, which not only resemble spider webs but also combine hydrophobic and hydrophilic properties. These meshes are made of polymer fibres with diameters spanning 100 nm to even 5 µm, and are created in the process of electrospinning. Electrospinning is a modern technique for producing nano- and microfibres from polymer solutions exposed to electric fields. '*In the electric field, a stretched polymer droplet creates a liquid jet that elongates spirally towards a grounded collector, reducing its diameter in the process*', Dr Knapczyk-Korczak explains. '*During the process, the solvent evaporates and the jet solidifies, creating a dry fibre deposited in the collector.*'

Electrospun fibres constitute an alternative to commercially used meshes for the collection of water from fog, and as a result of their high porosity and extensive surface, they facilitate efficient droplet extraction even when the fog is thin. '*Our research has proved that to create an effective system for droplet collection, you have to combine hydrophilic and hydrophobic materials*', continues Dr Knapczyk-Korczak. '*The mechanism based on this combination facilitates not only the harvesting of water drops, but also allows them to quickly filter down from the mesh to a container thanks to a special irrigation system. This solution prevents the pores between the fibres from being obstructed by lingering water, and the flow of the fog is unimpeded*'. The fog flow rate has a tremendous influence on the amount of water collected. Studies have shown that the use of electrospun polymer nanofibres in commercial meshes for water collection has increasingly improved their efficiency with no wind, when normally their effectiveness was significantly diminished. The method is also quick and inexpensive, and does not require additional chemical modifications.

Electrospun fibres are innovative materials whose application possibilities are still expanding, and using them to harvest water drops from fog is only one of them. For example, the introduction of piezoelectric nanofibres into the currently used structures could facilitate energy generation for powering small electronic devices. Certainly, current research gives hope for the optimisation and popularisation of the FWC technology, even for individual household use.

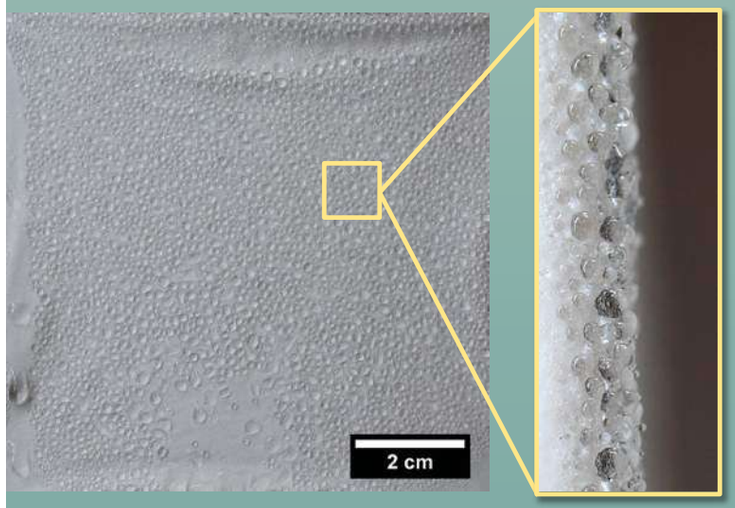
Electrospun polymer fibre mesh



Microscopic image of nano- and microfibres

Team led by **AGH UST Professor Urszula Stachewicz**
Faculty of Metals Engineering and Industrial Computer Science
Department of Physical and Powder Metallurgy

The *Bioinspired design of nanofibres network for water and energy collection* project implemented within SONATA BIS/NCN



Water droplets on the mesh

From an anechoic chamber to the opera. Innovation in room acoustics

When praising the sound quality in a concert hall or marvelling at the silence in a room, we rarely wonder what has given these places their special properties. Meanwhile, these are cutting-edge solutions resulting from long-lasting research in architectural acoustics, sound sources, materials, acoustical structures, and other acoustical parameters of rooms. Many of such solutions have been authored by scientists from the Faculty of Mechanical Engineering and Robotics.

The Laboratory of Technical Acoustics (LAT) at the Department of Mechanics and Vibroacoustics boasts an 844 m³ anechoic chamber, a 181 m³ echo chamber, labs, and auxiliary rooms. The LAT has state-of-the-art measuring equipment that allows scientists to carry out comprehensive tests and computational simulations, classes, and industrial projects. The team led by Prof. Tadeusz Kamisiński, which is currently in charge of the lab, comprises experienced assistant professors: Dr (Eng.) Artur Flach, Dr (Eng.) Łukasz Gorazd, Dr (Eng.) Adam Pilch, Dr (Eng.) Jarosław Rubacha, and doctoral students: Wojciech Binek, Aleksandra Chojak, Bartłomiej Chojnacki, Julia Idczak, Klara Juros. The LAT is also supported by the Architectural Acoustics Student Research Club. The team's multi-year work put into the successive modernisation and construction of research stands resulted in numerous scientific papers and implementations (more than 400 publications and about 30 patents).

In the field of concert and theatre hall acoustics:

- Overhead reflective panels integrated with the Schroeder diffuser, reflecting sound in a wide frequency range, used to achieve the desired acoustic effects on stage and in the audience (patent PL 227198, implemented by the Varieté Theatre in Krakow);
- Installation of a frontal wall of the orchestra pit – a barrier separating the audience – with adjustable blinds, improving sound propagation in the pit, audience, and stage by regulating sound screening and reflection (implemented by the Krakow Opera Hall);
- Sound diffusion systems for the orchestra pit, improving sound emission and acoustic comfort of musicians;
- Diffusion-sound-absorbing panels intended as an element of the acoustic screen, as the sound-absorbing and soundproofing casing, or as the diffusion structure for acoustic adaptation of rooms (patent application P.425769, design EU No. 000977053-001, implemented by the Lviv National Opera, numerous Polish concert halls, and other facilities).

As a result of the implementations by concert halls, an improvement in the sound quality received by the audience has been noticed, which expands the creative capabilities of the artists.

However, the advantages of the innovations created by the LAT team do not end there. A research project carried out in cooperation with the Poznań University of Life Sciences has resulted in the development and implementation of new honeycomb boards (patents: PL 229521 B1, 2018; PL 228784 B1, 2018; PL 232942 B1, 2019; PL 235039 B1, 2020). Several other solutions also increase the sound-absorbing qualities of furniture and the possibility of applying them to shape the acoustic parameters of interiors. The application of the research results by furniture-making companies (BeJot, Nowy Styl, MARO) allowed them to introduce their products into competitive world markets in the field of office and school interiors.

Since 2014, the team has been cooperating with CBK PAN (Space Research Centre of the Polish Academy of Sciences, Poland), MPE (Max Planck Institute for Extraterrestrial Physics , Germany), and UNIPA (Università degli Studi di Palermo, Italy), as part of the ATHENA programme. Athena is a new-generation X-ray telescope endorsed by the European Space Agency, scheduled to be placed in orbit in 2028. The task of the LAT team is to secure the UV filter of the X-ray spectrometer against the acoustic wave generated during lift-off. To do this, the team performs numerical calculations and laboratory tests using sounds of high-level acoustic intensity (142.5 dB).

A 600 × 115 mm panel was made from PVC and wood dust composite. One side of the panel was designed as the Schroeder diffuser based on the prime number 7, the other as three convex half-cylinders.

Diffusion-sound-absorbing panels in the Lviv National Opera

Team led by **AGH UST Professor**
Tadeusz Kamisiński
Faculty of Mechanical Engineering and Robotics
Department of Mechanics and Vibroacoustics

The frontal wall of the orchestra pit in the Krakow Opera – sound screening and reflection by the elements of the barrier

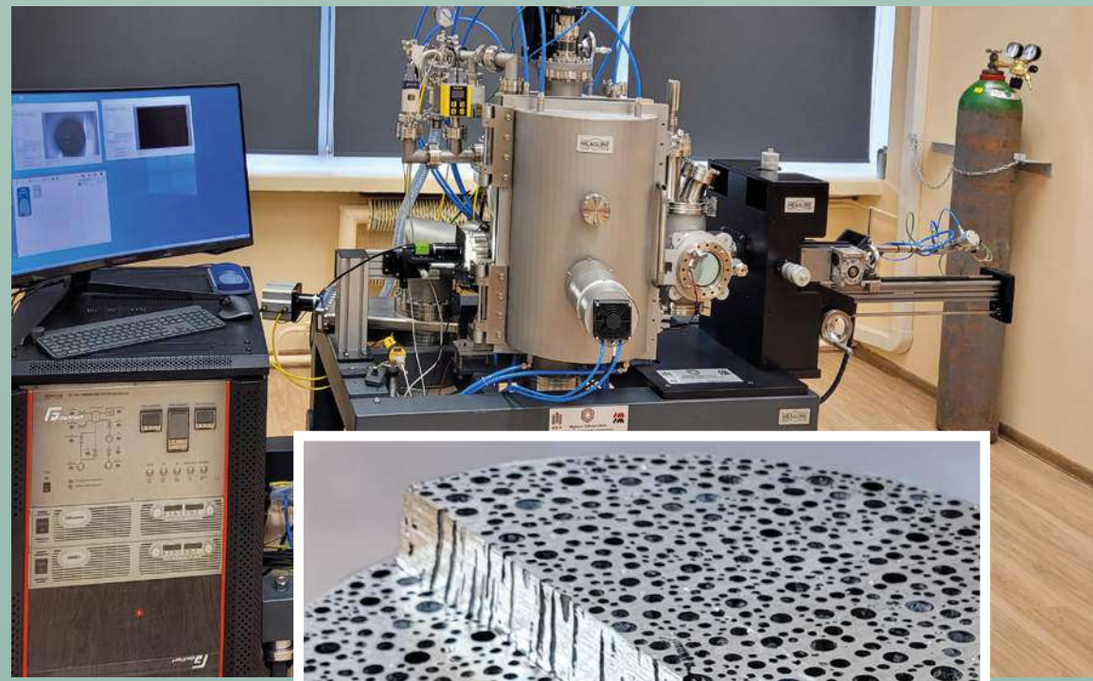
Gasars – light and resistant materials for innovative applications

Ultralight, resistant, sound- and energy-absorbing, mechanical vibration-damping – these are just a portion of the properties of gasars, highly porous that are created by pumping gas into a liquid metal (magnesium, for example) under high temperatures. They can transform our everyday lives, making them literally lighter. The benefits abound: reducing weight of everyday objects, e.g. laptops, will make them more comfortable to use, and lowering vehicle mass will reduce energy consumption and, by extension, the harmful impact on the environment. Therefore, the AGH UST works towards developing a technology to produce these unique materials.

Gasars, lotus-shaped structures, are a new class of porous materials with unique operational properties that can positively influence many aspects of our lives. They are made in special digesters with hydrogen, a gas that is widely used in electric vehicles. Because of the presence of hydrogen, the process might seem dangerous, but modern technology and knowledge allow us to do it perfectly safely, using a mixture of other, less explosive gases. In this case, hydrogen is not an energy-storing gas, but it plays the role of an element that shapes the structure of the porous material. Controlling the concentration of hydrogen atoms, temperature, and pressure, we have practically unlimited possibilities of creating structures with a controlled pore distribution. Therefore, these unique materials, which contain up to 70% hydrogen, are ultralight and possess a set of material properties absent in other porous materials, such as metal or syntactic foams.

Gasars are perfect for absorbing sound and energy waves, and they show a high damping capacity; additionally, provided that they contain a ceramic content, they are good at conducting high temperatures. Moreover, they are perfect in places where mass is the key issue, i.e. in all kinds of machines here on the Earth and in space. This is what virtually all industries are after – starting with automotive, through arms, to space. The automotive and aviation industries aim to make the materials they use more durable and lighter at the same time, so that the ratio of durability to density is as high as possible. And this is the chief objective of innovation in the entire world industry. Gasars can be applied to light construction materials, radiation or kinetic energy absorbents, and atomisers/mixers of fuel. Currently, they are used as filters in the chemical industry, insulin filters in medicine, radiators, parts of rockets and rocket engines, space equipment elements, or implants in reconstructive surgery.

The Liquid Metal Engineering Laboratory at the Faculty of Foundry Engineering investigates the phenomena of creating porous structures in the presence of active gases, but also the interactions between materials used to build digesters. The team of Professor Jerzy Sobczak, in cooperation with the PAN Institute of Metallurgy and Materials Science together with MeasLine company, have developed a mobile stand for testing the properties of liquid metals, alloys, glasses, slags, and other substances in a wide range of melting points. It allows the scientists to recreate the conditions of gasar synthesis, which facilitates the understanding of the process of controlled porosity creation. The device allows the researchers to “take a peak” of places currently unavailable due to pressure and high temperatures inside the pressure reactor. Further research into gasar synthesis methods, the improvement of process efficiency, and control over the structure of the material will become more broadly available after the conclusions of two projects (OPUS16 and OPUS21) funded by the National Science Centre.



Team led by **Professor Jerzy J. Sobczak**
Faculty of Foundry Engineering
Department of Moulding Materials, Mould Technologies, and Casting of Non-Ferrous Metals

The importance of a healthy spine. Robotic rehabilitation support

Afflictions of the musculoskeletal system, especially spine problems, are among the most common health problems in highly developed countries. Estimates say that pathological curvatures in the coronal plane of the spine affect 68% of the population. Therefore, in addition to effectively diagnosing spinal pain syndromes, we should also focus on preventive measures for spine diseases and rehabilitation.

Rehabilitation is a long-lasting process that requires patience, regularity, and involvement of both the patient and the rehabilitator. To be successful, rehabilitation must use a variety of techniques and exercises, but also reach for specifically designed tools and medical equipment.

To answer these needs, Professor Jerzy Kwaśniewski and Dr (Eng.) Szymon Molski, from the Faculty of Mechanical Engineering and Robotics, developed a device for individual rehabilitation in afflictions of the spine, muscles, and nervous system. It is an automated lifting system for muscle stimulation, protected by patent PL 226008 and patent application P.431381.

Currently, the market offers simple, manually operated devices for exercises in suspension that comprise a frame bearer, lines, slings, and weights to suspend selected parts of the patient's body. This invention proposes to substitute the weights with mechanical actuators, the position and operation of which can be controlled by a computer.

This technological solution allows patients to generate a precise and smooth movement by isolating specific segments of the body, while simultaneously changing the position in three planes – in any configuration for each pair of actuators. The configurations include:

- Twisting movements, lifting and lowering the head, shoulders, and hips (in various amplitudes, movement speeds, frequencies, etc.)
- Side movements of the trunk
- Extremities movements with the use of a drum motor
- Possibility of generating spinal traction and partially or entirely non-weight bearing exercises with or without traction

The fact that the actuators are completely automated allows patients to achieve high precision of movement with maximum security and control over the rehabilitation process.

Therefore, the device combines the functions of the multi-layer spinal traction with a possibility to perform partially or fully non-weight bearing exercises, creating numerous potential ways of working with patients suffering from acute and persistent spinal pain syndromes. This functionality removes the weight off the rehabilitator, who does not have to use their own strength to lift the patient and rehabilitate them in suspension. This is especially important in overweight and obese patients. The device can not only improve and perfect the rehabilitation process, but also increase its availability for bariatric patients.

To make it happen, scientists need to develop specialised software that will tune the device to the individual needs of each patient. The software will contain a library of cases with dedicated exercise sets. It will also facilitate the visualisation of a spine model and manual control over the respective actuators. The data collected by the device will allow the software to create a model of vertebrae movements, based on which the optimal rehabilitation methods will be chosen. Rehabilitators will have a possibility to create their own sets of exercises or use ready-made programmes so that they can adjust the device to the needs of their patients. The database will record the frequency of exercises, allowing the rehabilitators to verify the completion of the rehabilitation plan by their patients, which, in turn, will enable them to assess individual rehabilitation sessions performed by patients on their own.

The device and its functionalities are currently being developed as part of a project at the National Centre for Research and Development, which is intended for industrial research and development and pre-implementation works carried out at the AGH UST and the Military University of Technology in Warsaw.

Professor Jerzy Kwaśniewski
Dr (Eng.) Szymon Molski
Faculty of Mechanical Engineering and Robotics
Department of Machinery Engineering and Transport

R&D work carried out within an NCBR project

Interventional method to reduce particulate matter concentrations in the smog layer

PM pollutants are the cause of a considerable number of diseases and premature deaths. The air quality evaluation in Poland for 2020, prepared by the Chief Inspectorate of Environmental Protection, have shown that in 16 out of 45 zones the PM_{10} concentration exceeded EU and Polish norms. Therefore, any action, including interventions, is necessary to reduce PM pollution. This goal can be achieved by accelerating air mass movements to prevent the formation of smog or to disperse it more dynamically.

The formation mechanism of high PM concentration in the troposphere is well-known. Unfavourable meteorological conditions (no wind and rainfall) and topography (depressions, valleys, basins) hamper the natural movement of air masses, causing local increases in pollution concentration emitted at low altitudes. What is particularly relevant for smog formation is thermal inversion (an increase in temperature linked to altitude in the troposphere) that reduces the vertical movement of air. This traps the pollution from low emissions in a stable air mass below the layer of warmer air, which rapidly increases the concentration of contamination near the ground.

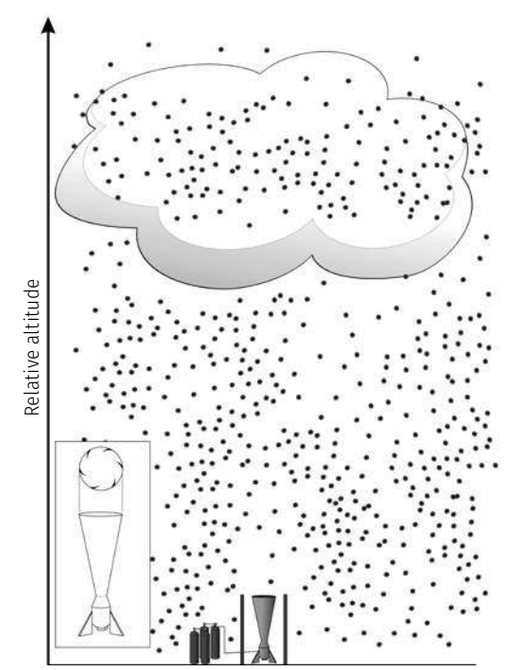
A solution to this problem and a temporary reduction in air pollution levels may be the invention developed by the team comprised of Prof. Jacek Leszczyński, Prof. Barbara Kubica, Prof. Wojciech Suwała, AGH UST Prof. Marcin Stobiński, AGH UST Prof. Katarzyna Szarłowicz, Dr (Eng.) Janusz Zyśk, Dr (Eng.) Filip Jędrzejek, and Dominik Gryboś, MSc Eng. from the Faculty of Energy and Fuels, as well as Prof. Jerzy Wiciak and Dr (Eng.) Dorota Czopek from the Faculty of Mechanical Engineering and Robotics. The technology relies on interventional reduction in $PM_{2.5}$ and PM_{10} concentration levels due to the destruction of the inversion layer by generating warm shockwaves. They are created in a specialised generator as a result of ignition of a mixture of flammable gases and air. By generating a set of several hundreds of such waves in an hour, the device forces a stack effect that transports cold air with particulate matter above the warmer layer. As a result, the natural convection mechanisms of air masses are partially restored.

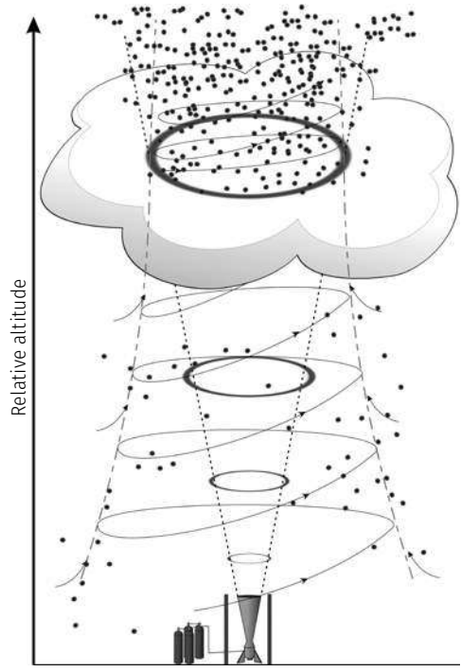
The solution comprises a shockwave generator, mobile measuring equipment, and a special operational algorithm. The air quality monitoring system is equipped with an autonomous drone that collects data on the concentration of pollution and meteorological conditions. By relaying the data to the central unit, the location and parameters of the inversion layers are determined, as well as the concentration of PM in vertical distribution. Based on that information, the frequency and duration of shockwaves are determined.

Two-year tests have shown that the system, as one of the few available solutions, can contribute to a temporary local improvement in air quality, as during a short intervention, it can reduce the concentration levels of PM_{10} and $PM_{2.5}$ in the area of 4 km^2 by at least 15%, and by 70% at the maximum.

The invention was submitted to the Polish and European Patent Offices and, in 2021, it won a gold medal at the 48th International Exhibition of Inventions in Geneva. The creators wish that it be soon used in interventional actions to reduce the time of human exposure to pollution by counteracting the formation of smog, shortening the periods of stagnation, and accelerating the process of dispersion. During the implementation phase, the scientists plan to cooperate with selected communes, with which they had already signed agreements. The system should be widely used, should the need arise, analogously to the response teams for road icing.

The system is still in development, especially in terms of the decision-making algorithm that would allow the device to autonomously begin an intervention based on input data collected via the analysis of meteorological conditions favourable to the formation of the inversion layer. Other research paths include the modification of the generator structure to enhance its capabilities and reduce noise.





Team led by
Professor Jacek Leszczyński
Faculty of Energy and Fuels
Department of Thermal and Fluid Flow Machines

R&D work carried out within a project funded by the Ministry of Education and Science

Mixed reality in detecting neurodegenerative diseases

MR/VR goggles are devices that make it possible to accurately mirror the user's movements in digital reality using a set of built-in sensors. Why not then use the processed signals in medical diagnosis?

Neurodegenerative diseases, which are accompanied by progressive and irreversible nerve cell degradation, manifest themselves most often in old age. The problem of aging populations is a dominant trend in developed countries, resulting in the rising percentage of people suffering from neurodegenerative disorders. Therefore, not only the development of an effective treatment method becomes a burning issue, but so does a method of precise and rapid diagnosis.

The two most fundamental methods to evaluate the condition of patients with dementia are anamnesis and physical examination. On their basis, doctors fill out medical charts which are then used to make a diagnosis on the type of disease and its stage. It is a time-consuming and fallible process because it is based on subjective feelings of the patient and observations of the doctor. It would be much more reliable to work with hard data. A helping hand is offered by biomedical engineering, which for a long time has been developing methods of collecting and processing various signals generated by the human body.

Developing methods to record signals and process them in order to diagnose neurodegenerative diseases, such as parkinsonism or Huntington's disease, is the goal of the team led by Dr Daria Hemmerling from the Faculty of Electrical Engineering, Automatics, Computer Science, and Biomedical Engineering. To obtain the signals, the scientists want to use mixed reality (MR) HoloLens 2 goggles.

What is mixed reality and what distinguishes it from virtual reality (VR)? The latter is commonly associated with video games, where putting special goggles allows the player not only to see the action on the screen, but also to become directly involved in it. In the case of mixed reality, we are dealing with a hybrid of the real world and the digital objects incorporated therein that can be manipulated. It has been increasingly used in professional settings. This allows surgeons to perform tutorial surgeries on 3D holograms of the patient's organs, and technicians to plan the installation of various elements of the physical space using their virtual models.

To make such surgeries happen, goggles developed for this purpose are equipped with precise cameras, microphones, and sensors that track user behaviour. And this is exactly what the AGH UST engineers want to use to collect diagnostic data from the patients. Using mixed reality, patients would be able to see the image of their doctor who would be able to ask them to perform one or several actions at a time, for example, walk a few steps back and forth, move their arms in a specified way, or say a few words. The system will collect data, such as posture, movement smoothness, or articulation, and the rate of speech in real time, which can be essential in making a diagnosis. It will also track saccades, that is, involuntary movements of the eyes, which vary between sick and healty persons.

Using the data collected by MR goggles, the scientists want their solution to achieve an 80% efficiency rate in making accurate diagnoses. If this is successful, it will be the first device in the world to facilitate simultaneous registration and analysis of multiple signals that are crucial in the process of detecting neurodegenerative diseases.

'We have come up with a prospective idea of having one device that will produce one examination record. This will make it possible to evaluate all parameters that we can measure with it (in the same way for every patient at various moments in time, etc.). The device might prove very useful for filling out medical charts, an activity that doctors have to do themselves. Now, instead of doing paperwork, the doctor will be able to focus on observing the patient because they will be tested by the mixed reality system', says Dr Hemmerling. The scientist also hopes that the data collected from a considerable number of patients will allow doctors to discover correlations between particular parameters, deepening our knowledge on parkinsonism and Huntington's disease. To analyse the data, engineers have to design artificial intelligence algorithms that will be able to find regularities in the signals and correlate them with specific nosological units. The last stage will include the creation of an app for computers and smartphones, which will allow doctors to make good use of the new system.

Team led by
Dr (Eng.) Daria Hemmerling
Faculty of Electrical Engineering, Automatics, Computer Science, and Biomedical Engineering

Project titled *The use of mixed reality to diagnose and evaluate the stage of neurodegenerative diseases* funded within LIDER/NCBR

HoloLens 2 goggles used for tests

New biodegradable Controlled Release Fertilisers – a green alternative for land cultivation

A growing demand for plant-based products leads to looking for new ways of boosting agricultural production. This entails a massive use of a variety of synthetic fertilisers, which do enhance productivity, but at the same time lead to soil degradation processes. This is practically irreversible damage – soil formation depends on a myriad of complex factors, and the whole process can last even thousands of years.

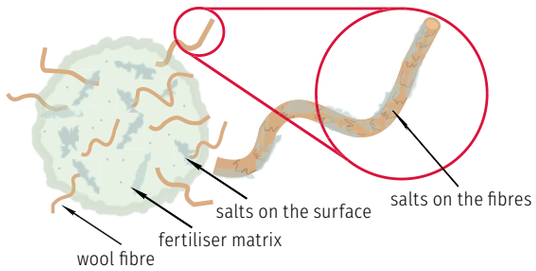
To increase the concentration of nitrogen, which fosters plant growth, food producers most often use compound mineral fertilisers. These constitute even 56.9% of the nutrient elements (nitrogen and phosphorus) in the cultivated soil in Poland. The data are alarming because such a robust use of mineral fertilisers can lead to a series of phenomena that are unhealthy for the environment (soil acidification, eutrophication) and climate (no plants on degraded land means no greenhouse gas absorption). It is also related to the use of considerable amounts of non-renewable materials and fossil fuels. Therefore, it is essential to develop better and more ecological methods of providing plants with nutrients.

This has become possible due to controlled release fertilisers (CRFs) made from biodegradable substances that will not overburden the environment and will not cause its deterioration. CRFs contain biogenic elements in a form that a plant cannot absorb immediately. They are usually coated or encapsulated using materials that facilitate controlling the rate, mechanism, and the release time of nutrients.

Research on CRFs is carried out at the AGH UST Faculty of Materials Science and Ceramics at the Department of Biomaterials and Composites. There, Dr (Eng.) Piotr Szatkowski and Katarzyna Suchorowiec, Eng. managed to optimise the process of producing such fertilisers, and investigated and evaluated their properties over time, in comparison to corresponding conventional mineral fertilisers (CRF-AGH and the tested mineral fertilisers had identical contents of biogenic elements). The tests regarding the effect of the developed fertilisers, composed of a mixture of mineral salts (23%), biopolymer (70%), and excipients (7%), were conducted in laboratory conditions on crops of various plants, including lacy phacelia, oat, and panicgrass. The crops underwent a simulation of rainfall and based on the amount of water that penetrated the soil and filtered down to a sealed container, the scientists determined the concentration of salt eluted therefrom. As it turned out, the concentration of eluted salts was higher in samples with a commercial fertiliser. Those plants that had received CRFs exhibited thicker stems and more intense colours. Additionally, they showed an improved ability to accumulate water compared to plants cultivated on other substrates (CRF-AGH accumulated and retained water in the soil – due to a natural excipient).

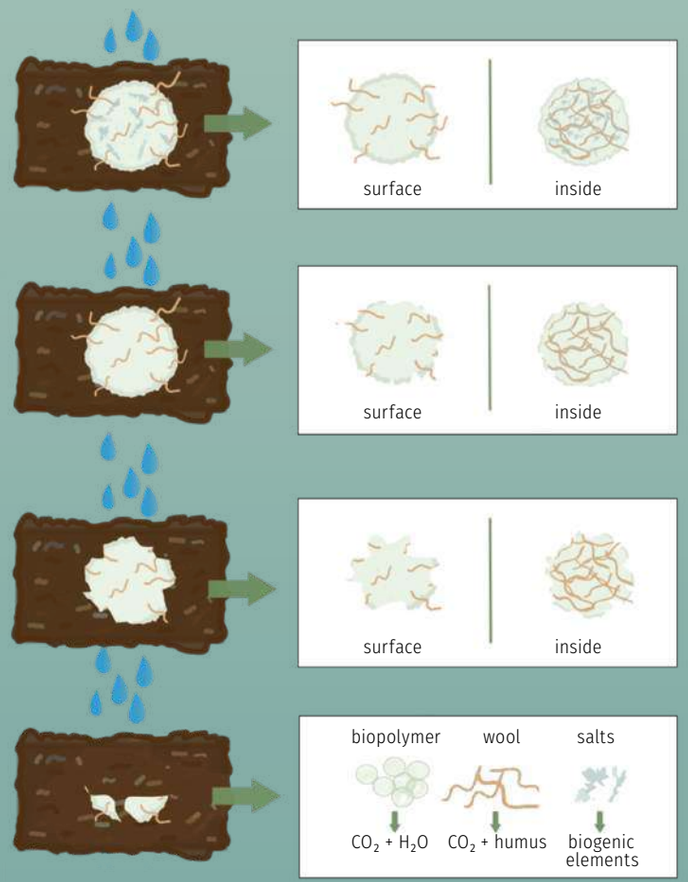
CRFs hold promise in terms of their use to fertilise plants that grow in water, which may also need to be supplemented with biogenic elements. To date, the possibility of fertilising such plants has been significantly limited due to a sharp increase in the concentrations of mineral salts in water, which has led to excessive salination and eutrophication. The AGH UST scientists studied the behaviour of their fertilisers in water. Based on the results, they claim that both in the initial phase and after long-term exposure, the CRF-AGH releases the accumulated salts gradually and proportionally, which means that the salt concentration increases by the same value in the same amount of time. The presence of an inhibitive barrier (several release mechanisms at once) causes the CRF used in aquatic environments (e.g., for aquarium plants) to decompose in a controlled way, which cannot be achieved with conventional synthetic fertilisers, as they dissolve immediately. For example, precise fertilisation of rice with the CRFs described above would result in a far less severe interference with the environment, both in terms of farmland and the areas surrounding it. A wider use of CRFs would give plant producers an opportunity to take serious responsibility for the ecosystems around them.

Structure of the CRF granule and its decomposition



Surface of the CRF granule

Team led by
Dr (Eng.) Piotr Szatkowski
Faculty of Materials Science and Ceramics
Department of Biomaterials and Composites



A new lease of life to oil and gas wells. Recovering lithium from produced water

The process of extracting oil and gas involves large quantities of brine, which may constitute a source of economically valuable elements. One of such is luthium, in demand by the automotive industry, where it is used to produce batteries to power electric and hybrid vehicles.

Hydrocarbons are not the main product extracted from oil and gas reservoirs. Rough estimates say that for 1 m^3 of petroleum, there is 3 m^3 of brine. As the extraction process continues, the ratio of water used to produce oil or gas increases steadily to the point where it is practically the only product. At best, brine is pumped back to the well, where it is used to displace oil or gas to the surface. However, this process cannot continue forever, and the hydrocarbon extraction business, sooner or later, ceases to be profitable. Simultaneously, the produced water itself can be the source of industrially valuable elements, if only we can manage it properly. The world is turning away from fossil fuels in favour of low-emission energy sources, which might give the old wells a new lease of life. This is the goal of engineers from the Faculty of Drilling, Oil, and Gas, who carry out the *CompLithium* project – a comprehensive technology of recovering lithium and sweet water from produced water.

Lithium does not occur naturally in an elemental form but in the form of lithium salts. In a warm climate, the element is extracted from brines concentrated in large ground pools by solar evaporation, using various precipitation techniques. If these methods fail, nanofiltration membranes and sorbents are used. *'Sorbents described in the literature to date occur in the form of powders that are difficult to use on large scales',* says Dr (Eng.) Ewa Knapik, the project leader. *'Our sorbents will be prepared using 3D printing so that we can create high-porosity spatial mouldings. They could be regularly placed in adsorption columns through which the brine passes continually.'*

The adsorption columns are part of a comprehensive apparatus that could be installed in oil and gas production sites. The machinery would simultaneously recover lithium and sweet water from the brine. The recovered water could then be used to irrigate neighbouring crops or to produce steam at the production plant. To desalinate brine, the scientists intend to use crown-ether-modified nanofiltration membranes, which will allow them to capture residual lithium that had not been previously recovered in adsorption columns. The currently used installations can recover either lithium or sweet water from brine, but cannot perform these two functions simultaneously. Merging them into one process will constitute an innovation. *'In the first phase, the installation will perform the initial treatment, i.e. coagulation and filtration',* explains Dr Knapik. *'The brine extracted from the reservoir contains petroleum derivatives, particulates, and dissolved gases. All contaminants must be removed so that they don't damage our adsorption module or the membranes. The second stage involves adsorption columns directly intended for lithium recovery. These columns work always in a dual system – when one captures lithium, the other gets regenerated – this means that the element is being eluted from it. The next phase is desalination using membranes. As a result, we always get two streams: sweet water and concentrated brine. In our technology, the latter will be pumped back to the reservoir.'*

For the apparatus to be economically profitable, formation waters must contain adequately high concentrations of lithium (at least 10 mg/1 L of water). Therefore, another important goal of the project is to investigate Polish brines in terms of their concentration. *'We've received first signals that there are a few prospective loci. Lots of such reservoirs are on the Polish Lowland, where the waters show high mineralisation. If they contain many different salts, there is a chance that lithium salts are among them,'* Dr Knapik says.

The scientists want to create a useful application that will allow its users to determine whether lithium recovery in a given area is profitable for a prospective investor. Apart from showing the concentration of the element itself, the application will consider the amount of extracted water, the pressure in a particular reservoir, or the presence of other ions. With a few modifications, it will later be used to choose the most magnesium- or potassium-rich brines.

Team led by **Dr (Eng.) Ewa Knapik**
Faculty of Drilling, Oil, and Gas
Department of Petroleum Engineering

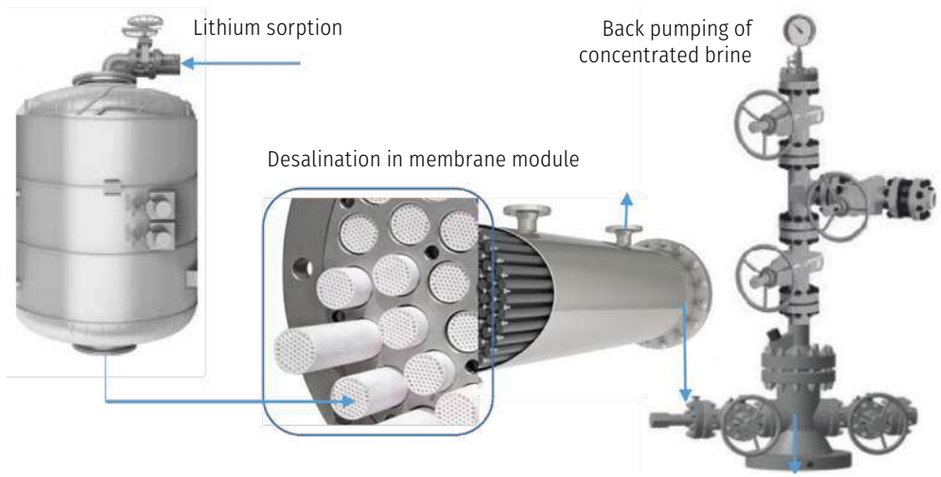
The *CompLithium* project carried out within a LIDER/NCBR project

Starting materials

reservoir brine

sorbent in the form of a moulding

Final configuration of the installation



Otoimplant – polymeric middle ear prosthesis with bactericidal effect

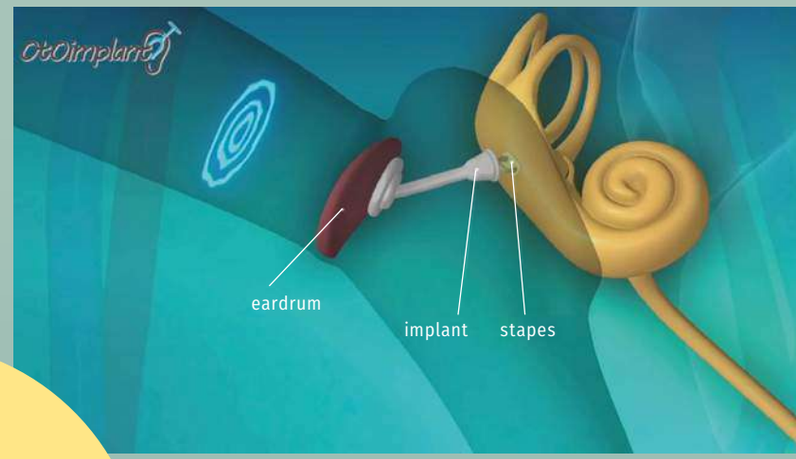
Middle ear infection, one of the most common otolaryngological ailments, can lead to conductive hearing loss due to the degeneration of bone structures within the middle ear space. The chief aim of modern ear microsurgery is to restore the function of the sound conduction apparatus. In situations of very extensive damage to the auditory ossicular chain, the use of prostheses is recommended. The application of new middle ear implants not only restores the continuity and function of bone structure in patients, but also reduces the risk of complications from bacterial infections.

These are exactly the features of the innovative prosthesis, in terms of shape and function, called Otoimplant, created by AGH UST Prof. Magdalena Ziąbka as part of her research conducted at the AGH UST Faculty of Materials Science and Ceramics. The research work included designing the prototype, its shape, structure, form, and chemical composition. It resulted in the creation of two implants: An Otoimplant made of polymeric material and the innovative Otoimplant containing nanoparticles of silver.

The implant's material can trigger various post-surgical responses. Modifying the composition, as it was done in this case, creates the possibility of changing the mechanical and biological parameters of the functionalities of the prosthesis. Tests have shown that the implant, made of composites, biostable thermoplastic polymers, and silver nanoparticles, is safe to use, is compatible with commonly applied surgical procedures, and can be used successfully in patients. It also shows two additional effects: it is bactericidal and super light, which eliminated the need to administer antibiotics after surgery and reduced the recovery period; furthermore, patients reported greater hearing improvement than in the case of patients with other types of reconstructions.

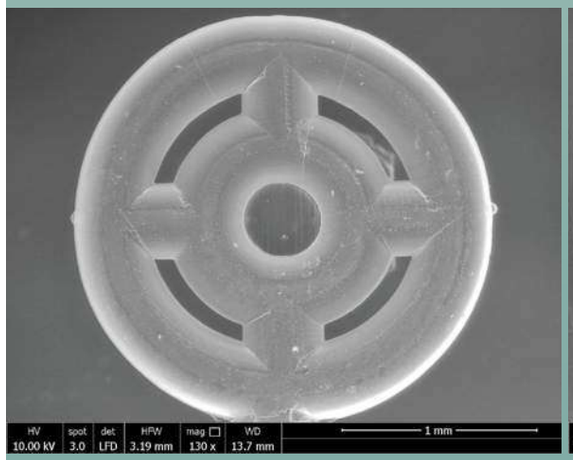
Otoimplants have been tested in terms of their physicochemical properties, such as mechanical strength, Young's modulus, or hardness. The distribution of nanoparticles in implants and their durability were investigated using ultrasound. The scientists performed structural tests, assessing the microstructure, conducting X-ray diffraction tests, and carrying out thermal tests, which were followed by biological in vitro studies. The bactericidal efficiency against Gram+ and Gram– strains of bacteria was assessed, which are the most frequently occurring bacteria in the middle ear. The volume of silver ions released to the biological environment during incubation was investigated to determine safe levels of this element in the organism. Studies were conducted on the cytotoxic effect and the life span of human cells after interaction with the implant. The scientists used human osteoblast and fibroblast cells to do this. The next stage included *in vivo* experiments on animals, which were implanted with both types of devices to check the reaction to the foreign body and to confirm the biocompatibility of both prostheses. *Ex vivo* tests of tissue components and CT scans were then performed to check the durability of the implants. The final phase entailed obtaining necessary approvals and permits from the Bioethics Committee and the President of the Office for Registration of Medicinal Products, Medical Devices, and Biocidal Products for clinical trials with patients. 6 patients received innovative Otoimplants and underwent observations after 7, 30, 90, 180, and 360 days. All tests were successful and patients' hearing had improved.

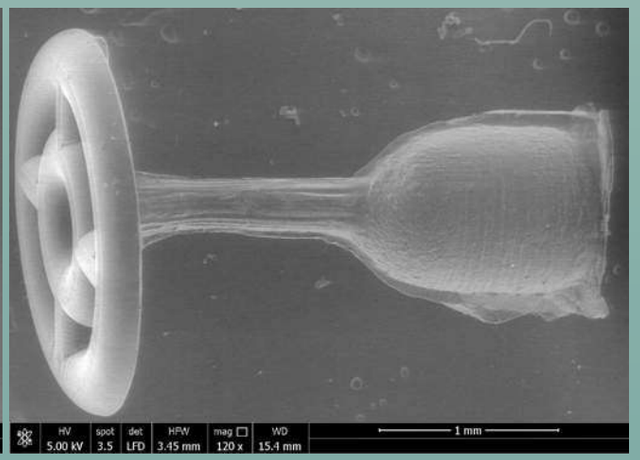
With the implementation of all stages of development, the implant can be successfully introduced into modern otolaryngology in patients with damaged ossicular chain resulting from inflammation, trauma, congenital defects, and otosclerosis. The Otoimplant solves the problem of hearing loss that causes social exclusion and gives patients an opportunity to resume normal functioning.



Team led by **AGH UST Professor Magdalena Ziąbka**
Faculty of Materials Science and Ceramics
Department of Ceramics and Refractories

R&D work carried out within a LIDER/NCBR project





Saving Achilles. Towards modern diagnostics of tendon diseases and failures

Tendons are tissues that are particularly vulnerable to mechanical injuries resulting from overloading them during physical activity. They remain relatively under-researched, especially in the context of pathological changes and therapy planning. Connective tissue studies in terms of the influence of structural and biochemical changes on its functioning are interdisciplinary by nature, which, coupled with the fascinating hierarchical and multiscale tendon structure, motivated the AGH UST scientists to attempt to describe the biomechanics of these pivotal tissues.

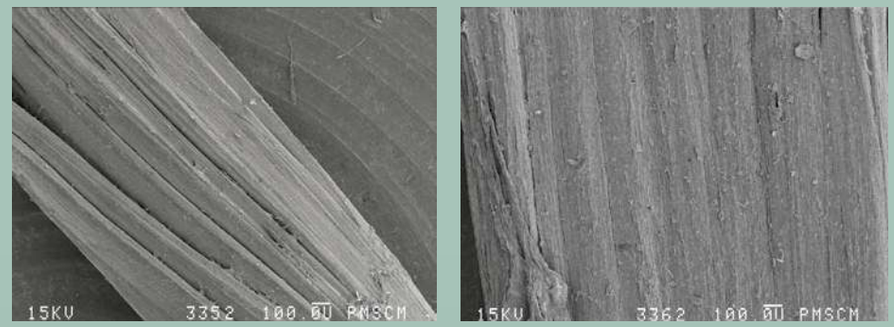
To respond to the need for a deeper understanding of the pathomechanisms of tendon failure and to correlate this knowledge with clinical and diagnostic images from USGs and MRIs, the AGH UST Team for Tissue Biomechanics has been researching the issue for years. The National Science Centre (NCN) projects, including the *Electro-chemo-mechanics of tendon failure – the role of interfascicular matrix, calcium and phosphate ions in tendon biomechanics* project, resulted not only in practical knowledge useful for diagnosticians and orthopaedists, but also in a series of valuable publications.

The interfascicular matrix, as described by the scientists, is responsible for the viscoelasticity of the tendon and controls the biomechanics of the fibres during overloads. It is mostly exposed to transverse deformations caused by the sliding of discontinuous subcomponents of the Achilles tendon. The team's work facilitated the early diagnosis of tendon enthesopathy caused by transverse deformation, leading to serious failures. For the first time in the literature, the scientists characterised the tendon subcomponents linking the calcaneus with various muscles (SOL, GM, and GL) in terms of viscoelastic properties stemming from structural and functional differences. In conjunction with demonstrating the correlation between the viscoelastic properties and the blood plasma diffusion phenomenon observed in MRI scans, this allowed the scientists to evaluate the condition of the interfascicular matrix, responsible for carrying axial stresses and the stability of the entire structure. To obtain these results, they had to devise a new system for building 3D tendon models, crucial in inverse analysis and material characterisation, as well as use 3D DIC analyses.

Thanks to the work of the AGH UST scientists, orthopaedists and diagnosticians have received a set of new diagnostic clues and new therapeutic goals. The team's research led to:

- Describing the differences between the biomechanical properties of the tendon subcomponents from various calf muscles, which facilitated the interpretation of differences observed during ultrasound elastography, and helps making more precise diagnoses
- Describing the deformation and strain in the matrix, occurring during tendon overload; explaining the mechanism of longitudinal tendon enthesopathy, which allowed orthopaedists to diagnose early stages of tendon failure and to treat it without surgical intervention
- Proving that the permeability and viscoplasticity of the interfascicular matrix is responsible for the biomechanics of the tendon, and demonstrating the possibility of diagnosing its condition, thus providing new possibilities for interpreting MRI and USG scan results. Another goal was to improve current diagnostic methods, so that orthopaedists could precisely assess the state of the matrix based on the available imaging methods. The matrix's elasto-visco-plastic properties change, for example, in the initial stage of tendon calcification or in the event of an electrolyte imbalance of the organism. These clues are invaluable when choosing diagnostic methods and treatment strategies.

The results have been put into practice, for example, in the Krakow medical centre "ULTRAGEN" that diagnoses and treats athletes designated by the Polish Olympic Committee and the Polish National Football Team.



**Images of Achilles tendon samples under a scanning electron microscope:
a) ultrastructure of the tendon after tendon enthesopathy caused by excessive loading,
b) control sample**

Team led by **AGH UST Professor Andrzej Młyniec**
Faculty of Mechanical Engineering and Robotics
Department of Robotics and Mechatronics

Project carried out within OPUS/NCN

The Achilles tendon divided into three subtendons (GM, GL, and SOL) and an anterior view of the GM subtendon

Senster's new life. Strategies of preservation and reactivation of interactive pieces of art

It was more than 5 metres tall and looked like an unidentifiable animal. Although made of steel, its movements were nimble due to the synchronised work of eight actuators. The change of position was navigated by a computer program. "Senster" reacted to nearby sounds and movements, reading signals collected by microphones and Doppler radars. It ceased moving in the mid-1970s. However, the efforts of a team of scientists and designers brought it back to life in 2018.

RE:Senster – this is the name of the endeavour to reconstruct one of classical media art pieces – a large-scale kinetic installation "Senster", created towards the end of the 1960s by Edward Ihnatowicz. Designing "Senster", Ihnatowicz made allusions to the experiences of contemporary robotics and artificial intelligence experiments. His work, counted among the canon of digital art and constantly revisited in studies dedicated to the interface of science, technology, and fine arts, has for long been considered lost. Its remnants were rediscovered and "reanimated" due to the efforts of a team established at the AGH UST Faculty of Humanities.

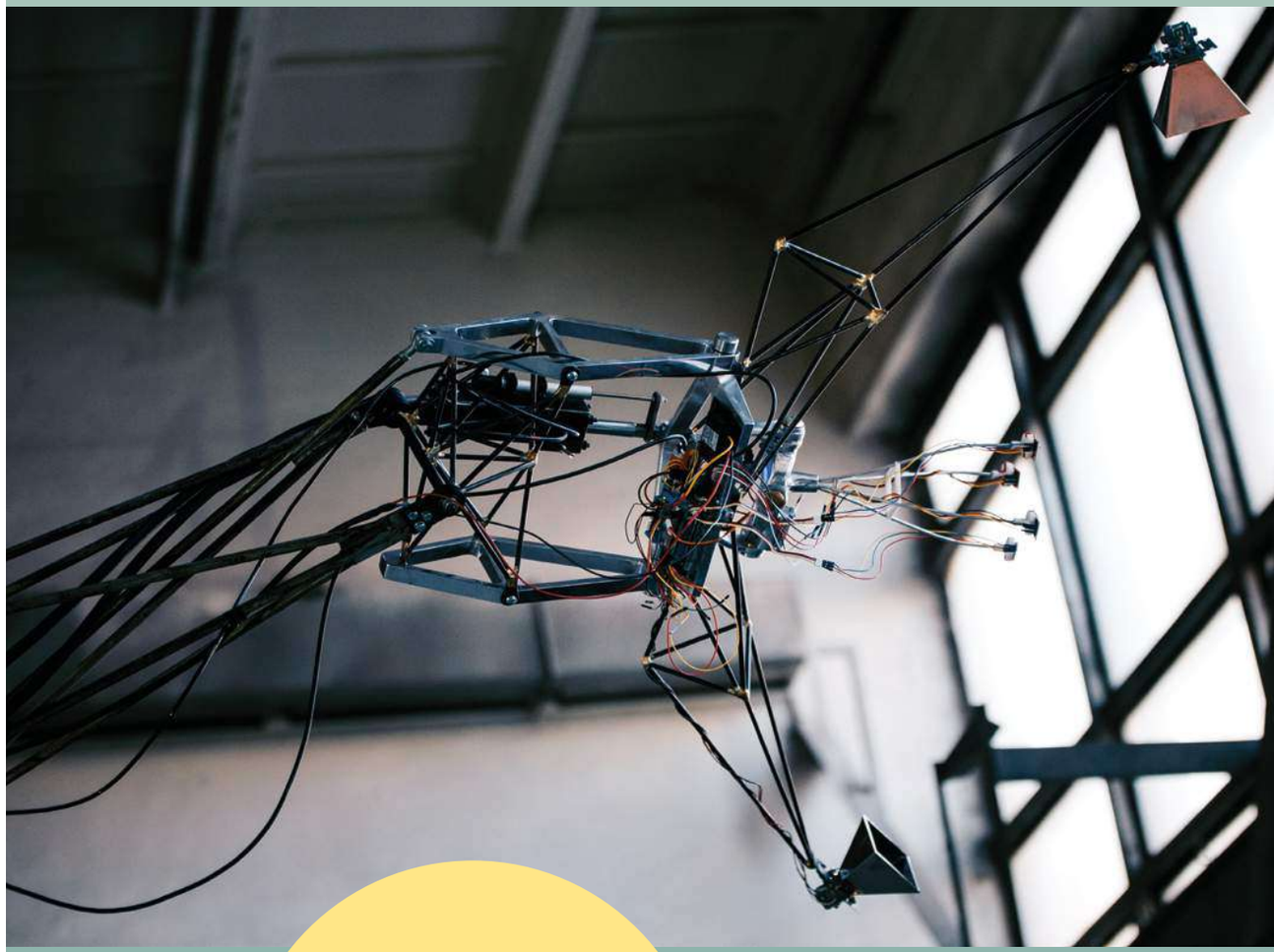
The project brought together specialists with multifarious research competencies, from the humanities – cultural studies on technology and media art, through preservation and curator efforts, to mechanical engineering, robotics, and automatics. The creation of this interdisciplinary team was necessary to develop a holistic strategy to reactivate the work, carry out an extensive source query, and find suitable technological solutions. As a result, RE:Senster, together with accompanying events, carries the torch of transferring the modern humanities into the domain of science and technology. The scientific activities of the team revolved around developing a strategy to restore technological treasures and maintain the continuity of modern pieces of art. The project contributed to the development of preservation procedures and rules of exhibiting large-scale art pieces that use advanced technological solutions, characteristic of creations from the second half of the 20th century.

The RE:Senster Lab – a laboratory for media art established during the restoration work – integrates the community of specialists and offers technical and conceptual support, indispensable for a performative (moving object) presentation of new media art in museums and art galleries.

Only two years after the work had been concluded, the project was spotted by art curators and aficionados in Poland and abroad. "Senster" was exhibited during the jubilee edition of the WRO Media Art Biennale (2019), in the Zachęta – National Gallery of Art in Warsaw (2020/2021), during the Sapporo International Art Festival in Japan (SIAF 2020 – online edition), and during the UNSOUND, Patchlab, and Audio Art festivals.

Fostering media art and, in a broader sense, digital culture required competencies that go beyond the knowledge acquired within universities, museums, or technological companies. The RE:Senster project contributed to the expansion of the cultural capital by consolidating the technical sphere with social circulation: educating young researchers and designers, provoking discussions in the field of art criticism, and popularising discourses of modern humanities outside the walls of academia.

The originator and curator of the project was Dr Anna Olszewska. The reactivation of the installation was carried out in cooperation with the Faculty of Mechanical Engineering and Robotics (mechanics: Dr (Eng.) Jerzy Stojek, Kamil Sikora, MA), the Faculty of Electrical Engineering, Automatics, Computer Science, and Biomedical Engineering (control: Dr (Eng.) Marek Długosz, Rafał Bieszczad), and the Faculty of Computer Science, Electronics, and Telecommunications (radars: AGH UST Prof. Kamil Staszek, Prof. Sławomir Gruszczyński). The project was carried out in collaboration with the Academy of Fine Arts in Krakow (consultations, bringing the installation to Krakow, sound interaction system, documentation). The interuniversity cooperation was coordinated by AGH UST Prof. Anna Siwik.



Team led by
Dr Anna Olszewska
Faculty of Humanities
Department of Culture and Digital Age Studies

RE:Senster project

Shall we trust artificial intelligence? AI algorithms in robotics and virtual reality

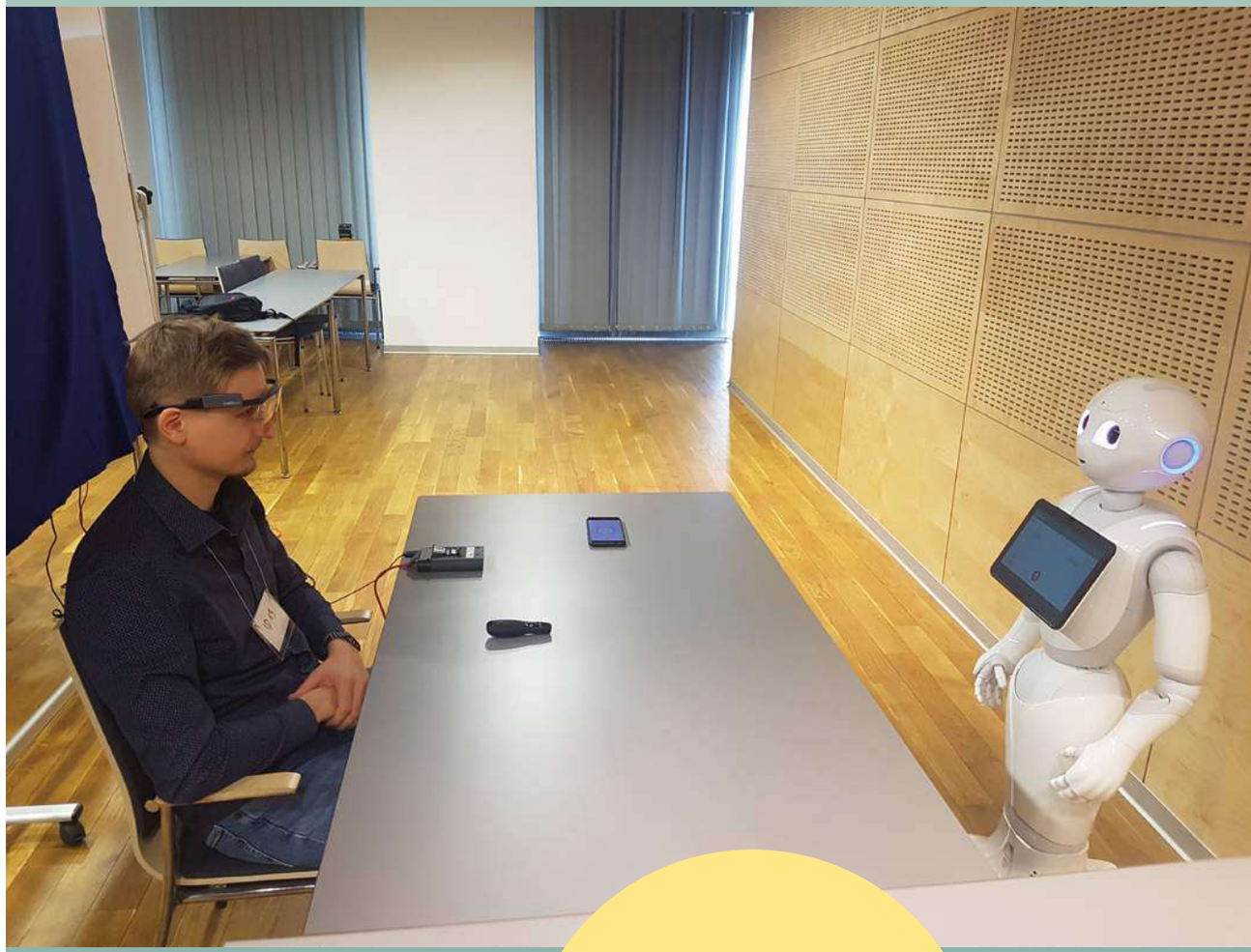
With the increasing use of robots in many aspects of human life, from simple utility robots to complex humanoid machines that are to assist us in a variety of situations, it is crucial to develop solutions that facilitate robots to interact in the most natural way with humans. We need to combine computer and cognitive sciences to ensure that a robot's behaviour is adequate for the information communicated by humans through gestures or facial expressions and evokes human trust.

This is exactly what the scientists from the AGH UST Institute of Computer Science have been doing for years. They have investigated convolutional neural networks for the interpretation of data from robot sensors and organised workshops devoted to the evaluation of human-robot interactions. The goal was to develop novel solutions for advanced perception mechanisms, including emotion recognition, question identification, and gaze estimation. A success in this field was the *Gaze4HRI* project implemented in cooperation with the Middle East Technical University (Turkey). The project resulted in the development of a gaze-mediated framework for multimodal human–robot interactions, supporting the creation of applications that interact with humans using eye tracking and emotion recognition. The implementation of the framework makes it possible to launch it on a variety of hardwares and softwares, including robots, virtual reality avatars, and mobile device avatars.

Initially, the scientists wanted to experimentally detect regularities related to the point of gaze during conversations in human–human and human–robot pairs. Particularly, they paid attention to eye contact or a lack thereof in the context of data related to utterances. The experiments collected data on gaze and audio. Based on these, the scientists created a computing environment for multimodal human–robot interactions and developed simple behaviours that detect situations when the user begins or stops speaking, which triggers predefined responses. Based on the framework, appropriate modules were implemented that allow the robot and avatar to interact with humans intuitively and naturally. The next step included more complex activities, such as question detection and responding to the point of gaze of the interlocutor. The scientists have also studied the possibility of emotion detection in humans based on the analysis of microexpressions and voice signal processing.

The usefulness of the software has been tested in experiments carried out with the use of the humanoid robot Pepper and on mobile/VR platforms. The form mimicked a job interview, but more complex scenarios were also tested. Another example might be the workshops organised as part of the work on perception algorithms for social robots, carried out in cooperation with the Jagiellonian University Institute of Philosophy. The aim was to observe human–robot interactions and identify aspects that significantly influence the trust we give robots. The workshops were held in nursery schools in Poland and Japan, providing different cultural contexts. The events had an important educational value, so crucial at this stage of development. The Pepper robot used during the workshops had its software extended by the developed perception mechanisms. The scientists observed children's expectations for the robot and their evolution with the increasing awareness of the robot's capabilities.

The results confirmed the optimal functioning of the environment and its considerable flexibility. It facilitates the definition of considerably varied and multimodal scenarios. Controlling robot or avatar's behaviours can occur with the use of multiple modalities, the signals of which are analysed by complex classification algorithms (e.g. convolutional networks). Due to its architecture, the capabilities of the software can be extended by additional hardware platforms, new modalities, and signal analysis methods.



Team led by **AGH UST Professor Bartłomiej Śnieżyński**
Faculty of Computer Science, Electronics, and Telecommunications
Institute of Computer Science

Project titled *A gaze-mediated framework for multimodal Human Robot interaction Gaze4HRI*
funded by the NCBR

Shining bright. A system for designing smart lighting

Old and badly designed lighting is not only expensive, but also unecological – starting with significant energy consumption linked to considerable CO_2 emissions and ending up with harmful light pollution. Designing modern lighting for urban spaces, in accordance with current norms, is a difficult task. Fortunately, artificial intelligence is there to aid us, as is the solution developed by the AGH UST scientists.

The design of outdoor lighting must consider a compromise between the energy costs of street lighting and the safety of road users. Optimal computer-based design is difficult due to the inability to analyse all cases: for a single street, several dozen parameters with many degrees of freedom must be analysed. As a result of interdisciplinary research at the AGH UST, a multi-agent artificial intelligence system has been created, facilitating a reduction of the number of analysed design variants of the lighting system using parallel graph transformations. The results guarantee at least 70% electricity savings when replacing the lighting with LEDs (hand-designed – only 50% savings). This results in reductions in CO_2 emissions, lighting replacement costs, and light pollution. The team led by Prof. Leszek Kotulski included Prof. Andrzej Bielecki, AGH UST Prof. Adam Sędziwy, AGH UST Prof. Igor Wojnicki, Dr (Eng.) Artur Basiura, and Dr (Eng.) Sebastian Ernst. The theoretical work was commercialised as PhoCa (as part of an NCBR project) by an AGH UST spin-off company – GRADIS Sp. z o.o. The company's solutions have been successfully implemented in Poland and abroad – in total, more than 100 projects have been completed for cities, energy providers, and international lighting companies.

In the case of individual owners of lighting installations, the application of PhoCa translated into profits resulting from a better design of a new LED-based system – statistically, 20% profit on energy expenditure and about 5% reduction in replacement costs compared to man-made projects. However, there are more important large-scale effects. Despite the fact that replacing lighting sources is the most effective method of saving energy, relatively few cities make the decision to do so. The reason is that these are long-term investments (13 years with 40% exchange efficiency, slightly over 10 years with 50% exchange efficiency). Therefore, 20% increase in exchange efficiency offered by PhoCa is a breakthrough solution because it reduces this time to 7.5 years.

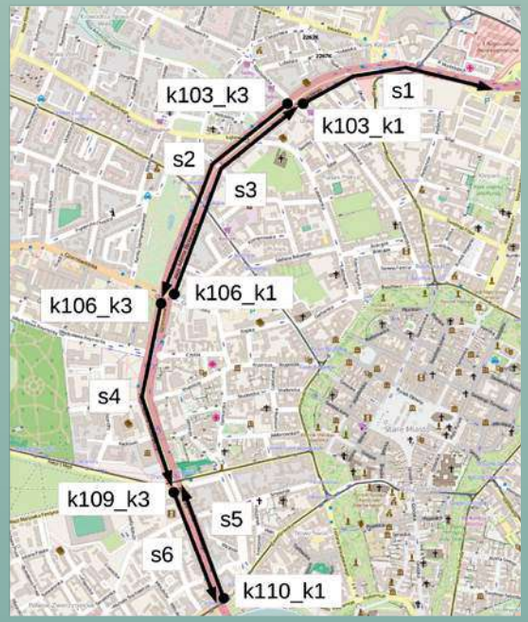
Moreover, PhoCa offers exceptional speed and scalability of calculations (at least several thousand times faster than a human). As a result, we can make variant designs to optimise the decisions we make. The larger the area of design/analysis, the clearer the advantages of using PhoCa. For projects implemented in Tbilisi, Georgia (91,000 points) and Washington, USA (56,000 points), the system calculated a single project variant within 24 hours. In Krakow, in the case of 4,000 points, designers, without using the system, needed 6 weeks to complete the task, while the first version of PhoCa prepared the design in 8 hours.

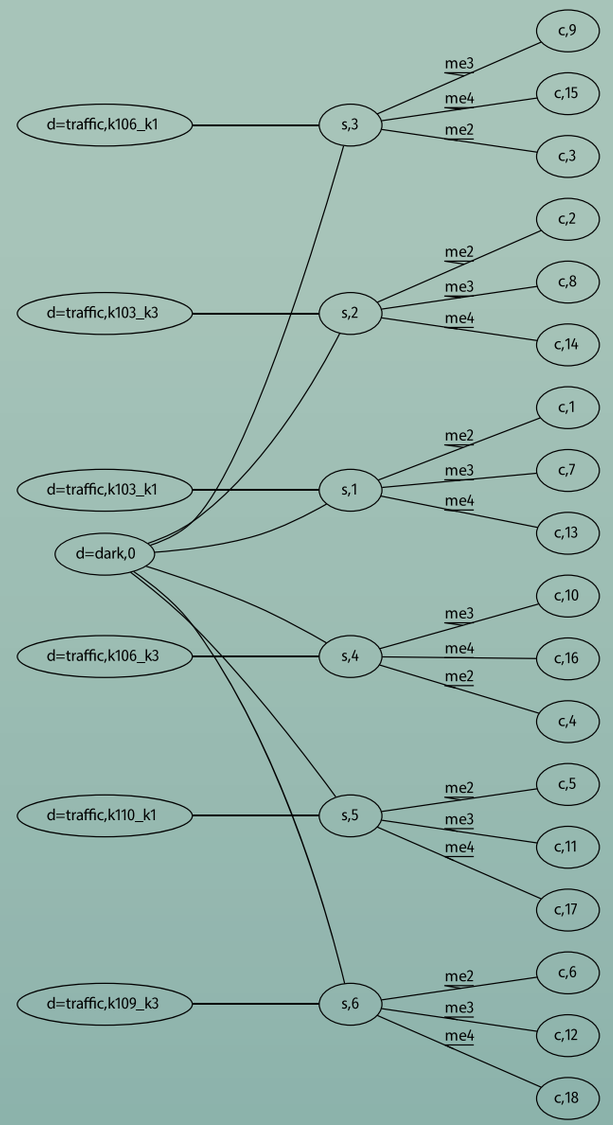
The possibility of analysing multiple design variants is even more important in the context of ESCO projects, where the company takes over the lighting tasks from the city for a fixed price. In this case, the number of variants analysed increases because they include the investment price and the profit from operating costs.

The solution is particularly useful in dynamic lighting control. The EU EN13201 Standard, which provides the guidelines for road lighting in Poland, makes it possible to lower the lighting requirements, e.g. when traffic intensity drops. The problem, however, is that the reduction is not expressed as a percentage, e.g. reduction by 10% or 20%, but by one or two lighting classes, and for these lower classes more projects have to be prepared. The dynamic control system, compliant with the EN13201 standard, has been in operation in Krakow for several years (Krasińskiego Avenue and Mickiewicza Avenue) and it generates 47% savings compared to a static system based on LEDs. The solution has also been successfully implemented in other cities in Poland. For instance, due to the application of the control system in Zgorzelec, electricity consumption dropped by 81% and in Polkowice by 68%.

Team led by
Professor Leszek Kotulski
Faculty of Electrical Engineering, Automatics, Computer Science, and Biomedical Engineering
Department of Applied Computer Science

The PhoCa system





The scope of the dynamic lighting control system (the map shows the northwest bypass of the Krakow city centre) and a fragment of the control graph that manages the data from sensors with dimming parameters of lamps

Smog, tsunamis, and pandemics. The capabilities of isogeometric simulations

Today, it is next to impossible to imagine a science or an industry that does not use computer simulations. Simulations of time-dependent phenomena are extremely difficult to carry out; moreover, they are usually unstable and produce faulty results. In a nutshell, it stems from the fact that mathematical theory simulations are based on functions in abstract mathematical spaces, not necessarily in the ones-and-zeros computer world. AGH UST scholars are working hard to solve this problem.

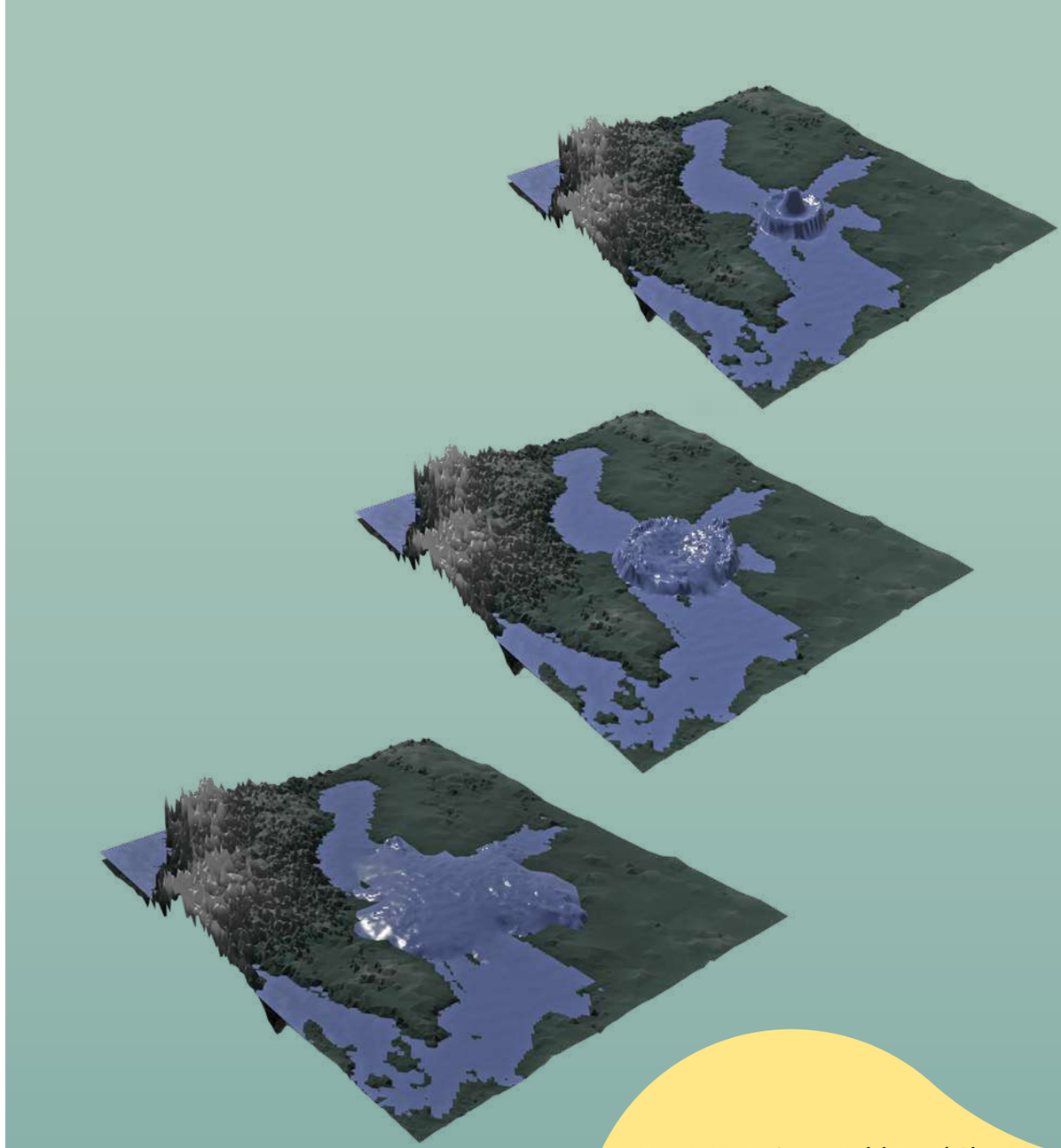
Professor Maciej Paszyński's team from the Faculty of Computer Science, Electronics, and Telecommunications have developed the Isogeometric Residual Minimisation Method (iGRM) – a way of running simulations that combines the advantages of the DPG method (stabilisation), modern solvers with alternating directions preconditioners (for ultra-fast simulations, even on a laptop), and a modern isogeometric finite element method (for running smooth simulations, integrated with the CAD/CAE systems, for time-dependent problems).

What is behind the isogeometric analysis methods invented in 2010 by Professor Tom Hughes from the University of Texas? '*Let's imagine that in the space around us we stretch an invisible sheet of fabric and, using it, we want to zoom in on certain physical quantities in a given area*', says Prof. Paszyński. '*In January 2022, an asteroid about 1 km in diameter flew close to the Earth at a distance of 1 million km. This is five times the distance from the Earth to the Moon. Using isogeometric analysis, we can run simulations of what would have happened if that asteroid had fallen into the Baltic Sea. In our simulations, we included a slightly smaller asteroid and used two sheets of isogeometric fabric, one to cover the topography of the coast and the sea bed, and the other to represent the sea level. Then, knowing the appropriate mathematical formulas and differential equations that control this phenomenon, we hung invisible "clips" in space to stretch over the sheet and then moved the "clips" so that the sheet could simulate tsunami waves and the changes of the sea level.*'

Prof. Paszyński explains the mechanism of simulations: '*From a mathematical point of view, these virtual fabrics used to mirror physical phenomena are linear combinations of thin basis spline functions. Of course, the simulations run over time, so we have a timeline and we divide it into sections – time steps, and we simulate these frames like in a film showing how the state of our system changes in individual time steps.*'

Virtual isogeometric fabrics can be spread in the air to mirror the concentration of pollution. Then, using appropriate formulas and methods, scientists can simulate the propagation of pollution in the air. '*We've been working on the following simulation: over the area of the Małopolska Province, a cloud of pollution approaches from the north, and the wind blows towards the southeast*', Prof. Paszyński continues. '*Our simulator can predict how this cloud of pollution can spread and how the concentration of pollutants will change over time in different places.*'

Applying virtual fabrics to geological layers, where they will represent pressure, facilitates the simulation of oil extraction processes using hydraulic fracturing or the process of underground CO_2 storage. We can also use these virtual sheets to model the concentration of pathogens (e.g. COVID-19) in the space around us and then simulate the propagation thereof through coughing. It is also possible to use these virtual isogeometric sheets inside the human body – they can simulate, for example, the development of tumors. In such cases, one sheet will represent the density of tumors, another will determine the concentration of angiogenic enzymes produced by the tumor, yet another – the concentration of oxygen delivered by blood vessels, and another one will model the degradation of healthy tissues.



A simulation of a tsunami wave in the Baltic Sea after the impact of an asteroid

(project funded by a university grant within the IDUB programme)

Team led by **Professor Maciej Paszyński**
Faculty of Computer Science, Electronics, and Telecommunications
Institute of Computer Science

Project titled *New computational paradigm of the Isogeometric Residual Minimization method (iGRM) and its application* (...) carried out within HARMONIA 9/NCN

Taking a deep breath in Krakow. Identification of particulate matter pollutants in the atmosphere

When fighting smog, we must first get to know the type of pollution and its sources. Advanced interdisciplinary research carried out at the AGH UST allowed scientists to assess the influence of selected emission sources on air quality and helped them fine-tune the air protection programme not only for Krakow, but also for neighbouring communes.

A team made of AGH UST Prof. Lucyna Samek, Prof. Kazimierz Różański, AGH UST Prof. Zdzisław Stęgowski, AGH UST Prof. Katarzyna Styszko, AGH UST Prof. Mirosław Zimnoch, Dr (Eng.) Zbigniew Gorczyca, and Alicja Skiba, MSc Eng. has thoroughly diagnosed the condition of Krakow's air as part of a project initiated by Krakowski Holding Komunalny S.A. in Krakow, with the support of the Provincial and Chief Inspectorates of Environmental Protection (WIOŚ/GIOŚ).

The underlying goal of the research was to determine the type and percentage of individual sources of atmospheric aerosol emission in immisions recorded at selected WIOŚ air quality monitoring stations in Krakow, related to road transport (Aleja Krasińskiego station [AK]) and residential areas (Złoty Róg station [ZR]). The objective was achieved through a comprehensive physicochemical and isotopic profiling of PM_{10}, supported by Positive Matrix Factorization (PMF) receptor modelling and the modelling of selected aspects of pollution distribution in the atmosphere.

It was shown that within a decade (2010–2019), PM_{10} concentration decreased by about 50% at both monitoring stations. The concentration of NO_2, which is the transport indicator, decreased by about 30% at the AK station. Among other factors, the reasons for the improvement of air quality can be linked to the replacement of old city buses with new electric or hybrid vehicles, the expansion of the heating network, and the introduction of a ban on fossil fuel combustion for heating buildings in 2019.

1. The composition of PM_{10} | The mean concentration of PM_{10} at the AK station was 76 µg/m³ in winter and 35 µg/m³ in summer; at the ZR station – 55 µg/m³ in winter and 26 µg/m³ in summer. Physicochemical tests of PM_{10} showed that, on average, the carbon fraction makes up 40%, about 25% – inorganic secondary aerosols (sulphate ions, nitrate ions, and ammonium) with the remaining ions at about 16%, metals 6–7%, and unidentified compounds – 12%. The isotopic composition tests have shown that the main ingredients of the carbon fraction include carbon from hard coal combustion, fuel combustion in vehicles, and biogenic carbon fraction (natural emissions and biomass combustion).

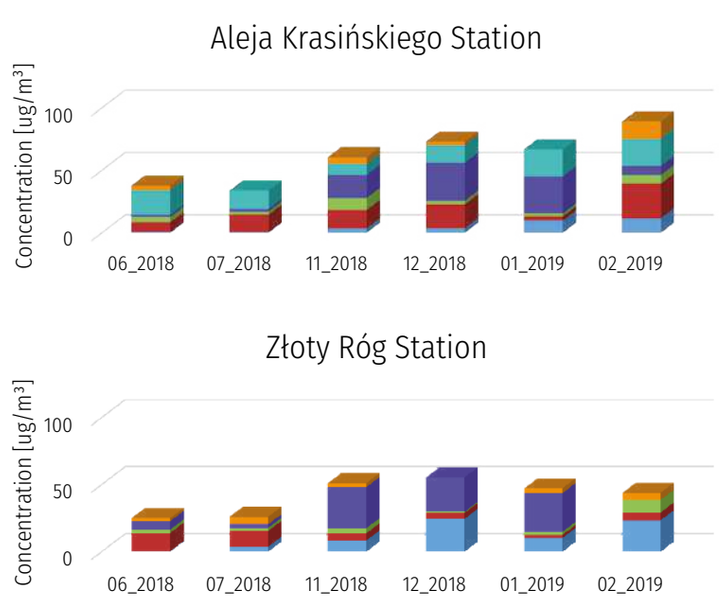
2. Sources of PM_{10} | The results of the PMF model of the sources of particulate matter showed that in the winter, the dominant PM sources are combustion of solid fuels and inorganic secondary aerosols. The following PM_{10} sources were identified and their percentage determined: solid fuel combustion: winter 10% (AK) and 36% (ZR); summer undetected (AK) and 8% (ZR); inorganic secondary aerosols: winter 28% (AK) and 29% (ZR); summer 5% (AK) and 16% (ZR); motor transport: winter 24% (AK) and summer 48% (AK); soil dust: winter 7% (AK) and 7% (ZR); summer 9% (AK) and 8% (ZR); other PM sources (resuspension of PM from road transport, PM from industrial processes and construction sites): winter 24% (AK) and 8% (ZR); summer 32% (AK) and 48% (ZR); unidentified PM sources: winter 8% (AK) and 4% (ZR); summer 5% (AK) and 19% (ZR).

The conclusion was that in summer, the percentages of PM_{10} from resuspension or construction sites and industrial processes increase for higher concentrations. For lower concentrations, the inorganic secondary aerosols had higher percentages at the ZR station, and from motor transport at the AK station. In winter, there was an increase in PM from solid fuel combustion for higher PM concentrations at the ZR station and a considerable increase in the percentage of inorganic secondary aerosols for higher PM concentrations at the AK station. In both cases, with an increase in overall PM concentration, the percentage of soil dust decreases.

The results were taken into account in the development of the Air Protection Programme for the Małopolska Province in September 2020.

Team led by **AGH UST Professor Lucyna Samek**
Faculty of Physics and Applied Computer Science
Department of Medical Physics and Biophysics

Project titled *Sources of particulate matter air pollution in Krakow in 2018*



Sources of PM_{10}

Thermal treatment of organic waste as a method for resource acquisition

A considerable percentage of all refuse in Poland is organic waste. How can we use it so that it doesn't heap up in landfills? One method to do that is thermal conversion processes – such as torrefaction, hydrothermal carbonisation, pyrolysis, or gasification – which can help us recycle biowaste to resource valuable products and transform them into an alternative fuel.

Research in this field subscribes to the idea of circular economy, which implies the minimisation of raw material extraction in favour of reusing the same products. This is a way to manage the problem of insufficient resources on Earth, but also to reduce greenhouse gas emissions.

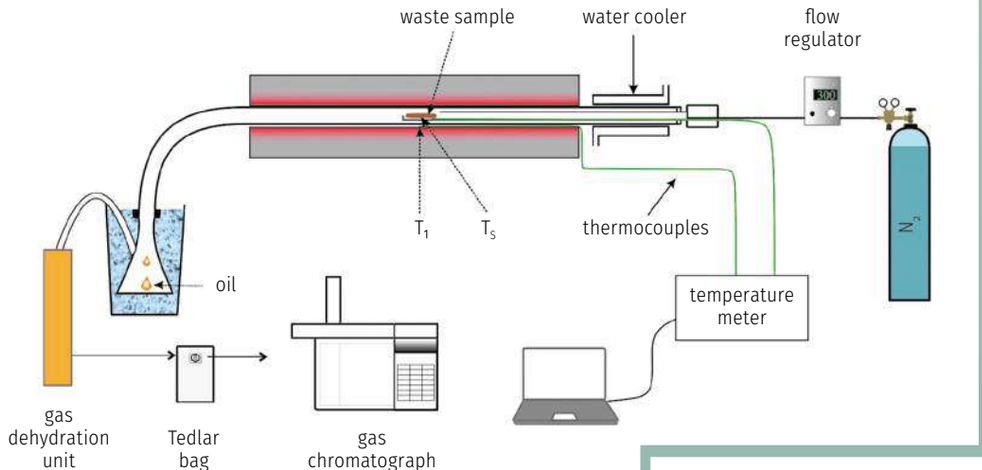
The investigation on thermal conversion of organic waste, which can be reclaimed as materials for the chemical industry or as a biofuel, is the focus of the research team led by AGH UST Prof. Aneta Magdziarz from the Faculty of Metals Engineering and Industrial Computer Science, which carries out a project titled *Multicriterial analysis of pyrolysis of agricultural waste biomass, biodegradable wastes, and RDF fuels.*

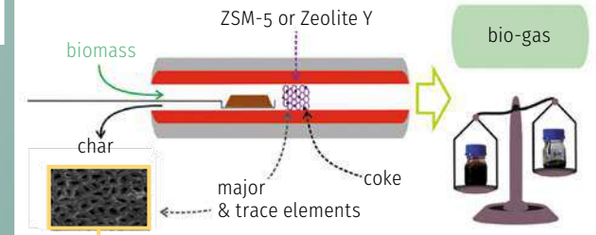
Pyrolysis (from Greek *pyr* – fire, *lysis* – disintegration) is a process of thermal decomposition of complex chemical compounds into simple ones, which occurs at high temperatures in an inert atmosphere (N_2, Ar). The research carried out at the AGH UST is related to the pyrolysis of agricultural and wood-type waste. During the research phase of the project, a detailed analysis of the physicochemical parameters of the substrates and pyrolysis products of the studied wastes was carried out with the use of a wide spectrum of advanced instrumental methods. Furthermore, the scientists investigated the influence of a catalyst on the efficiency of the process and the quality of particular products. In cooperation with Xi'an Jiaotong University, they have also studied the so-called 'co-pyrolysis' of wood waste biomass and rubber waste during the catalytic cracking process. As a result, a decrease in the concentration of phenol in pyrolysis oil and a reduction in the water content in the products of pyrolysis were achieved.

The project includes several sub-studies carried out by doctoral students. Artur Bieniek uses numerical methods in computational fluid dynamics to compute the efficiency of pyrolysis products with changing process conditions, that is, temperature, type of carrier gas, or its flow rate. Małgorzata Sieradzka analyses the composition of pyrolysis gas using gas chromatography. *'Gas chromatography is an instrumental method used to analyse the composition of particular chemical compounds in mixtures. To put it briefly, we have a certain gaseous mixture – pyrolysis gas, for instance – and we analyse it in terms of the content and concentration of, e.g. hydrogen, carbon monoxide, carbon dioxide, or hydrocarbons. To analyse particular compounds that make up our gaseous mixture, they are carried by a neutral carrier gas (He) to a chromatographic column, where they are separated on the basis of the so-called "time of retention". The column is chosen specifically for the substances analysed. As a result, we receive a chromatogram that shows peaks for particular compounds against the retention time. These results are then compared with chromatograms obtained during analyses of calibration gases of known composition and concentration'*, Prof. Magdziarz explains.

Organic waste can be reused in a number of ways. Another method of recycling it is to transform it into RDF (Refuse Derived Fuel). This is the name of alternative fuels obtained from selected waste materials with high thermal value (14–19 MJ/kg). Such energy sources can be a good alternative to conventional fossil fuels – coal, oil, or natural gas. Furthermore, biowaste is also a valuable source of chemical compounds that can be successfully used to produce cosmetics. An example of such a biowaste material comes from the brewing industry, namely, the so-called 'draff'. It is a lignocellulosic material that contains bioactive compounds, including phenols, which attract a great deal of attention from the scientific community given their wide scope of application.

Materials studied

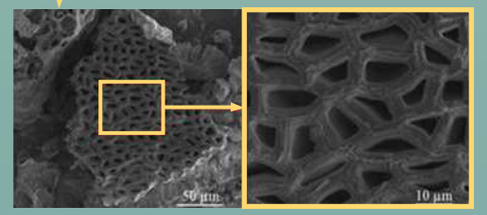




Conversion products

Team led by
AGH UST Professor Aneta Magdziarz
Faculty of Metals Engineering and Industrial Computer Science

Project funded by a university grant within the IDUB programme



Magnified biochar structure

Towards climate-neutral power engineering. Unconventional geothermal systems

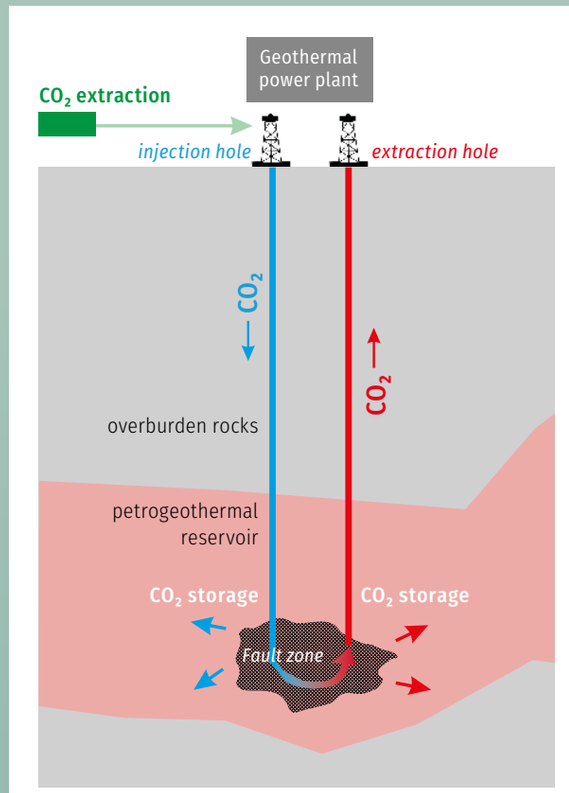
In many places, traditional exploitation of geothermal energy reservoirs, primarily associated with the use of hot water, is restricted by hydrogeological conditions. The alternative might be systems using the potential of energy trapped in hot dry rocks. Heat absorption in such systems occurs by injecting fluids under high pressure, which circulate through the hot rocks. Around the world, the Enhanced Geothermal Systems (EGSs) are attracting more and more attention, because, instead of water, they use carbon dioxide as their working fluid.

The reasons for this interest stem from the possibility of geological storage of CO_2 during the geothermal energy conversion process. The CO_2-EGS technology contributes to the protection of the climate by providing pure geothermal energy, while simultaneously eliminating CO_2 emissions from fossil fuel combustion. The investigation has also shown significant advantages of using CO_2 as the working fluid, including beneficial thermodynamic and transport properties and low chemical activity.

The research focused on the analysis of EGS efficiency, using carbon dioxide as the supercritical fluid, is carried out by a Polish-Norwegian consortium led by AGH UST Professor Anna Sowiżdżał from the Department of Energy Resources at the Faculty of Geology, Geophysics, and Environmental Protection. The consortium led by the AGH UST consists of: Mineral and Energy Economy Research Institute of the Polish Academy of Sciences in Krakow, SINTEF Energi AS (Trondheim, Norway), the Norwegian University of Science and Technology (Trondheim, Norway), and EXERGON Spółka z o.o. (Gliwice, Poland). Since October 2020, the consortium members have been carrying out a project titled *CO_2-Enhanced Geothermal Systems for Climate Neutral Energy Supply*, EnerGizerS in short. It received funding as part of the Polish-Norwegian POLNOR 2019 research project financed by the Norway Grants through the National Centre for Research and Development.

The chief objectives of the project include the development of enhanced geothermal systems using supercritical carbon dioxide as the medium, but also the intensification of cooperation between Polish and Norwegian partners, as well as the exchange of experience in the field of using geothermal energy and geological storage of carbon dioxide. The actions taken aim to reduce carbon dioxide emissions and palliate human-induced climate changes, while simultaneously satisfying the energy needs of societies.

The EnerGizerS project comprises six components, which focus on research aimed at identifying and characterising geological structures appropriate for the installation of CO_2-EGS systems in Poland and Norway. The completion of the first stage has resulted in the determination of relevant parameters for the location of such systems on land (Poland) and on sea (Norway), as well as the identification of prospective geological structures: Mogilno–Łódź Trough and the area around Gorzów in Poland, as well as the Åre formation on the Norwegian Sea. Comprehensive laboratory tests of core samples from selected geological formations were performed, which facilitated the petrophysical, thermal, and mechanical profiling of the rocks. The results of laboratory tests were used for advanced mathematical modelling, including structural modelling of the geological reservoir, modelling of the fracturing process of solid rocks and 3D modelling for multi-variant simulations of CO_2 injection and exploitation with forecasts of reservoir behaviour over time. As part of an experimental campaign aimed to determine the properties and behaviour of working fluids in the CO_2-EGS systems, a doctoral student from the AGH UST Department of Energy Resources went on a research visit to SINTEF (Norway). Currently, the scientists work on models of underground and surface systems. The final results will be presented at the end of 2023.



EGS-CO_2 installation

Prospective geological structures for the EGS-CO_2 indicated in the *EnerGizerS* project

Team led by **AGH UST Professor Anna Sowiżdżał**
Faculty of Geology, Geophysics, and Environmental Protection
Department of Energy Resources

R&D work carried out within the *EnerGizerS*/NCBR project

Towards sustainable power technologies. Safe hydrogen storage

Energy storage and conversion are two huge challenges of the 21st century. Safe hydrogen storage is the key segment of power systems based on this element. Currently, hydrogen is stored widely in its gas form under high pressures, reaching 700 bars, or in its liquid form at extremely low temperatures (20 K). However, for many applications, neither solution is optimal due to the high costs these technologies entail. Therefore, scientists have been working on technologies to store large amounts of hydrogen in smaller volumes without the need to maintain high pressures or extremely low temperatures.

At the Faculty of Physics and Applied Computer Science, scientists have developed the concept of imaging and quantitative analysis of hydrogen storage containers (during loading or unloading), which was a novelty on a global scale. They showed that the assumptions underlying the construction of hydrogen reservoirs had been erroneous.

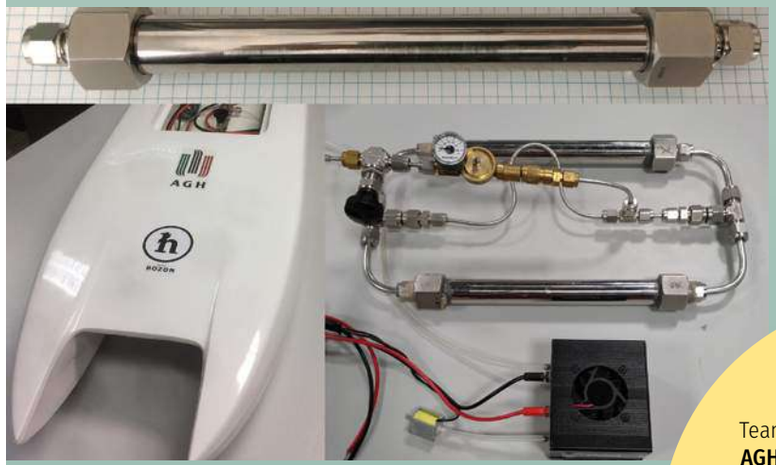
Metal hydride formation is a highly exothermic reaction; therefore, it is crucial to manage the heat flow, while simultaneously ensuring a possibility of the expansion of the material volume during hydrogenation. The investigation indicated how hydrogen tanks should be designed to achieve the desired efficiency. It was shown that nanostructuring of the active material with graphite, which is a heat-transporting matrix, facilitated a significant increase in the effectiveness of reservoirs. Making composites prevents the release of nanoparticles that, while travelling with hydrogen through installations, can damage moving parts, e.g. valves.

The Team for Magnetic, Electrical, and Structural Research at the Department of Solid State Physics developed an *in situ* neutron imaging technology to monitor containers for solid hydrogen storage bound in metal hydrides. The investigation was carried out in cooperation with Helmholtz-Zentrum Berlin, where a neutron beam from the BERII reactor was used. Professor Łukasz Gondek, Dr Joanna Czub, and Anna Zarzecka, MSc Eng. – implemented a neutron imaging technology for studying the behaviour of hydrogen-penetrating metallic materials, where it can be stored under low pressure at a room temperature. This technique allows scientists to observe the processes that occur in the hydrogen container in real time. This, in turn, facilitates the optimisation of the container's structure and an increase in efficiency. The main limiting factors were shown to include the rate of heat absorption and changes in the volume of the metallic material. After the material absorbs hydrogen, its volume can increase by more than 15%. The research showed that efficiency can be significantly improved by using composites that contain an active material (e.g. $TiMn_2$) and a heat-transporting matrix (e.g. graphite).

Storing hydrogen in metallic compounds finds application in stationary hydrogen storage facilities, rail-bound and maritime transport. With the Bozon Student Research Club, the team designed and built a power supply system for the prototype of a fuel cell-powered boat. The project showed that hydrogen containers are stable and do not cause problems during operation.

In addition to hydrogen storage, this technique is also useful in nickel–metal hydride battery (Ni-MH) investigations to verify the functioning of the electrode into which hydrogen diffuses.

The results of the team's research translate into commercial applications. Several European companies in the field of materials and storage systems related to hydrogen technologies are currently using their solutions (GKN Hydrogen, MCPhy, SGL Carbon, GfE).

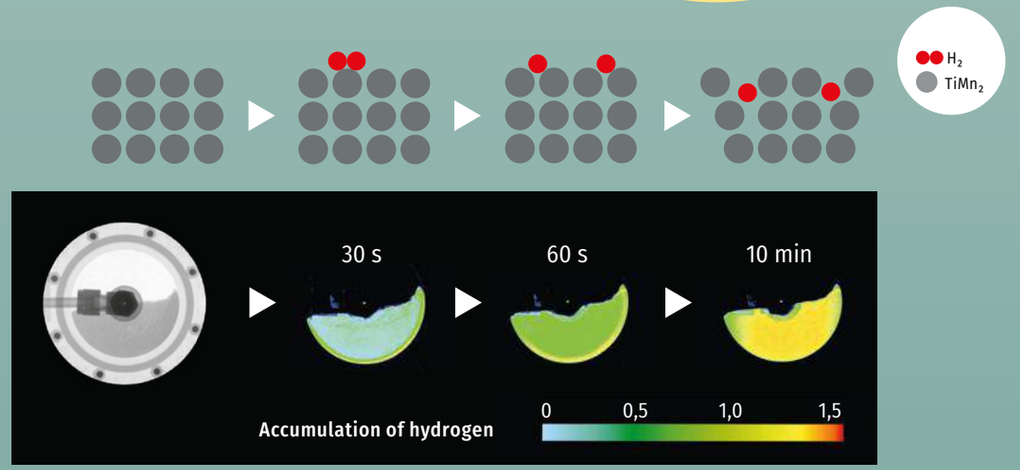


Power supply system for the hydrogen boat

In a single 20 cm-long container, there is 2 litres of hydrogen stored in a metallic nanocomposite. The system can power the boat for more than 1 hour.

Team led by
AGH UST Professor Łukasz Gondek
Faculty of Physics and Applied Computer Science
Department of Solid State Physics

R&D work implemented due to the *Nanomaterials for hydrogen storage* project within the Polish–Norwegian Research Programme



Hydrogen absorption by metals

a) Illustrative image (H_2 molecule dissociation and its absorption by the $TiMn_2$ metal)
b) The process captured by neutron imaging

Used coffee grounds – raw material for groundbreaking ceramic materials

Each year, the world produces about 10 million tonnes of whole bean coffee. If we ground the entire year's harvest and made coffee from it, we would be left with an equal mass of coffee grounds, with an additional volume of unfiltered water. This waste is not environmentally neutral, because when deposited in landfills, it emits methane, which belongs to the group of gases that contribute to global warming. Little wonder that scientists are investigating ways of repurposing it.

After adequate preparation, it can be used as a fertiliser, a biodegradable material for industrial production, or as a biofuel. Dr (Eng.) Ewelina Kłosek-Wawrzyn from the Faculty of Materials Science and Ceramics, is working on using coffee grounds as an eco-friendly material to produce porous ceramic materials. Such materials show lower thermal conductivity than solids, and this property makes them useful in construction industry to improve thermal insulation of buildings.

Pores in ceramic materials are obtained as a result of stoving clay mixed with additives. The latter simply burn out during the production process, leaving microspaces filled with gas. In traditional construction ceramics, the additive used to obtain the porous structure is usually cellulose pulp or sawdust. Replacing those with coffee grounds of considerably higher calorific value makes it possible to conserve the fuel used to produce heat. *'Furthermore, wet coffee grounds collected from coffee shops contain between 55 and 60 percent of water. Usually, when producing construction materials with the use of clay, we have to add water to make them plastic. Here, however, if we can organise the entire production process appropriately, adding water won't be necessary at all'*, says Dr Kłosek-Wawrzyn. In her research, she uses a mixture of coffee grounds from two chains of coffee shops. Although they come from different sources, the only difference between them is the content of water, whereas they are identical in terms of granularity and very similar in terms of calorific value.

The idea of using ground coffee waste as a clay additive in the production of porous ceramic materials is not new. The challenge for engineers is to optimise this process to obtain a material with desired thermal parameters, while simultaneously meeting the norms of mechanical resistence. The materials used in construction must remain rigid under various stresses, and adding too much of easily burning-out materials to clay reduces its resistance.

'Construction materials manufactured today have, in my opinion, too high strength parameters, which translates into higher thermal conductivity. In our material, we want to find a balance between thermal conductivity and strength. However, we're not aiming at high constructions, one- or two-storey is enough, where material strength doesn't have to be that high, which makes it possible to increase the porosity and, consequently, lower thermal conductivity. 'Due to the fact that we have completely modified the production process, we can put much more used coffee grounds into the material than has been described in the literature to date, and obtain significantly better thermal parameters of about 0.15–0.25 watts per meter-kelvin', says Dr Kłosek-Wawrzyn.

Dr Kłosek-Wawrzyn conducts her research together with her colleagues from the Department of Building Materials Technology. She prepares samples of ceramic materials, altering the proportions of used coffee grounds, and analyses them thoroughly. *'Above all, we study the efficiency of the heat transfer coefficient using a stationary heat flow meter'*, says the scientist. *'We test its compressive strength because construction materials are exposed to various mechanical forces. We analyse its density and porosity, but we also apply other techniques, including scanning electron microscopy, to find out what the material under investigation looks like in microstructure, that is, what its distribution of pores is and whether there are cracks. As a result, we can regulate the production process and shape the direction of future research projects.'*

A stationary heat flow meter to study the efficiency of the heat transfer coefficient of materials made of clay and used coffee within the range between 0,1 W/(m·K) and 10 W/(m·K)

Used coffee grounds and a ceramic material made thereof

Team led by
Dr (Eng.) Ewelina Kłosek-Wawrzyn
Faculty of Materials Science and Ceramics
Department of Building Materials Technology

Project funded by a university grant within the IDUB programme

VRSophy – translating classical philosophical concepts into the language of the present

What do we see when we think of philosophy? Dusted volumes, abstract notions, and intricate academic discussions? Only a handful of enthusiasts try to convince us that it is truly about issues that matter to us all, and the seemingly dry philosophical discourse actually reveals a powerful emotional load, speaking about truth, breaking from the illusion, and the sense of everyday existence.

What if we showed philosophy from a completely different perspective? If we invited people to play a game instead of reading a text? A game that engages body and mind at the same time? A survival game, anyone? This is the idea behind the VRSophy project, carried out by the EduVRLab at the AGH UST Faculty of Humanities in cooperation with the Film School in Lodz. The project is coordinated by AGH UST Prof. Jowita Guja and Adam Żądło from the Department of Information Technology and Media Studies. The project, a series of applications, opens up with the VR Cave – an adaptation of the classical Plato's text embedded in virtual reality.

The text is a fragment of the *Republic*, in which Plato presents a vivid metaphor of human life. Let's imagine a cave, he writes, and inside this cave – prisoners, their eyes always on the wall facing away from the entrance, which displays shadows of people and objects moving far in the distance. The prisoners have no idea that they are imprisoned. They are convinced that the true reality is the shadow theatre, and their cave – the whole world. We are these prisoners, Plato claims, and whatever we accept as the truth is, in fact, an illusion. There is a way of breaking out of the prison and turning to the true reality. However, it is a difficult task and would require us to abandon everything that we know and consider safe.

The conviction that the surrounding world is a lie that we have to pierce through is a momentous cultural paradigm, which lays foundations for philosophical and religious systems, as well as works of pop culture, such as *The Matrix* and *The Truman Show*. The core of the cave allegory is the disruption of obviousness: what we know and collectively respect proves fake. Waking up from the illusion is only the tip of the iceberg of a long-lasting and difficult process depicted by Plato as breaking out of the shackles, tedious climbing, being blinded by the light. Plato places the cave narrative in the context of his own ontology. However, the metaphor itself is universal. Being uprooted from the familiar and safe is always precarious, regardless of the cave in which we are imprisoned. It can be an ideological, religious, or political system. A cave can also be the "inside" of a VR headset, although it can be treated as a metaphor inside a metaphor. A contemporary reading of the cave metaphor also generates questions: what if the cave is limitless? What if it is like the matryoshka doll – a cave inside a cave inside a cave to no end?

'By transplanting a philosophical text to VR, we want to provoke these questions', says Prof. Guja. '*Simultaneously telling its receiver to physically break out of the chains, climb, and swim (our cave is filled with water), we ask them about the relationship between the thought and the body. We assume that "serious" philosophising means something more than a quiet read in a lecture room. Delivering a multimedia experience that requires an intellectual and physical effort, we want to emphasise the experiential nature of philosophy.*'

The VR Cave can be experienced at many levels – it can be an existential phenomenon, a foundation for a philosophical debate, or simply entertainment. It reveals its subsequent layers depending on the user's attitude and situation: the immersant can receive a proper background during a philosophy seminar or explore the cave individually as one of the games they can download from Steam or Oculus Store.

The VR Cave is an experimental project that initiates a series of VR adaptations of classical philosophical concepts. '*They can serve as reference points for philosophical debates, complementing a traditional reading of texts. However, we'd like those experiences to function also outside the academic discourse: to speak with its own unique language going beyond the boundaries of film, video game, or philosophical treatise*', Prof. Guja adds.

Team led by
AGH UST Professor Jowita Guja
Faculty of Humanities
EduVRLab – interdepartmental Virtual Reality Laboratory

The *VRSophy* project implemented within the nvLab programme and an MKiDN grant

Wastewater-based epidemiology. Innovative methods of biomonitoring

Xenobiotics are a group of biologically active chemical compounds found in human bodies, which are neither produced by them nor found in nature. The group contains medicines, but also a number of harmful substances artificially introduced into the environment. For example, polycyclic aromatic hydrocarbons (PAHs). Some of them show carcinogenic or mutagenic activity, causing DNA mutations, leukaemia, or lung cancer. How can we measure the extent to which the population is exposed to these compounds?

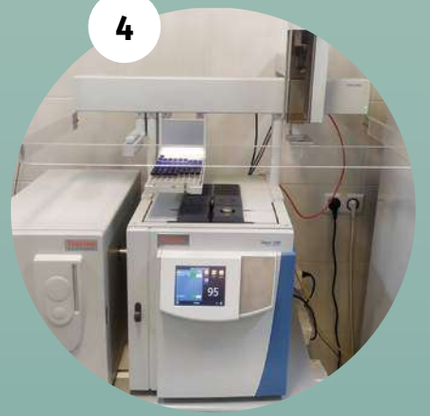
PAHs constitute an ingredient of particulate matter air pollution, and their primary source is the incomplete combustion of organic materials. Given that they are part of the small PM_1 and $PM_{2.5}$ fraction, they can easily penetrate our respiratory and cardiovascular systems. The highest concentrations occur in highly urbanised areas. However, PAHs can penetrate the organism not only from the air. *'They can come from contaminated water. High exposure to these toxic substances can also result from smoking cigarettes, diet, or job,'* explains AGH UST Professor Katarzyna Styszko, the leader of the project focusing on developing innovative methods of wastewater analysis for epidemiological purposes.

To determine the degree of exposure to those compounds, it might be helpful to combine measurements in the city with biomonitoring of humans with respect to PAHs and their metabolites that are a result of chemical transformations occurring in the body. To do this, it is possible to take advantage of an innovative method based on a chemical analysis of specific products of human metabolism found in sewage works, that is, wastewater-based epidemiology (WBE). In contemporary biomonitoring studies, a very precise correlation has been shown between population exposure to PAHs and finding their biomarkers in urine.

'Classic epidemiology is based mainly on surveys or blood and urine tests of patients or volunteers who participate in such activities. This usually represents a narrow spectrum of the population; moreover, such studies are very expensive, require a lot of work, and you have to wait a long time before you get the results. In the case of WBE, we can practically assess the exposure of a specific population to selected substances in real time. We usually count it in mg/24h per 1,000 citizens', says Prof. Styszko. WBE provides objective data on aggregate exposure to PAH xenobiotics of citizens from a specified area, which, after penetrating the human body, are metabolised quickly and after a few days leave the body in the form of hydroxy derivatives. This method was used by our engineers, who, during their comprehensive tests, not only thoroughly analysed the PM, but also made precise measurements of wastewater, while establishing fruitful cooperation with the largest sewage works in Krakow.

The researchers organised two wastewater measurement campaigns – a summer edition (2020) and a winter edition (2021) to determine seasonal changes in the compounds. The samples collected at the sewage works were transported to a laboratory, where, after appropriate treatment, they were analysed with the use of a gas chromatography–mass spectrometry method. *'Chromatography is an analytical technique aimed at separating a particular fraction within a sample, while the application of mass spectrometry is to determine the substances contained in the sample and to indicate their concentrations',* explains Prof. Styszko. To assess the degree of exposure to PAHs, it was necessary to know the processes of PAH metabolism and adequate back-calculations.

The initial results showed a significant seasonal correlation of the exposure of Krakow citizens to PAHs. The positive effects of the research will allow scientists to expand wastewater analyses to other cities – not only in Poland, but also in Europe. The study will also facilitate risk assessment related to the penetration of PAH hydroxylic derivatives into water environments, which – as it turns out – are not completely filtered out in sewage works and, according to the researchers, can be even more toxic than the initial compounds.



Team led by **AGH UST Professor Katarzyna Styszko**
Faculty of Energy and Fuels
Department of Coal Chemistry and Environmental Sciences

Project funded by a university grant within the IDUB programme

The procedure:

1. **Sample collection in sewage works**
2. **Filtration**
3. **Solid-phase extraction**
4. **Gas chromatography with mass spectrometry analysis (GC-MS)**

Where computer science meets economy. Computational aspects of social choice

Where is the link between searching for interesting films to watch in the evening, putting together a participatory budget to make our cities better, and hiring new employees to elevate our businesses? Each activity can be presented as a collective decision-making process that involves specific conditions and problems.

On the one hand, there are candidates, that is, all the films available in the database, ideas to improve the city's environment and a group of potentially suitable employees; on the other, a set of evaluations of those candidates. The evaluations include opinions of people who had already seen the film and shared their thoughts online, the votes of residents of a given city, and the assessment of recruiters evaluating potential employees (some might look at technical and others at interpersonal skills). Based on these assessments – or, more formally, the votes cast – we want to select the winning group: good films to watch, city projects to fund, and a short list of prospective employees.

Such decision-making processes are considered in economics, political sciences, philosophy, and operational research. However, these considerations have recently entered the domain of computer science. It turns out that surprisingly many electoral problems are difficult to compute and require nontrivial algorithmic solutions, especially as in the aforementioned situations when we want to select a group of winners, and not one candidate. For example, for numerous natural generalisations of the D'Hondt method, which allows voters to express their opinion on individual candidates, the problem of finding out the winner is NP-Hard. This means that calculating the results of elections could theoretically take decades. Luckily, there are a number of ideas to avoid this scenario.

As part of the PRAGMA project, Prof. Piotr Faliszewski and his team from the Faculty of Computer Science, Electronics, and Telecommunications focus on analysing the theoretical side of the problem of choice, simultaneously transposing mathematical results into practice. The scientists aim to develop algorithms to bypass computational difficulties that could be easily implemented in practice. *'In particular, we'll be looking for effective algorithms that will allow voters to make their choices fairly and in an informed way as to which candidates, contestants, or citizen projects they should choose'*, Prof. Faliszewski sums up.

One of the most important issues that the PRAGMA project touches upon is the analysis of electoral data. It turns out that, although many problems can be theoretically difficult to compute, practice shows that they are scarce. Therefore, Professor Faliszewski's team have been developing novel methods for comparing electoral data, which allows them to select the choice models that are possible to implement in practice. To date, the team's research has allowed it to indicate a natural metric of elections and pinpoint the areas in which such elections occur in practice, as well as show the areas in which, depending on the parameters, the elections generated on the basis of standard randomised models are located (an example of such a map of elections is depicted in the figure). This makes it possible to generate any amount of electoral data, which can then be used to design and analyse algorithms. For instance, if we know that in certain elections we can expect data distributed in a specific way (with a margin of approximation), then the electoral data generated from this distribution will allow the scientists to predict the behaviour of the tested algorithm.

The PRAGMA project (Pragmatics of Multiwinner Voting: Algorithms and Preference Data Analysis) thrives due to the prestigious ERC Consolidator grant that Prof. Faliszewski has received. The research results related to the project were published in renowned academic journals and as conference materials devoted to artificial intelligence, such as *Artificial Intelligence* or the AAAI and IJCAI conference publications, as well as economic journals, such as *Social Choice and Welfare*. The results will surely find application in multiple areas of life related to voting and decision-making – in communities and institutions, sport, culture, and business.

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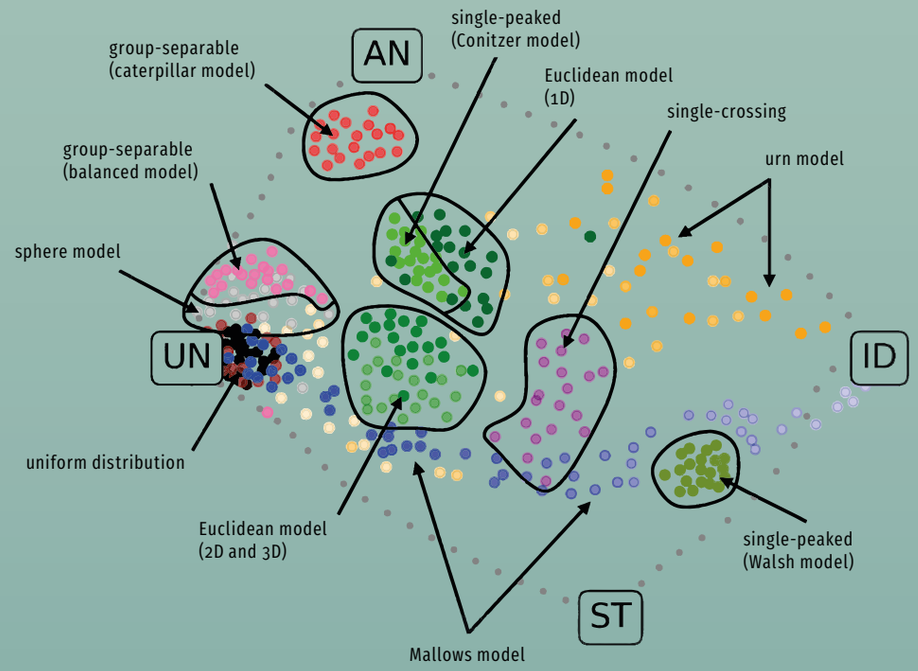

Map of elections obtained in the PRAGMA project

Each dot is a single election, i.e. a pair (C,V) where C is a set of candidates and V is a collection of voters whose votes are represented as linear orders over C. The votes are generated using a number of well-known statistical models, such as the Mallows model.
The map also contains four characteristic points, namely:
- UN (uniformity; the votes are maximally diverse),
- ID (identity; all votes are identical),
- AN (antagonism; half of the voters have opposite preferences to the other half),
- ST (stratification; half of the candidates are preferred to the other half by all the voters).

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