MODELAIR

NEWSLETTER

PROJECT MID-TERM

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Issue: I

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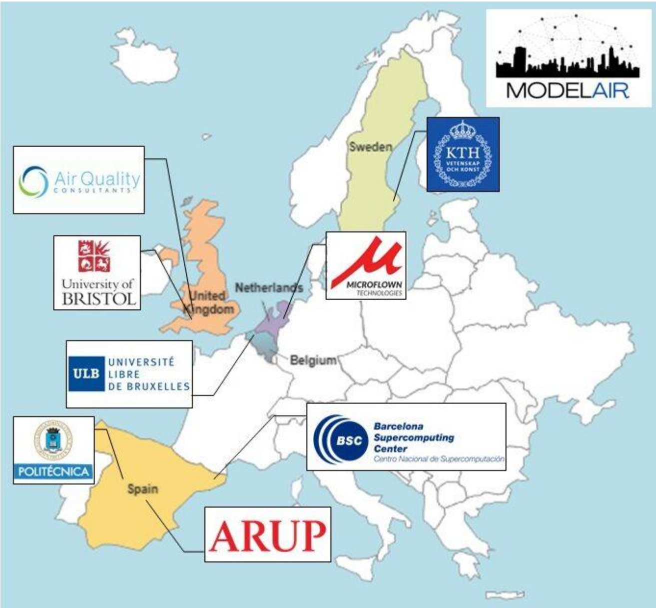
SUMMARY

MODELAIR is a research initiative under the Marie Skłodowska-Curie Actions, funded by the European Commission through the Horizon Europe Framework Programme. The project blends theoretical, experimental, numerical, and data-driven approaches to innovate, simulate, and design cutting-edge technologies for sustainable cities of the future.

2.69 M€ EU funding | 48 months duration | 9 european Partners | 3 major cities



The MODELAIR consortium consists of specialized partners distributed among Europe, from industrial experts to prestigious research centres and academic institutions. These partners are responsible for hosting our 12 doctoral candidates (DC), who are responsible for developing groundbreaking technologies to control air quality.

PROJECT IMPLEMENTATION STATUS

24 months after the start of the project in January 2023, significant results, deliverables, milestones have been achieved. All public deliverables and main activities are freely accessible through the project's website: www.modelair.eu

In Work Package 2: Problems in Urban Environments, we defined three test cases where the edge-cutting technology developed by our doctoral candidates will be tested. These are: Bristol (UK), Ixelles (Belgium) and Madrid (Spain).

The upcoming sections cover the work that has been developed by our team in these test cases.

TEST CASE 1: BRISTOL (UK)

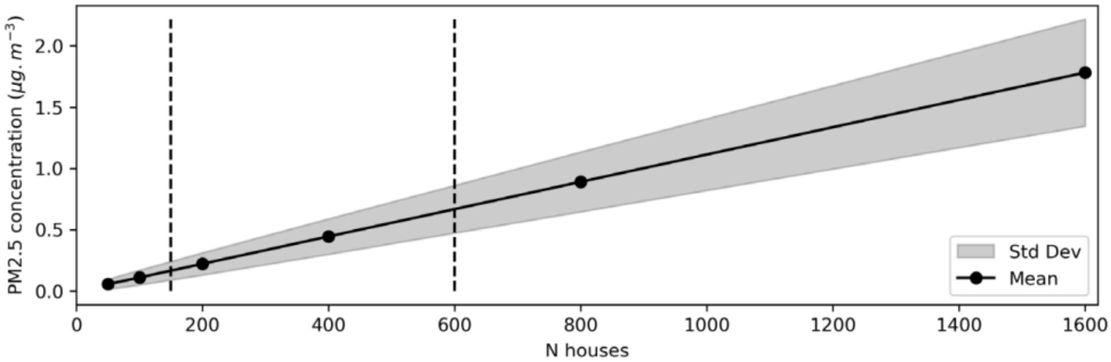
Urban air pollution continues to pose a serious challenge, impacting both human health and the environment. In Bristol, researchers are pushing the boundaries of innovation to tackle this issue through advanced tools, simulations, and cutting-edge machine learning techniques.

Efforts led by **DC2**, Arindam Sengupta, who is conducting his research at Universidad Politécnica de Madrid, are focused on understanding the intricate dynamics of air pollution. A powerful tool has been developed to clean, analyse, and predict pollution patterns, leveraging methods such as Singular Value Decomposition (SVD), Higher-Order Singular Value Decomposition (HOSVD), and Deep Learning. This tool has already been validated using experimental and numerical datasets simulating airflow around structures and is now being scaled for larger urban environments. With extensive datasets obtained from Air Quality Consultants in Bristol, DC2 is identifying correlations between monitoring sites across the city to enhance predictions, even in areas with sparse sensor coverage. These advancements are paving the way for a more comprehensive understanding of pollutant dispersion and behaviour in urban areas.

DC3, Sai Bharath, who is researching at KTH Royal Institute of Technology, is contributing to this effort with the development of advanced machine learning models capable of addressing the challenges of sparse urban flow data. By employing inverse modelling techniques using diffusion models, DC3 has demonstrated how unseen data can be inferred from limited observations. This groundbreaking approach has been successfully applied to 2D flow datasets, including collaborative work undertaken during Stanford's CTR Summer Program, and promises to transform predictions of urban airflow patterns in cities like Bristol.

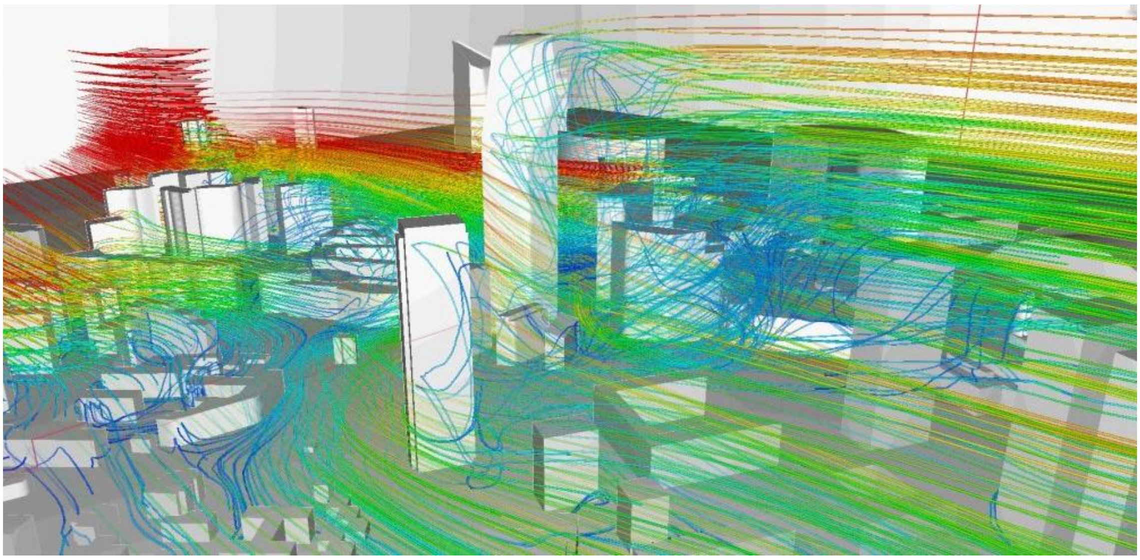
Meanwhile, **DC5**, Muhammad Jalal, allocated at Barcelona Supercomputing Centre, has delved into numerical simulations and reduced-order models to better understand pollutant dispersion in simplified urban scenarios. By using tools like the Spectral High-Order Code 2 (SOD2D) flow solver, as well as exploring Physics-Informed Neural Networks (PINNs), DC5 has taken significant strides toward solving complex equations relevant to urban air quality. These efforts align with ongoing attempts to use reduced-order modeling to create faster, more efficient simulations.

DC6, Matheus Rocha, who is working for our industrial partner Air Quality Consultants, has taken a different angle, focusing on how domestic wood-burning impacts PM2.5 pollutant levels in urban areas. Collaborating with Imperial College and contributing to the UK Urban Environmental Quality group, DC6 has explored the factors influencing pollutant distribution from point sources. This work has also supported national air pollution control strategies and highlighted new approaches to urban design that can mitigate air quality challenges. At the University of Bristol, these findings have been showcased as part of discussions around novel urban topologies aimed at reducing pollution.



Adding to this, **DC8**, Nada Taouil, researching from the University of Bristol, has developed a cutting-edge boundary layer wind tunnel to simulate the atmospheric boundary layer (ABL) over Bristol's urban landscape. The wind tunnel, which incorporates industry standards for accuracy, has been used to study airflow over a city model of Bristol manufactured using CNC technology. The results of these simulations have been shared at leading conferences, including the UK Fluids Conference 2023 and PHYSMOD 2024, where this innovative work earned the Best Presentation Award for Sustainability.

Additionally, **DC11**, Álvaro Manzano, who is researching at Microflown Technologies, has achieved a significant milestone by reconstructing Bristol for fluid dynamics simulations. This reconstruction, carried out during the first year of the project, focused on a selected region of interest and utilized public governmental vector and LIDAR data to account for the water and vegetation areas as well as terrain height. The varying terrain in Bristol adds complexity to fluid dynamics simulations, making the accurate representation of building effects crucial. DC11 modified the vector data to include features like towers and improved height distributions for buildings, ensuring a more precise simulation. The geometry was then integrated into the OpenFOAM simulation software with the aid of the opensource tool City4CFD, allowing for detailed CFD simulations of urban flows and pollutant dispersion.



Together, these efforts reflect a collective ambition to make Bristol a leading example in the fight against urban air pollution. By combining advanced computational tools, machine learning techniques, and real-world simulations, researchers are uncovering new ways to address one of the most pressing urban challenges of our time.

TEST CASE 2: IXELLES (BELGIUM)

Research in Ixelles is evolving with the combined expertise of DC3, DC9, and DC10. Together, they are advancing our understanding of urban airflow dynamics and pollutant dispersion, paving the way for more accurate predictions and effective mitigation strategies.

DC3's work on machine learning models for sparsely observed urban flows has been a central contribution. In the previous test case, we mentioned that DC3 has developed a method for test-time inverse modelling using generative diffusion models. This technique, which leverages pretrained models to predict unperturbed samples from noisy data, has shown promise in urban flow simulations. The methodology was successfully applied not only to natural image data but also to 2D flow data, providing valuable insights into air quality prediction in cities like Ixelles. The framework developed by DC3 bridges the gap between traditional fluid dynamics and modern machine learning, offering efficient ways to handle incomplete datasets in complex urban environments. These findings are pivotal for improving pollutant predictions in Ixelles, where flow data is often sparse or disrupted.

Building on this foundation, DC9, Haoyan Li, who is conducting his research from Université Libre de Bruxelles, has furthered this work with the development of reduced-order models (ROMs), specifically for simulating atmospheric boundary layer flows and pollutant dispersion. At prominent conferences like ERCOFTAC and ECCOMAS, DC9 presented his Gaussian-Process-Regression (GPR)-based ROM framework, which has demonstrated its effectiveness in urban flow simulations. These models are key for making sense of the fragmented data that cities like Ixelles face, offering a computationally efficient solution for high-dimensional flow predictions, especially in areas with sparse monitoring systems.

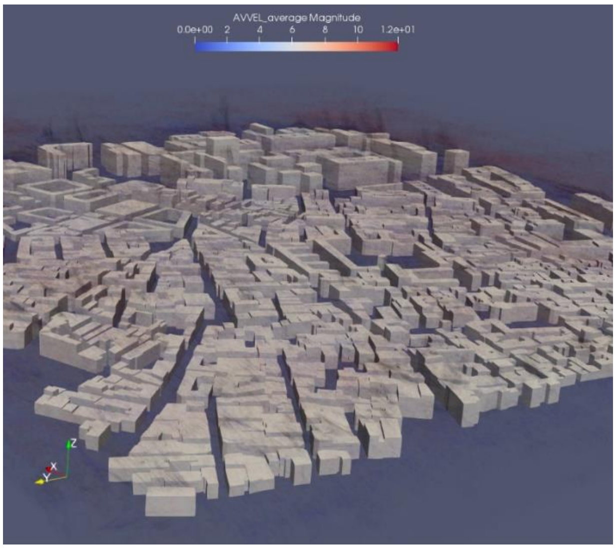
Meanwhile, DC10, Emanuele Bombardi, also researching at Université Libre de Bruxelles, has refined computational fluid dynamics (CFD) methods to study urban flows and pollutant tracking. His extensive review of turbulence models pointed to the SST k−ω model as the most effective for simulating atmospheric boundary layers, a finding that is crucial for cities like Ixelles, where complex interactions between buildings and pollutants are prevalent. DC10's work also extends to combining CFD with machine learning techniques like the Ensemble Kalman Filter and MCMC methods for urban pollutant source identification. This research, which is under review for publication in the Journal of Computational Physics, will be presented at major events like the ERCOFTAC Workshop and EACWE 2025. The framework developed by DC10 is already showing its potential for improving pollutant tracking in urban environments.

Together, the efforts of DC3, DC9, and DC10 are transforming the way we approach urban pollution prediction and mitigation. By blending machine learning with traditional fluid dynamics, their work is advancing the predictive capabilities necessary for addressing air quality challenges in cities like Ixelles, where data scarcity and complex flow patterns often hinder progress. Their integrated approaches are set to redefine urban environmental strategies, offering data-driven solutions for a cleaner, healthier future.

TEST CASE 3: MADRID (SPAIN)

In Madrid, researchers are advancing the understanding and control of urban air pollution through the combination of innovative computational tools, cutting-edge machine learning models, and real-world simulations. The efforts span data cleaning, predictive modelling, sensor optimization, and airflow simulation, offering a comprehensive approach to tackle the complexities of air pollution in densely populated urban areas.

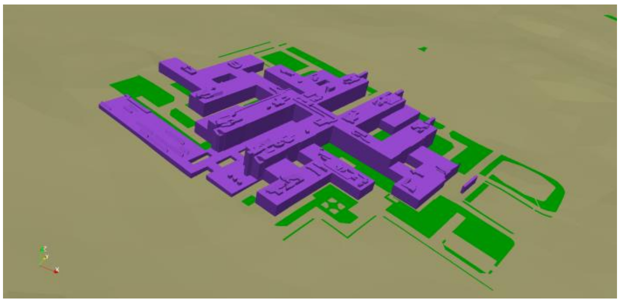
DC1, Guillermo Barragán, researching for Universidad Politécnica de Madrid, has developed highly efficient tools to clean and analyse sparse, noisy sensor data. Utilizing Singular Value Decomposition (SVD) and Higher-Order SVD along with Deep Learning, DC1's tool predicts pollutant behaviour, enhances spatial resolution, and can forecast air quality under unseen flow conditions. This work, tested with experimental and numerical datasets from Madrid, has been presented at the "First Machine Learning for Fluid Mechanics" workshop by ERCOFTAC.



DC2 enhances these efforts by leveraging advanced machine learning to improve predictions of air pollution in sensor-sparse regions. DC2 uses large urban datasets, including those from Madrid, to predict pollution episodes with increased accuracy.

DC4, Marcial Sanchis, researching from KTH Royal Institute of Technology, has contributed a machine learning framework combining autoencoders, transformers, and causality to model chaotic systems. Their development of a new attention mechanism for transformers was presented at the European Fluid Dynamics Conference and is relevant for understanding complex air flow and pollution dynamics in Madrid.

DC7, Paul Jeanney, who is working for our industrial partner ARUP, has made significant strides in urban simulation geometry and data assimilation, particularly for Madrid. The team introduced an Ensemble Kalman Filter (EnKF) approach for enhancing computational efficiency in low-resolution techniques, integrating Super-Resolution methods with SVD and Multi-Dimensional Interpolation (MDI). DC7 also worked on generating urban geometries for Madrid's Vallecas district using QGIS and City4CFD, supporting CFD simulations with OpenFOAM to investigate airflow patterns and pollutant dispersion.



DC12 has worked on developing training data for machine learning models through DNS-based simulations of urban flows. Their optimal sensor placement framework, combining diffusion models and explainable deep learning, provides critical data for improving air quality predictions in urban environments like Madrid.

OTHER NEWS

During these past 24 months, we have celebrated the project kick-off meeting, supervisory board meetings, and our first mid-term check meeting with the European Commission. Additionally, our doctoral candidates have received specialized training in the main topics of our project, including hands-on training in the fields of reduced order modelling, machine learning and computational fluid dynamics. This training has been complemented with soft-skills training. In February 2025, our doctoral candidates will enjoy a joint-training course with ENCODING, which is another Marie Curie Doctoral Network, and CYPHER, a COST action project in which some of our principal investigators are involved in.

THANK YOU

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