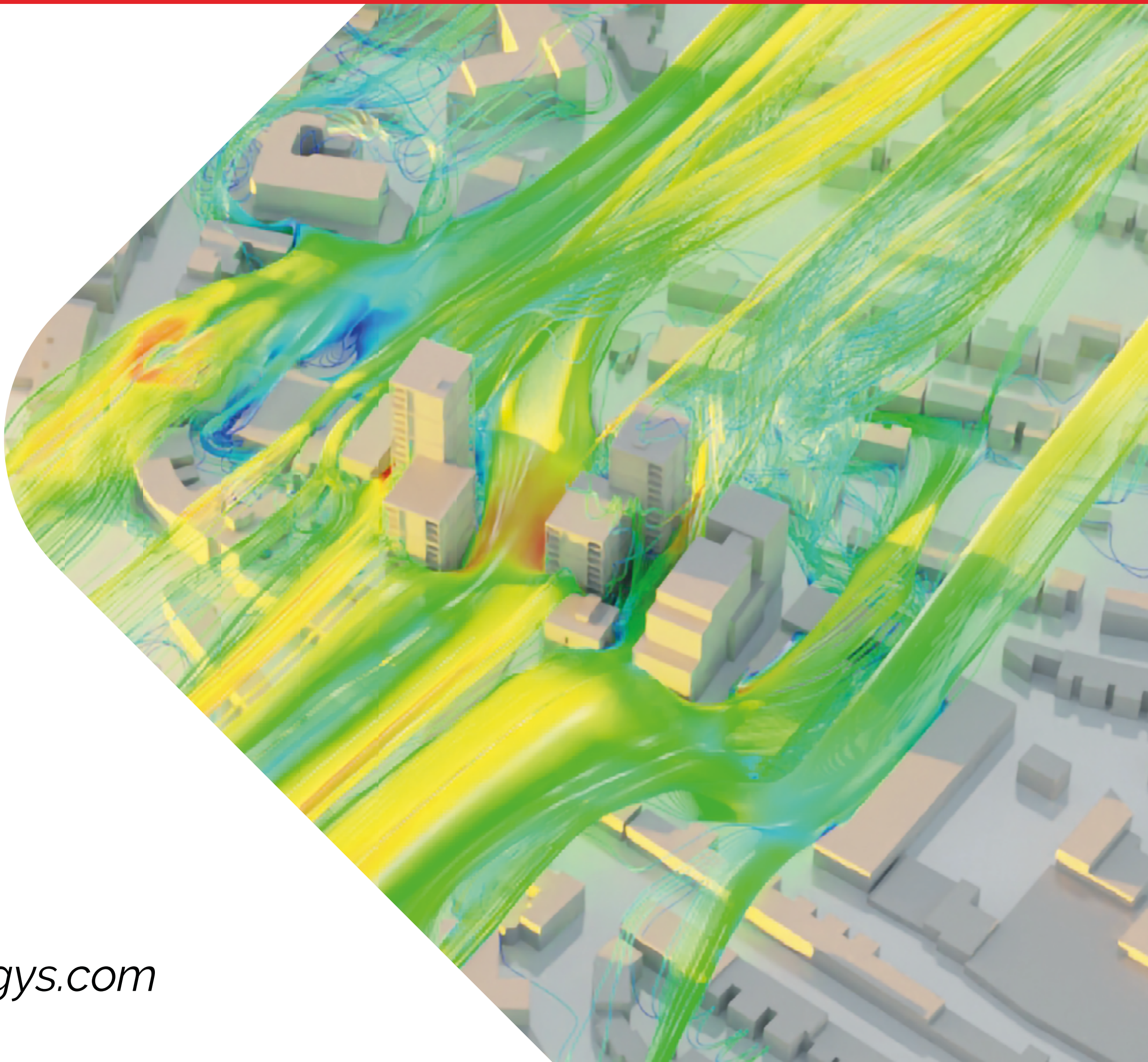
URBAN PHYSICS MODELLING

WITH OPEN-SOURCE CFD



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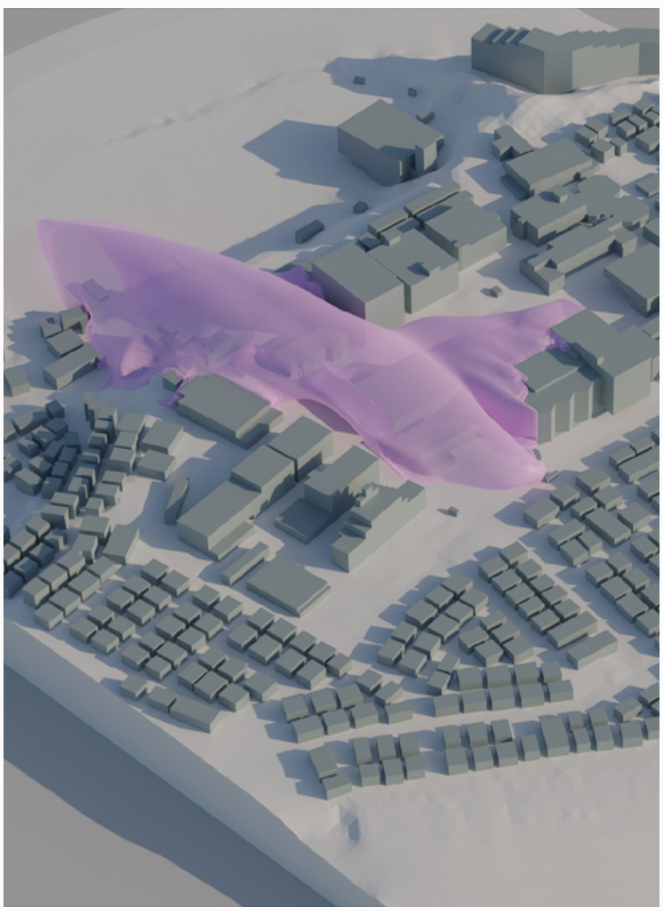
The Rising Significance of CFD in Urban Physics

Cities are dynamic living systems, a complex interplay of architectural structures, human activity, and environmental conditions. As urban environments continue to evolve in their complexity and diversity, the need for tools that can accurately model and predict urban physical phenomena has become increasingly important. This is where Computational Fluid Dynamics (CFD) has emerged as a critical tool, providing the ability to simulate and understand the myriad of physical processes that occur within urban environments.



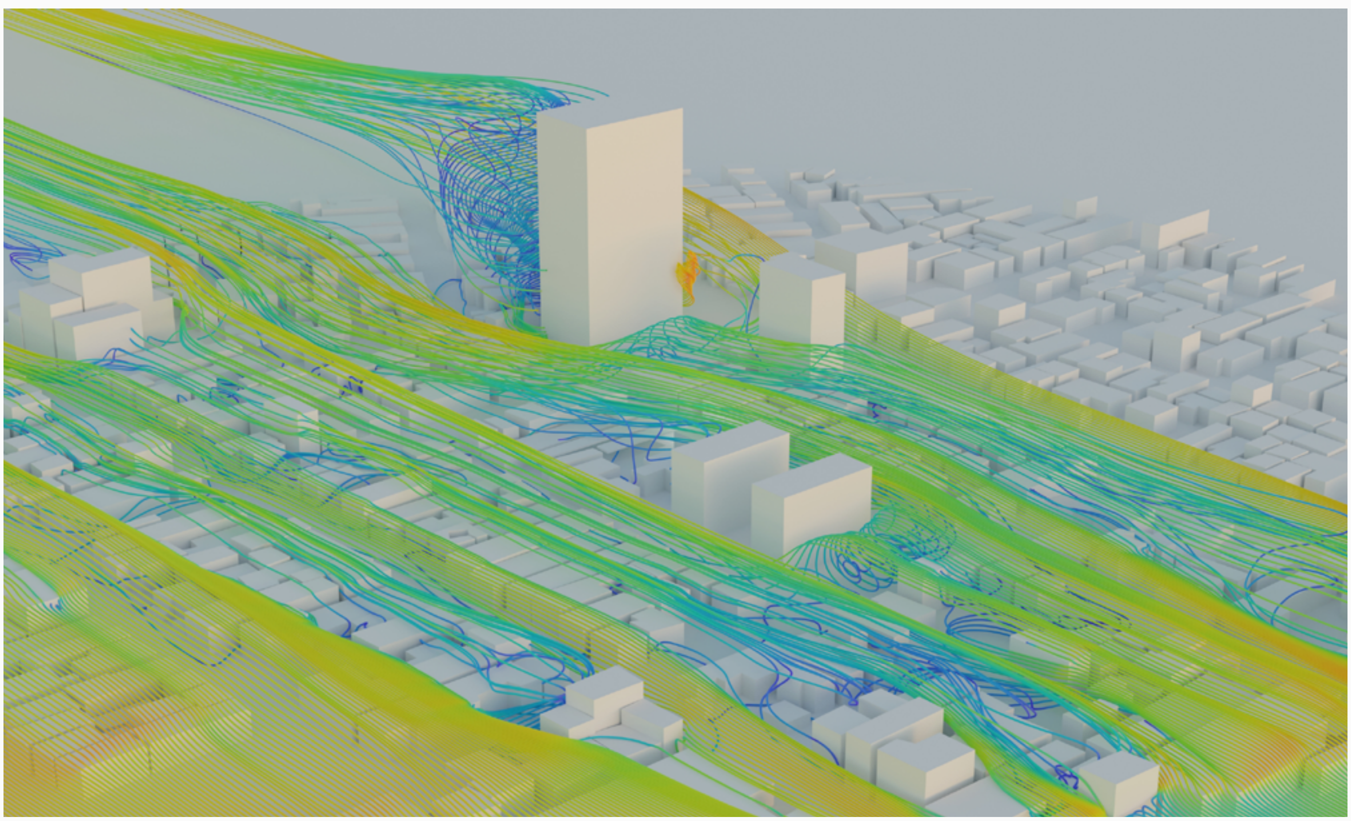
CFD simulation assessing pollutant dispersion at Sofia's (Bulgaria) city center.

Urban physics essentially refers to the fluid mechanics and the transfer of heat and mass in the outdoor and indoor urban environment, and its interaction with humans, fauna, and flora. It has rapidly become a focus area as it is key to understanding and addressing grand societal challenges such as climate change, energy, health, security, transport, and aging.

CFD uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. In the context of urban physics, these fluid flows could be anything from wind blowing through a narrow alley, to heat being transferred through a building, to pollutants being dispersed in the air. By mathematically modelling these fluid flows, CFD allows us to simulate how changes in environmental conditions, building designs, or human activities might affect urban physics. Over the past 50 years, CFD has undergone a successful transition from an emerging field into an increasingly established field in urban physics research, practice, and design.

Urban Physics Modelling (UPM) is an interdisciplinary field that uses these CFD simulations to understand and predict the behavior of various environmental factors in urban settings. It can include everything from the flow of wind around buildings, to the dispersal of pollutants in city streets, to the propagation of noise in urban areas. The insights gleaned from UPM can then be used to inform a wide range of decisions. For example, architects might use UPM to optimize building designs for natural ventilation, urban planners might use it to plan for pedestrian wind comfort, and environmental scientists might use it to study the impact of urban development on local microclimates.

With the significant societal challenges that urban environments are currently facing, the importance of UPM and its associated tools such as CFD is becoming increasingly recognized. As our cities continue to grapple with issues related to climate change, energy use, health, and safety, the role of CFD in urban physics modelling will only continue to grow in importance.



CFD was used to simulate the wind environment influenced by the construction of buildings in Niigata, Japan.

The Benefits of Open-Source CFD for Urban Physics Applications

In the world of computational modelling, the advent of open-source CFD has marked a significant shift, offering a host of benefits for users. Firstly, open-source CFD codes are generally developed by a community of experts who are driven by a shared goal of advancing the field of computational fluid dynamics. This collaborative approach often results in highly robust and efficient software that is continually refined and updated.

One key advantage of open-source CFD codes is their inherent flexibility. Users are free to modify the code to suit their specific needs, enabling them to tailor their simulations to the intricate and varied challenges presented by urban physics. They can add new features, modify existing ones, or optimize the code for their particular use case. This flexibility is particularly important for Urban Physics Modelling (UPM) applications, which often involve complex and unique urban environments that require highly customized simulations.

This flexibility also proves invaluable when addressing city-specific regulations. Cities around the world often have their own unique urban physics regulations and engineering goals. For instance, the "Wind Microclimate Guidelines for Developments in the City of London" provides a comprehensive set of requirements for wind microclimate studies as part of planning applications for new development proposals in the City of London. These guidelines range from general technique requirements to specific wind tunnel test and CFD modelling requirements, as well as stipulations for the presentation of results and reporting. Open-source CFD codes, due to their modifiable nature, can be easily adapted to meet these specific requirements, ensuring the outcomes of their simulations align with the stipulated standards and contribute effectively to urban development planning.

For UPM applications, open-source CFD also offers significant cost benefits. These applications are typically computationally intensive, requiring large mesh sizes to accurately simulate a building and its surrounding environment. Traditional proprietary CFD software charges licensing fees based on the number of cores used for the simulation and on the number of allowed simultaneous CFD runs. Given the large-scale nature of UPM applications, these fees can quickly become prohibitive. In contrast, open-source CFD offers free scalability, meaning that users can run as many simultaneous simulations on as many cores as needed, without incurring additional costs.

Furthermore, in the domain of urban physics, the challenges faced are not just complex but also diverse in nature, requiring a multifaceted approach. The flexibility and scalability of open-source CFD tools make them well-suited to address this diversity. Whether it's modeling the wind flow around a new building design or simulating the dispersal of pollutants in a city street, open-source CFD tools can be adapted to a wide range of scenarios.

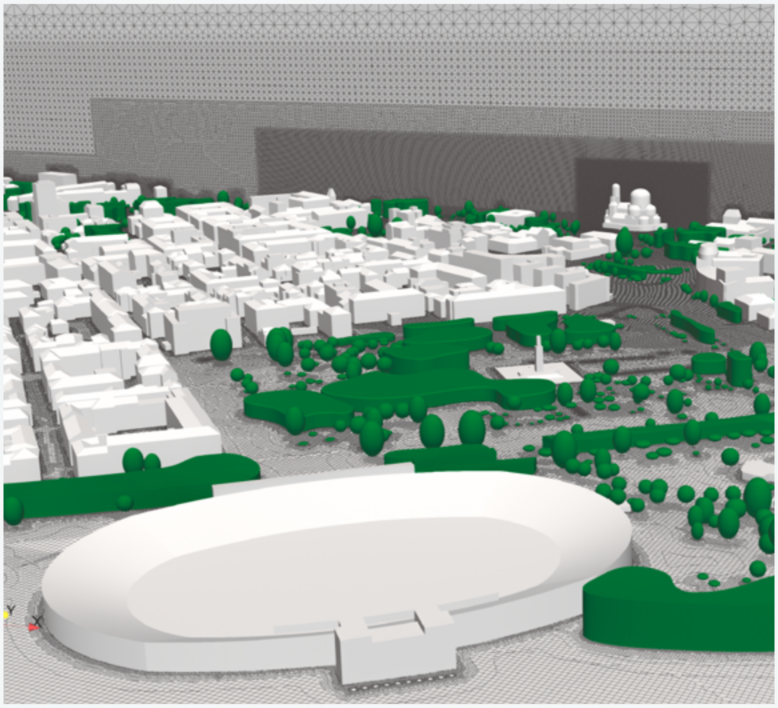
ENGYS, a leading developer of open-source CFD software, offers ***HELYX***, a robust and flexible CFD solution tailored for industrial use. ENGYS provides its customers with full access to the code, ensuring that they can benefit from its scalability and flexibility while also receiving all the benefits from traditional proprietary CFD software, such as an intuitive graphical user interface, highly responsive technical support, reliability and robustness of the code. This unique approach allows users to leverage the benefits of open-source software, while also benefiting from the expert support and continual development provided by ENGYS.

> "The unparalleled value our customers derive from HELYX being open-source stands in clear contrast to traditional licensing methods. An open-source CFD tool like HELYX brings a flexibility that many engineers, who work with CFD on a daily basis, might not yet be familiar with. Consider the (often) demands of Urban Physics Modelling: typically, it involves vast domains and a significant mesh cell count. Imagine the complexity of simulating a city domain with a 2km diameter to accurately gauge the airflow around a specific building, all to predict the precise pollutant dispersion around it. This could mean a simulation with a mesh size of around **50-100 million cells**, possibly using DDES or LES for turbulence modeling. With a powerful computer cluster and a **CFD software free from additional licensing costs, such results can be achieved overnight.**"

LISANDRO MADERS
ENGYS

The FF4EuroHPC Project: Spotlight on AENEAS and Cloud-Sophia

The FF4EuroHPC project, funded by the European Commission, was established with a clear vision: to enhance the competitiveness of European companies, particularly small and medium-sized enterprises, by providing access to high-performance computing (HPC) resources. The project recognized that the high computational requirements of many industrial applications, including CFD, were often a barrier for smaller companies due to the prohibitive costs of maintaining their own HPC infrastructure. By providing access to shared HPC resources, ***FF4EuroHPC*** aimed to level the playing field, allowing these companies to compete effectively on a global scale.



The FF4EuroHPC projects heavily benefited from the flexibility of the open-source CFD software HELYX. The image shows a portion of the surface mesh used in the CFD simulation of the Cloud-SOPHIA task.

A key component of the FF4EuroHPC project was the creation of a streamlined CFD workflow based on open-source solutions that harnessed the power of HPC. This workflow, developed by ENGYS and its partners in the AENEAS and Cloud-Sophia projects, brought together the robustness and flexibility of the HELYX open-source CFD software with the computational power of HPC. By streamlining the process of setting up, running, and analyzing CFD simulations on HPC systems, the project made it easier for companies to leverage these powerful tools for their applications.

The presented experiments have received funding from the European High-Performance Computing Joint Undertaking (JU) under grant agreement No 951745. The JU receives support from the European Union's Horizon 2020 research and innovation programme and Germany, Italy, Slovenia, France, Spain.

In the AENEAS and Cloud-Sophia experiments, ENGYS and its partners demonstrated the immense potential of this streamlined workflow. In AENEAS, ENGYS worked with ***Tecnosistem*** to conduct detailed fire simulations at train stations, showing how CFD combined with HPC could help improve safety in these complex environments. In Cloud-Sophia, ENGYS and ***SoftSim*** used the workflow to tackle a wide range of urban physics problems, from wind-driven rain to wind loading analysis and pollutant dispersion, demonstrating the versatility and power of the approach.

" The primary goal of the AENEAS and Cloud-Sophia experiments, as part of the FF4EuroHPC project, was the productionization of streamlined workflows using HELYX for large-scale industrial applications via HPC. To achieve this, our development and engineering teams faced several challenges in order to enhance the accuracy and reliability of HELYX as a tool for creating virtual CFD models for complex real-world engineering problems.

Firstly, with regard to physical modelling, accuracy was of paramount importance. As a result, we developed optimized models for wind loading, pollution dispersion and wind-driven rain applications in the context of the Cloud-Sophia experiment. In contrast, for the AENAS experiment, which focused on fire simulation to study smoke control systems and emergency strategies, we deployed robust and reliable models that included multi-species transport, buoyancy and radiation.

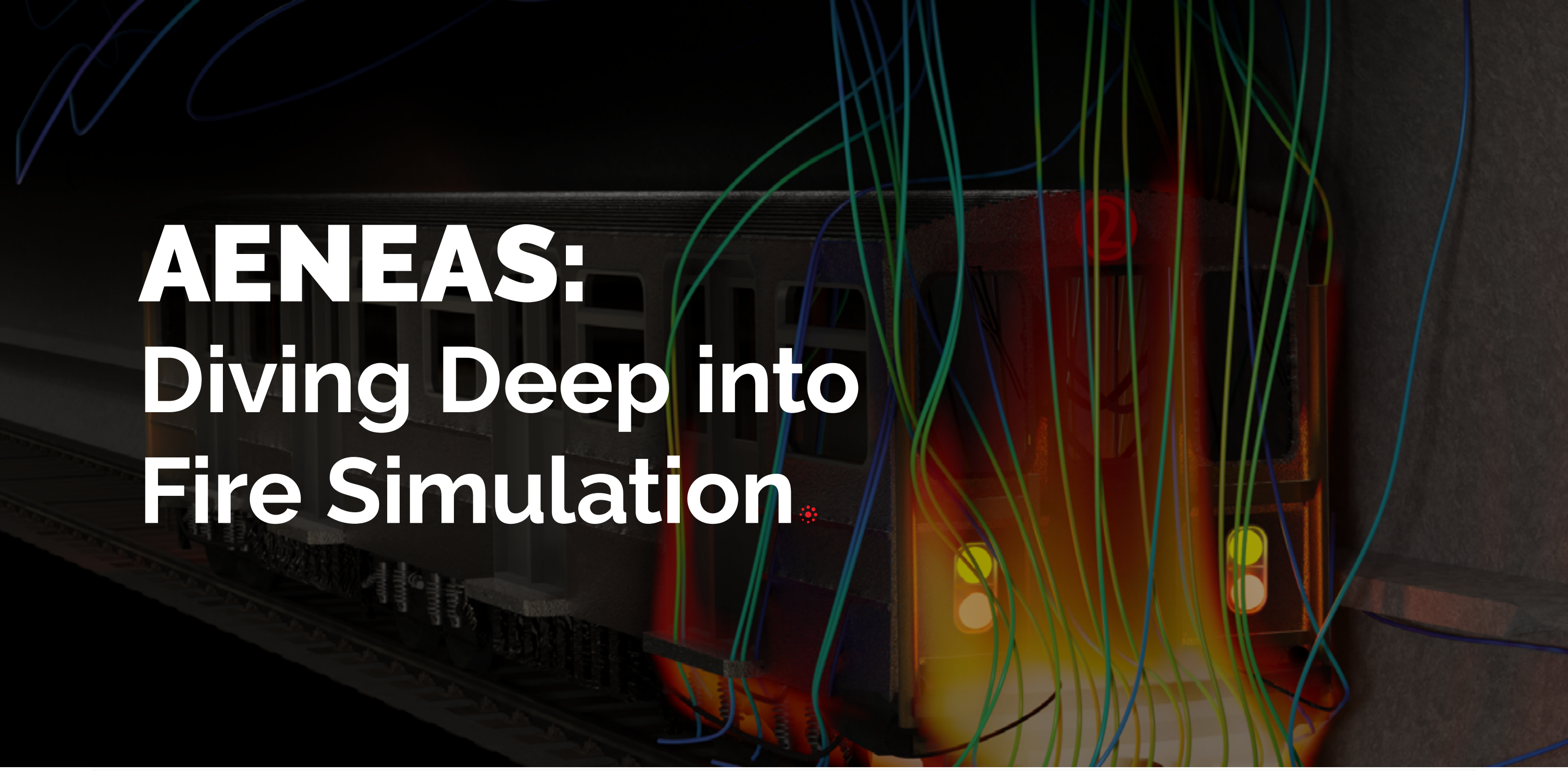
Secondly, we leveraged advanced multi-instance and macro language tools available within HELYX to enhance the CFD models employed in the FF4EuroHPC project. These tools were instrumental in developing automated workflows necessary for conducting parametric and sensitivity studies on both steady-state and transient CFD models with a large cell count.

Our team also delved into the performance and scalability of our solvers when dealing with these extensive CFD models. In this context, our block-coupled solvers consistently outperformed the segregated ones in terms of speed-up, making HELYX-Coupled an ideal tool for HPC-based applications involving large computational models.

Lastly, FF4EuroHPC enabled ENGYS to expand its current offerings for on-demand capabilities, by providing a seamless interface to the HPC facilities made available by HLRS in Germany and CINECA in Italy. This was made possible through the client-server framework available in HELYX. "

PAOLO GEREMIA

ENGYS



AENEAS:
Diving Deep into Fire Simulation

The AENEAS project, under the broader umbrella of the FF4EuroHPC project, embarked on a mission to tackle one of the most critical safety concerns in urban settings: fire in train stations. Fires in such environments pose a unique set of challenges due to the complex geometry of stations, the presence of multiple materials with differing thermal properties, and the human factors associated with evacuation procedures.

In a collaborative effort, ENGYS and Tecnosistem, armed with the power of HELYX and the computational might of high-performance computing (HPC), undertook this intricate task. The primary goal was to develop and validate a CFD model capable of simulating fire dynamics within a train station environment accurately. This included the propagation of fire and the dispersion of smoke, two factors crucial to devising effective safety measures and evacuation strategies.

One of the key achievements of the AENEAS project was the successful implementation of the Fractional Effective Dose (FED) model in HELYX.

The FED model, used to quantify the combined effects of heat and cumulative toxic gases on humans during a fire, was incorporated into the CFD simulations. This allowed for a more comprehensive analysis of safety factors, providing valuable insights into the potential human impact of a fire and informing the development of effective evacuation strategies.

Throughout the AENEAS project, a vast array of CFD simulations were conducted, creating a wealth of data. This data was meticulously analyzed to draw conclusions and make predictions about fire behavior in train stations. The simulations accounted for a multitude of factors, including different types of materials present in the station, various potential ignition sources, and the impact of ventilation systems on smoke dispersion.

ANTONIO RETAGGIO

Tecnosistem SpA

Antonio is a CFD Engineer graduated by Università degli Studi di Napoli Federico II in Aerospace, Aeronautic and Astronautic Engineering. Currently works as a CFD Engineer at the Naples based Tecnosistem SpA.

Design of smoke control systems and emergency strategies for fires in subway tunnels represents a very challenging task. In this context, traditional methods currently in use by engineering companies are not cost-effective and accurate, with potential adverse consequences in terms of passengers' safety in the early stage of the evacuation phase.

The AENEAS application, through a streamlined CFD workflow based on open-source software, together with the power of HPC infrastructure, allows to efficiently manage and run large 3D CFD cases to simulate fire smoke propagation inside subway, railway and road tunnels.This allows both to optimize the effort of the typical design process and to significantly improve the safety conditions for passengers in tunnel.

The social impact of the solution is also enhanced considering that a more efficient design of ventilation systems leads to a downsizing of ventilation fans and silencers, thus reducing the excavation volumes and civil work related costs.

These advantages, for engineering companies like Tecnosistem, immediately lead to a substantial internal cost saving and a remarkable competitive advantage compared to competitors: the new methodology will make it possible to improve company's performance both in direct proposals to stakeholders with a technological "plus", both in public tenders, guaranteeing to the partnership a higher technical score and a reduction in the construction cost of the work.

The AENEAS project illuminated the vast potential of CFD for fire simulation in urban environments, revealing a path towards safer urban living and reinforcing the value of open-source CFD and HPC in addressing real-world challenges.

The AENEAS Project

Explore how advanced HPC technology revolutionized smoke control in subway tunnels through CFD simulations.

Cloud-Sophia:
Unveiling the Multifaceted Applications of CFD

The Cloud-Sophia project, another pillar of the FF4EuroHPC project, underscored the versatility of CFD in tackling various facets of urban physics. This project was a testament to the multifaceted nature of CFD, showcasing its application in an array of urban physics scenarios, each presenting unique challenges and requiring specialized modelling approaches.

In Cloud-Sophia, ENGYS and SoftSim, utilizing the capabilities of HELYX, embarked on a series of complex CFD analyses. Each focused on a different aspect of urban physics modelling, such as wind-driven rain, surface/facade wind pressure, pollutant dispersion, and pedestrian wind microclimate. These analyses were not just theoretical exercises; they were designed to address real-world problems faced by urban planners, architects, and engineers.

One of the key analyses involved modelling wind-driven rain, an important factor not only affecting the durability and performance of building facades, but also influencing human comfort in outdoor spaces such as semi-opened terraces/balconies, restaurants and recreational areas. By accurately predicting the impact of rain droplets penetration on different building designs and materials, the simulations provided crucial insights that could help enhance building durability and longevity. This type of analysis can also help to determine the need for architectural modifications on the facades, rain protection and gutter systems to ensure a pleasant experience for people in areas susceptible to wind-driven rain issues, while still maintaining the aesthetic design of the building.

Surface/façade wind pressure analysis was another critical focus area of the Cloud-Sophia project. Buildings and structures within urban environments are subjected to various wind impacts, among which wind pressure can be particularly challenging to predict due to their variable and dynamic nature. Through detailed wind pressure simulations, the HELYX could provide data that is invaluable for structural and MEP engineers in supporting on preliminary stage the design of the buildings and mechanical system operation.

Pollutant dispersion is a significant concern in urban environments, with implications for air quality and public health. The Cloud-Sophia project conducted detailed simulations of pollutant dispersion in various urban layouts, providing insights into how urban planning and design strategies could affect air quality.

Dr. Sergey Mijorski, Managing Director of SoftSim Consult Ltd. was involved in the Cloud-Sophia project. His experiences with the implementation of the HELYX for large city center site was as follows:

SERGEY MIJORSKI

SoftSim Consult Ltd.

Sergey is a CFD and building physics engineer with extensive knowledge in all aspects of numerical modelling, analytical and theoretical analyses. Ph.D. in Fluid Mechanics / CFD Modeling by the Technical University of Sofia.

“*Through Cloud-Sophia project it was demonstrated great and powerful capabilities of HELYX Block-Coupled Solver for assessment of Urban physics problems within largescale city center areas. During the project it was successfully completed various analyses, including wind-riven rain, pedestrian wind microclimate, wind pressure, and pollution dispersion. Total of 4 km² city area was covered in the CFD models. Through employing HPC facilities, the new HELYX features and capabilities enables small and medium size companies to perform complex and largescale site assessments with fast and competitive way, thus satisfying the contemporary industry demand.*”

The work done in the Cloud-Sophia project provides a compelling demonstration of the power of CFD in addressing complex, real-world problems in urban physics. It also underscores the value of open-source CFD tools like HELYX, which provide the flexibility and scalability needed to tackle these challenges effectively.

Learn how SoftSim's quest for enhanced CFD capabilities transformed architectural planning with ENGYS' cloud-based CFD and HPC technology.

WATCH WEBINAR

ENGYS, HELYX, and the Future of Urban Physics Modelling

Urban physics has emerged as a critical field at the crossroads of architecture, environment, and human interaction. Understanding this interplay is pivotal for shaping the future of our cities. ENGYS, with its rich history rooted in the AEC sector, is leading this transformation, offering ***groundbreaking tools like HELYX***.

With AEC being the second-largest contributor to ENGYS' revenue stream, it's evident that the company has not just dipped its toes in the sector but has plunged deep into its waters. This focus has continuously steered the enhancement of software capabilities, ensuring that ENGYS remains at the vanguard of industry needs.

With its maturity and refinement over the years, HELYX has proven to be a complete CFD tool for Urban Physics Modelling (UPM) applications. It's not just about having a CFD tool; it's about having one that addresses the multifarious challenges of the urban environment. HELYX achieves this with its cutting-edge engineering and numerical models, combined with state-of-the-art solvers. It's the tool that engineers trust when precision and accuracy are paramount.

One of the defining features of HELYX is its open-source nature. HELYX users have the freedom to run multiple simulations concurrently across numerous processors. In the realm of UPM, where high-resolution transient runs using DES/LES solvers are commonplace, and large mesh sizes demand high computational power, this flexibility is invaluable. It obviates the need for additional HPC licenses, making large-scale simulations more accessible and cost-effective.

"We believe our tools align perfectly with the needs of the AEC sector. Often, we see our customers effortlessly solving large DDES or LES cases using HELYX, and running multiple variations of the same case. This is the vision we uphold as a CFD software provider: empowering our customers to craft transformative solutions and tackle the most intricate engineering challenges in their sector, all through our scalable and user-friendly software."

"ENGYS is consistently investing in fresh methods, models, and solvers to ensure our software complements our customers' remarkable accomplishments as scientists, designers, and engineers. With a rich history of serving the AEC industry, we've always centered our focus on refining our tools to match the cutting-edge applications in this field. And from my perspective, we're doing a great job!"