IMPERIAL
Department of Earth Science and Engineering

PhD Project Description

Project Title: AI Surrogate Models for Radiation Transport in Urban and Energy Systems

Supervisors

Lead Supervisor: Prof Christopher Pain
Co-supervisor: Dr Claire Heaney

Department of Earth Science and Engineering

Research Group – Applied Modelling and Computation Group (AMCG)

The PhD student will be based in AMCG, an interdisciplinary research group developing innovative computational and mathematical modelling techniques across earth, nuclear, environmental and biomedical science and engineering. The group combines expertise in mathematical modelling, scientific machine learning, high-performance computing, data assimilation and optimisation.

A recent focus has been the development of AI surrogate models that are independent of computational domain size and geometry [1,2,3], together with Neural Physics approaches in which numerical discretisations are represented within neural networks using analytically specified weights. These capabilities provide a foundation for developing fast, accurate and generalisable surrogate models for radiation transport, with applications spanning urban environments, industrial furnaces and nuclear reactors.

Project Summary

Radiation transport is fundamental to many important physical and engineering systems. In urban environments, radiation from the atmosphere, the Sun, buildings and other surfaces influences the thermal environment experienced by people and affects building energy requirements. Radiation can occur over both **short distances**, such as the exchange of radiation between nearby surfaces and objects, and **long distances**, such as radiation propagating through the atmosphere or between widely separated regions of an urban environment.

Accurately modelling these processes can require computationally expensive radiation-transport calculations, particularly when complex three-dimensional geometries, multiple wavelengths, scattering, absorption and emission must be represented. This makes high-fidelity radiation models difficult to use repeatedly within large-scale urban simulations, optimisation, uncertainty quantification and real-time prediction.

Similar challenges occur in industrial furnaces, where radiative heat transfer can dominate the thermal behaviour of the system, and in nuclear reactors, where the transport of neutrons and other radiation through complex materials and geometries is central to reactor analysis and safety.

This project will develop **AI-based surrogate models for radiation transport** that can provide rapid predictions while retaining the accuracy and physical behaviour of high-fidelity numerical models. The primary application will be **radiation transport in urban environments**, with particular emphasis on the representation of both short-range and long-range radiation. The resulting methods will also be investigated for applications to **industrial**

furnaces and nuclear reactors, providing a demanding test of the generality of the underlying AI methodology.

Research Context

Radiation transport in urban environments is computationally challenging because buildings, streets, vegetation and other structures create complex three-dimensional geometries. Both **short-wave radiation**, primarily from the Sun, and **long-wave radiation**, emitted thermally by the Earth, buildings and other surfaces, undergo absorption, emission, reflection and scattering.

Accurate radiation-transport models can be computationally expensive, particularly for large urban domains and when many simulations are required. A key challenge is therefore to develop surrogate models that can efficiently represent both **short-wave solar radiation and long-wave thermal radiation**, including their local and non-local interactions. For example, the radiation received at a location may depend on nearby surfaces as well as distant buildings, atmospheric conditions and solar position.

The project will investigate AI architectures capable of learning these complex radiative interactions while **generalising across different urban geometries, spatial scales and physical conditions**. The aim is to develop fast, accurate and transferable surrogate models that can replace expensive radiation-transport calculations within large-scale urban environmental simulations.

Overall Objective

The overall objective is to develop **accurate, efficient and generalisable AI surrogate models for radiation transport**, with particular emphasis on the coupled short-wave and long-wave radiation processes occurring in complex urban environments.

The longer-term aim is to enable high-fidelity radiation calculations to be replaced, where appropriate, by rapidly evaluated AI models within **large-scale urban environmental simulations, optimisation and real-time prediction**, while also providing a transferable methodology for industrial furnaces and nuclear reactors.

Collaborators and Partners on the Project

The project will involve collaboration with researchers across Imperial College London, including researchers in Earth Science and Engineering and other groups working in environmental modelling, computational physics, artificial intelligence and nuclear engineering.

There is also potential for collaboration with external partners working in urban environmental modelling (e.g. through the AI4URBAN-HEALTH network), building energy systems, industrial heat transfer and nuclear engineering, providing opportunities to apply the developed methods to realistic engineering and environmental problems.

Further Reading

[1] CE Heaney, X Liu, H Go, Z Wolffs, P Salinas, IM Navon, CC Pain (2022) *Extending the Capabilities of Data-Driven Reduced-Order Models to Make Predictions for Unseen Scenarios: Applied to Flow Around Buildings*, Frontiers of Physics 10:910381. https://doi.org/10.3389/fphy.2022.910381

[2] NC Pinheiro, D Guo, HP Menke, AC Joshi, CE Heaney, AH Elsheikh, CC Pain (2026) *Surrogate models for rock–fluid interaction: a grid-size-invariant approach*, Engineering with Computers 42:131. https://doi.org/10.1007/s00366-026-02353-x

[3] D Guo, CE Heaney, NC Pinheiro, L Li, B Chen, CC Pain (2026) *Domain-agnostic AI-based surrogate models: Transient flow prediction with domain-size and geometry invariance*, Computer Methods in Applied Mechanics and Engineering 461:119258. https://doi.org/10.1016/j.cma.2026.119258

Who Are We Looking For?

We are looking for a student interested in artificial intelligence, radiation transport, environmental modelling and computational physics, with a strong mathematical and computational background and a good degree in, for example, mathematics, physics, computer science, engineering, environmental science or earth sciences.

Experience in **programming, machine learning, numerical modelling, scientific computing or radiation transport** would be advantageous, although applicants with a strong mathematical foundation and a willingness to learn are encouraged to apply.

The project is inherently interdisciplinary and would suit a student interested in developing new AI and computational methods while applying them to important real-world problems. The student will have the opportunity to work at the interface of **artificial intelligence, radiation physics, urban environmental science, high-performance computing and energy systems**, developing methods with applications ranging from the radiation environment of cities to industrial furnaces and nuclear reactors.