PhD PROJECT PROPOSAL

## **PhD Project Title**

## Topological Analysis to Understand Emissions formation and transformation processes from Fused Deposition Modelling Additive Manufacturing

## **PhD Supervisory Team**

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## **Project Abstract**

## The adoption of additive manufacturing is increasing the use of 3D printers at manufacturing hubs, education centres and residential households exposing unaware users to emissions. This project aims to develop methods and tools from topology, to understand the formation and transformation of particles from the emission source (3D printer) to the user using new waste-based filament materials. This new knowledge and tools will be useful to mitigate the emergent health impact associated to particles exposure in real working environments. Knowledge and solutions will be disseminated via publications, social media, research-informed teaching and advocacy activities by the academic team and collaborators.

## **Detailed Project Description**

**Background**



Additive manufacturing using 3D printers coupled to topological design has emerged as a design tool for various applications such as automotive, aerospace, healthcare, and education[1]. Its popularity is growing thanks to the time efficiency[2] and cost[3] of prototyping 3D models. A widespread type are affordable desktop fused deposition modelling (FDM) printers which employ plastic filaments to form objects. The use of waste-based filaments reduces the reliance on oil feedstock, the lifecycle environmental impact of 3D printing products and plastic waste[4]. FDM printers employ a heated nozzle to melt the filament and deposit melted plastic to form the object. During the heating and extruding process, the filament emits nano-size particles[5] (Figure 1) within the high alveolar deposition size range of 5 to 50nm[6-7].

3D printing particle formation depends on filament materials, product design and 3D printing process as well as are subjected to transformation processes modifying emission levels and characteristics (size, morphology). The evolution of emission characteristics need to be understood as they affect the filtration properties required to design efficient abatement systems as well as their environmental and health impact.

**Intended Outcomes**

The project will provide knowledge to understand additive manufacturing particle emissions formation and transformation processes utilising characteristics from fractal geometry and algebraic topology. This knowledge will further enable the design and production of waste-based clean emission filament materials underpinning circular economy.

The new knowledge, data and tools will be disseminated via publications (three publications are expected) and 1 conference. The project will provide breakthroughs in the areas of air quality and application of mathematical methods by providing critical foresight, data and models relating emissions transformation processes and characteristics to exposure levels under real conditions and environments as well as materials and manufacturing by designing waste-derived low emissions eco-filaments and enabling clean manufacturing processes.

The **objectives (O)** of the project are:

**O1.** Particle quantification and characterisation in terms of composition/nature, size, morphology and nanostructure.

**O2.** Determine the mathematical topological relationships between waste-based filament material properties, 3D printing process parameters, and geometric design with the formation and transformation of particle emissions during 3D printing.

**O3.** Identify and understand the governing emissions transformation mechanisms and their influence on emissions levels and characteristics using topological modelling techniques, calibrated and experimentally validated.

**Methodology**

**WP1:** Development of emissions sampling and characterisation methods.

**WP2:** Study the topological relationship between material and manufacturing parameters and resulting particle characteristics: 2.1 – Waste-based filament materials production and characterisation; 2.2 – Design and manufacturing parameters; 2.3 – Studying the topological relationships between particles, and how they change based on the parameters from 2.1 and 2.2.

**WP3:** Understanding the topological dynamics of 3D printing emission transformation processes: 3.1 - Understand the governing transformation mechanisms and their influence on emissions levels; 3.2 – Define the topological relationship between 3D printing processes and particle formation over time; 3.3 – Study the interactions of emissions from multiple printing devices.

**Training and skills to be developed**

The project aims to develop the career of the PhD student in the area of topological design applied to the utilisation of clean waste-derived 3D printing filaments underpinned by a foundation of world-leading expertise on 3D printing emission formation and transformation processes. The following training objectives (TO) are proposed:

**TO1.** Enhancement of technical skills through hands-on training at the School of Engineering, University of Birmingham; the operation of 3D printers and emissions characterisation equipment.

**TO2.** Training on the use of in-house developed emission characterisation methodologies.

**TO3.** Training on the development and application of material characterisation to create database of material properties.

**TO4.** Training on fractal geometry and algebraic topology which will then be used to analyse large data sets and images, to be guided by the associated academics.

**TO5.** The postgraduate researcher will have the opportunity to obtain a diploma on numerical simulation for engineering, organized by our industrial partner [Andaltec](https://www.andaltec.org/training/?lang=en).

**Project suitability for the CDT in Topological Design**

The project requires the application of topological data analysis to understand particle formation from 3D printing, the influence on particle characteristics and of particle transformation processes. Concepts from fractal geometry and algebraic topology, will be developed to predict the evolution of particle morphological characteristics, which have a key impact on the design of particle abatement technologies, exposure levels and air quality and human health effects (e.g., lung deposition).

**Links with research in the research groups of the supervising team**

The research team, based at the School of Engineering, has a strong track-record in the areas of emissions and Additive Manufacturing carried out in collaboration with industry and supported by EPSRC and European Commission. The vision of the team is to enable efficient, clean, and sustainable manufacturing preserving air quality. The supervisory team has published articles with issues on outdoor[8] and indoor[9] emissions. The supervisory team is PI in the MSCA-2021-PF 101065979 (EP/X02279X/1) designing added value products from waste in collaboration with Andaltec and University of Cordoba; and Co-I in the EPSRC project on emission abatement solutions via Additive Manufacturing (EP/P03117X/1) and AMTECAA project supported by the ERDF funded Smart Factory Hub on 3D printing.

The associated academics have a strong track-record in fractal geometry, dynamical systems, and topology, with 33 peer-reviewed journal articles in these fields. Their research has been supported by grants from, EPSRC (UK), London Mathematical Society (UK), the German Research Council (DE), the National Science Foundation (USA), and the Royal Swedish Academy of Sciences.

**Links with research strategies**

This project is well aligned to the strategic link between The University of Birmingham and Manufacturing Technology Center in sustainable manufacturing. Project findings will contribute to the EPSRC research areas of “Manufacturing technologies”, “Engineering design”, “Particle technology”.

The project partner, Andaltec, will provide relevant expertise and waste-derived materials to produce new clean 3D printing filaments. Their experience is key to deliver added value fit to purpose eco-products, being unique by considering emissions footprint in the design process. The experience of Andaltec in 3D printing under real operation conditions complements the University of Birmingham’s team to develop experimental methods and models to understand emissions formation and transformation mechanisms under real manufacturing hubs.

**References**

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