Lit Review

**Abstract**

In real-world engineering problems, design problems are often complex with components composed of intricate parts and features that define the functionality or aesthetics of the component. One of the key driving concepts in engineering innovation is design exploration and optimisation, referring to the ways in which potential designs are identified that result in the most optimal performance being realised in context of a performance goal or objective function. To determine this, and as is common in industry, numerical tools such as Computational Fluid Dynamics (CFD) or Finite Element Analysis (FEA) are used to provide performance data associated with engineering designs (e.g lift performance for an aerofoil or heat losses for a heat exchanger). These tools are computationally expensive, and not suited to fast, iterative design exploration attributed to the computational cost of solving physical equations to provide numerical data. They are typically used towards the end of a design process, downstream of opportunities to iterate or change designs. This computational burden generally increases with added complexity in the inputs, such as number of elements in unstructured meshes, point clouds or voxels. In contrast, popular optimisation methods rely on our ability to parameterise the problem in an efficient way. While simpler shapes such as tubes or rings can be easily parametrised by properties such as radius or thickness to enable a well-defined set of search dimensions that denote different design configurations, more complex shapes such as turbine cooling channels, or intricate heat exchange surfaces cannot be concisely described by a finite set of parameters and reside in high-dimensional geometry representations. As part of this research by conducting a systematic literature review, we will investigate approaches to representing high-dimensional engineering problems in a low-dimensional space to overcome the curse of dimensionality to enable efficient design space exploration and optimisation. Identified methods will be implemented develop a framework for embedding such representations into a proof-of-principle geometric optimisation problem. The research will also explore the interpretability and controllability of the low-dimensional representations to enable targeted design modification and optimisation in the low-dimensional representation.

**Introduction**

**Background**

Design Space Exploration

Design Optimisation

Geometry Representations

**Methodology**

**Discussions**

Engineering often requires exploration of a vast design space to identify and implement effective solutions that satisfy performance or functional objectives. It is also common to use tools such as Finite Element Analysis (FEA) or Computational Fluid Dynamics (CFD), or in some cases physical experimental testing to assess performance associated with designs. In any case, these approaches are either computationally costly (i.e, requires significant compute resource) or physically expensive (labour, materials, hardware). Assuming infinite exploration of the complete design space is naïve, and likely intractable for complex engineering problems. Numerical simulations are often used in place of physical testing as a more efficient way to gain performance data. However, these tools are not well suited to fast, iterative design iterations that require many design changes and consequently costly numerical simulations to be run. This loop is ubiquitous in engineering design to enable identification of an optimal solution and is typically complicated by complex, high-dimensional input data types such as unstructured meshes, voxels or points clouds that do not lend themselves to easy parametrisation. The design space can be thought of as a multidimensional representation of all design configurations each of which has an associated performance – in 3D, as real-world problems exist, the potential configurations for the design space is vast and suffers from the curse of dimensionality [1].

Introduction

For the likes of CFD, components are often represented as complex data formats such as unstructured meshes, voxels or point clouds. For CFD simulations, multi-million element mesh structures are not uncommon, and running complete simulations on such components can takes hours, to weeks which is unfeasibly inefficient for rapid design optimisation. Components of high complexity do not typically lend themselves to easy parameterisation and therefore the design space is not easily described concisely, rather the design space can thought of as a high-dimensional space where the elements of a component have the freedom to occupy all positions in space

### References