Abstract

The goal of this thesis is the development of theoretical methods targeting the implementation of topology optimization in structural engineering applications. In civil engineering applications, structures are typically assemblies of many standardized components, such as bars, where the largest gains in efficiency can be made during the preliminary design of the overall structure [4]. The work is aimed mainly at truss-like structures in civil engineering applications, however several of the developments are general enough to encompass continuum structures and other areas of engineering research too. The research aims to address the following challenges:

- Discrete variable optimization, generally necessary for truss problems in civil engineering, tends to be computationally very expensive,
- the gap between industrial applications in civil engineering and optimization research is quite large, meaning that the developed methods are currently not fully embraced in practice, and
- industrial applications demand robust and reliable solutions to the real-world problems faced by the civil engineering profession.

In order to address these issues, the research is divided into several research papers, included as chapters in the thesis. An overview of the papers making up the chapters is given in figure 1, and the chapters are summarized as follows:

Discrete binary variables in structural topology optimization often lead to very large computational cost and sometimes even failure of algorithm convergence. A novel method was developed for improving the performance of topology optimization problems in truss-like structures with discrete design variables, using so-called Kinematic Stability Repair (KSR) [5].

Two typical examples of topology optimization problems with binary variables are bracing systems and steel grid shell structures. These important industrial applications of topology optimization are investigated in the thesis. A novel method is developed for topology optimization of grid shells whose global shape has been determined by form-finding [7]. Furthermore a novel technique for façade bracing optimization [8] is developed. In this application a multiobjective approach was used to give the designers freedom to make changes, as the
Figure 1: Overview of the various publications making up the PhD.
design advanced at various stages of the design process.

The application of the two methods to practical engineering problems, inspired a theoretical development which has wide-reaching implications for discrete optimization: the pitfalls of symmetry reduction [6]. A seemingly self-evident method of cardinality reduction makes use of geometric symmetry reduction in structures [3, 1, 2] in order to reduce the problem size. It is shown in the research that this assumption is not valid for discrete variable problems. Despite intuition to the contrary, for symmetric problems, asymmetric solutions may be more optimal than their symmetric counterparts.

In reality many uncertainties exist on geometry, loading and material properties in structural systems. This has an effect on the performance (robustness) of the non-ideal, realized structure. To address this, a general robust topology optimization framework for both continuum and truss-like structures, developing a novel analysis technique for truss structures under material uncertainties, is introduced. Next, this framework is extended to discrete variable, multi-objective optimization problems of truss structures, taking uncertainties on the material stiffness and the loading into account. Two papers corresponding to the two chapters were submitted to the journal Computers and Structures and Structural and Multidisciplinary Optimization.

Finally, a concluding chapter summarizes the main findings of the research. A number of appendices are included at the end of the manuscript, clarifying several pertinent issues.

References


