A differentiable assignment algorithm for high performance inventory-driven structural design

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Recently, the sustainability imperative has inspired emerging interest in the reuse of materials for construction, and in particular of linear structural components for bar-based structures such as trusses and frames. Many of the computational approaches to this reuse approach require an efficient algorithm for the assignment of inventory elements to the elements of a designed structure. This assignment is guided by both cost, e.g. the cutoff waste in assigning bar elements, and constraint, e.g. the assigned element must have sufficient geometric and material properties to fit the target and resist anticipated loads. Of many approaches, the Hungarian Algorithm has proven to be effective in the context of circular structural design [1]. Computational speed and implementation simplicity enables its inclusion in common structural design pipelines, including optimization. However, as the matching process is combinatorial in nature, the propagation of sensitivity from downstream performance metrics (such as overall matching score) to design variables (such as node positions) is ill-posed, and must rely on gradient-free optimization algorithms. As such, problems with many design variables or large inventories suffer in computational time or the quality of results.

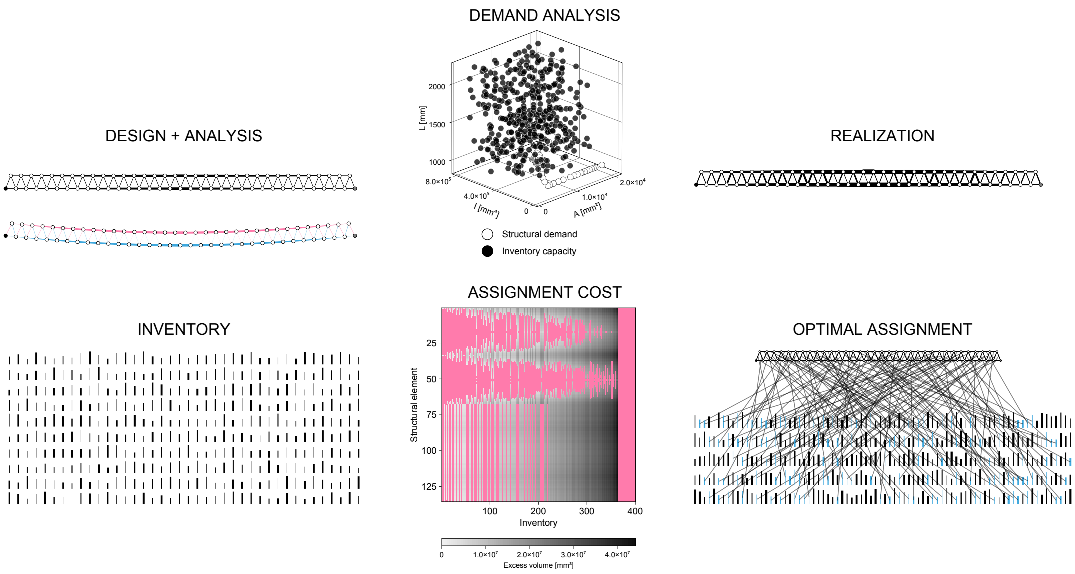

Figure 1: Key components of optimal assignment

With advancements in Automatic Differentiation (AD), general structural optimization problems are readily solved with speed and precision using gradient-based algorithms. To extend this performance to structural reuse problems, we require a suitable AD-compatible algorithm for optimal assignment. We show preliminary results for a differential assignment algorithm that relaxes combinatorial matching into a smooth optimal transport problem by considering structural demand and inventory capacity as probability distributions. The performance of this algorithm is evaluated against conventional matching across objectives and problem scales. We show that differentiable matching enables rapid solutions to complex inventory-based optimization problems of arbitrary scale, and the composition of assignment and geometric objectives allow for mediation between reused inventory utilization and design intent.

References

[1] Yijiang Huang et al. “Algorithmic circular design with reused structural elements: method and tool”. In: *Proceedings of the International fib Symposium on the Conceptual Design of Structures*. Vol. 55. Fédération Internationale du Béton (fib). 2021, pp. 457–468.