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Structurally informed exploration of a grammar-based design space

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1. BACKGROUND

Shape grammars are a very powerful concept in design, they consist in creating a design through a set of predefined *rules* that define a *grammar*. Applying said grammar on a start shape can result in an indefinite amount of new shapes.
'Grammar Design using Graphic Statics – GDGS' (Lee, 2015) proposed combining the broad creative space enabled by shape grammars to the geometric rules of graphic statics into a creative design tool for structural design.

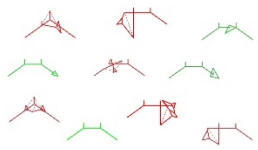
In GDGS, a design is generated through the following steps:
1. The user defines a load case and the corresponding support conditions to ensure a state of global equilibrium.
2. All nodes are equilibrated with temporary forces
3. The GDGS grammar is applied on the temporary forces until all temporary forces are resolved and the system is in global equilibrium

Because the algorithm is based on a lot of randomness, the design space is hard to explore. The project aimed at providing a guide method to the algorithm to allow for the designer to explore the design space in an informed way.

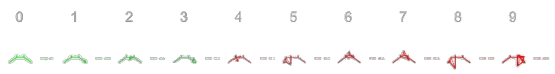
2. ALGORITHM

The method applied is an evolutionary algorithm (EA). EA's are based on the Darwinian principle of evolution, using basic concepts of natural selection to generate new solutions out of a given parent set. In essence, individual solutions of a population are ranked on their fitness within that population, out of the best performing individuals of that generation new offspring is bread. The offspring can inherit form its parents' features through cross-overs or mutations. The population is ranked again and the same process is applied until a set iteration count is reached. The basic workflow of the applied algorithm is illustrated hereafter:

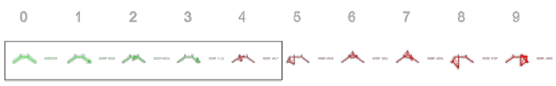
1. Generate population of n random designs



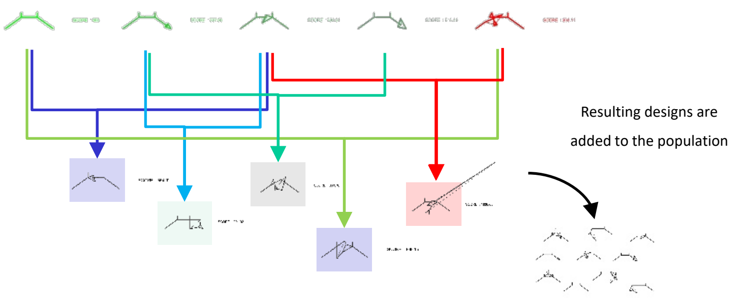
2. Evaluate and rank designs



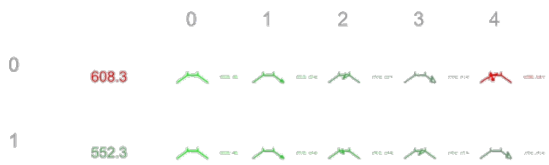
3. Select m top performing designs



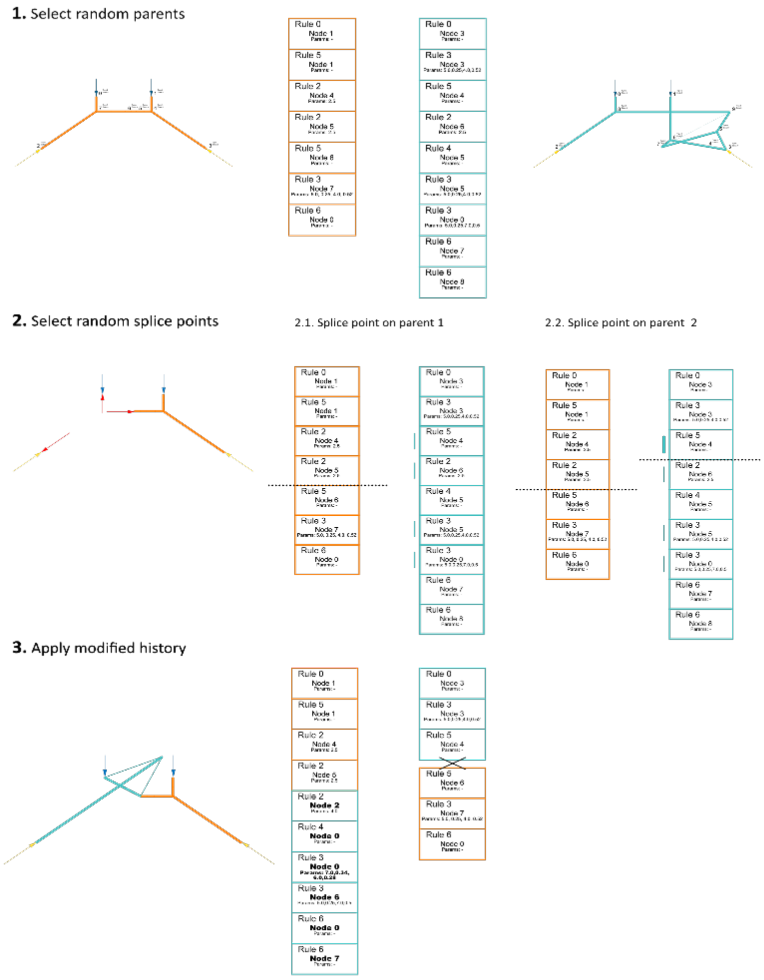
4. Create m new designs through random cross-overs using previous top designs as parents



5. Start over at step 2



Unlike parametric designs, GDGS-designs are not defined by a set of parameters but by the rule history through which they were created. An adapted cross-over method was therefore developed, presented in the figure below.
Geometry from the first parent is constructed until a certain rule in its history – the first splice point. Part of the history of the second parent is then grafted onto the unfinished shape. Rules can only be applied in specific conditions, hence not all rules of the second parent are possible candidate splice points. The compatible rules are identified (blue tags) and one is chosen randomly. The history starting at said splice point is then applied on the unfinished shape, resulting in a new design.



3. FITNESS FUNCTION

Different fitness functions were considered to assess the performance of designs in a given population:
- The total load path, i.e. the sum of force * length products over all members
- The total volume, taking into account a buckling criteria in the estimation of the minimal area for members in compression
- The standard deviation of member specific features over all members of a design, i.e. their length, force, volume, F*L score

These scoring functions allow to lead the EA towards designs with specific features, for example designs with less elements for F*L, structures with less long spanning members for V and designs with more equally distributed lengths when considering standard deviation on lengths.

4. REFERENCES

Lee, J. (2015*). Grammatical design with graphic statics : rule-based generation of diverse equilibrium structures,* Massachusetts Institute of Technology