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Solving structural design challenges with generative solutions

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Abstract. Topology optimization is one of the main engineering problems, that should be addressed from the conceptual stage. An existing design is developed through traditional means and attempts to optimize it through an algorithmic postprocess, regarding various criteria. Physical systems that determine fixtures or contact in the assembly relate to design constraints, while the outcome material, optimal distributed, responds to criteria like minimal mass or maximum stiffness.

The paper presents the principles and criteria used in shape design. Using a case study in Fusion 360 Generative Design workspace, the preserves and obstacles in generative design are identified at components and equipment level, along with main parametric CAD geometric definitions.

The results in the generative solutions proposed for a given fixture are graphically presented and explained, also, analysed from the manufacturing point of view.

1. Introduction

With advanced manufacturing techniques and topology optimization, designers have the freedom to design ideal geometry, with less restrictions on how it will get produced [1]. Assemblies in existing products often consist of clustered parts, that require significant time for manufacturing, assembly and verification. The total cost is enhanced from the design stage, where managing large assembly, with variation of components, require both time and computing resources. Manufacturing and assembly of these components add to the production cost. Multi component assemblies also burden the maintenance of the system, induce more variables in the structural behavior and the modal response. These are exact reasons for redesigning the assembly architecture, narrowing the modularity, where a single component could overtake its functions, and leveraging cost reduction.

One of the approaches in redesigning subassemblies is replacing parts or subassemblies with generative design. The first step in this process is to explore and identify different aspects of the design, finding the geometry that links the object of the redesign with the rest of the assembly, as fixtures, brackets, flanges, bolts, and find the components that do not have to change, mainly because their shape is controlled by their role as interfaces. Exploring a complex assembly aims to identify the stationary geometry, the space that should remain material free, for tooling, manufacturing and assembly phases, the forces reduced to that substructure and their distribution, direction and module, along with the structural constraints that block or control degrees of freedom of each component.

Overall, the components role in the assembly is analyzed and understood from structural and functional points of view.

2. Setting up the problem

While working with a generative design problem, one must be aware of the complexity of the approach. The real-life working conditions of the part or subassembly should be well understood, and different aspects of the design and optimization criteria should be also agreed upon [2]. First of all, generative design is a team work, as structural, modal, buckling, thermal analysis, manufacturing and materials, manufacturing and assembly, aesthetics of the design will all be approached, having in mind the cost of any change may bring or cut from the initial existing variant. First step of working with a CAD file, designated for generative design, is to inspect and understand the various aspects of the design.

The parametric CAD model should be organized with clear components, having distinct, clearly defined solid bodies, conveniently grouped. The hierarchy of the model should be as compact as possible, with clear definition of substructures, no overlapping or defective solid bodies. It is best to handle the data base/ history of the design in an appropriate manner, in order to have clear reference about parts, their functionality, their variations and source files.

In Fusion 360®, the design can be locally defined, then submitted to various types of analysis and optimizations. Generative design is an algorithm driven engineering approach, aiming to mastering the design at the level nature does it. Not always an expressive form means an expressive performance in terms of costs; the design might, sometimes, tilt to the extremes of strength, manufacturing or assembly capabilities, so, most of the generative solutions are strictly cut of the potential shortlist of winning variants. A correct hypothesis and a precise objective are paramount for the versatility of the variants, which means that initial data should be extremely precisely defined, taking account of all possible load cases and constraints.

For this work, a subassembly is proposed to be studied as a candidate for generative design, having in mind mass reduction and, if possible, overall cost reduction, as the initial variant consists of multiple parts, sheet metal parts, assembled together with rather rigorous and costly centering operations.

2.1. The initial assembly

The design proposed for this case study (figure 1, constructed after a design challenge in [2]) consists of two cylindrical pivots, sustained by one mount handle each, assembled with a sheet metal flange and a sheet metal support, mounted on a bulky spacer. The design is considered prone to optimization, as one single mass could join the cylindrical pivots, replacing three parts assembly between. As the handles are the interface with the machine, they should be kept, at least the hole pattern and centered mount hole for the smaller handle.

The assembly is loaded with 1134 daN tension, 1134 daN normal forces, oriented at 45 degrees front and back the median, vertical plane and a moment along the long cylinder of 340 Nm. Looking at the assembly, the designer should impose such initial conditions, so that the new material will develop only in the space between the two cylindrical pivots, that should be preserved, due to their functionality. and should not interfere with the handles, that represent the connection with the rest of the assembly. In this perspective, the two mounts will be considered as obstacles (figure 2) in the further generative design, while the cylinders should be defined as preserved bodies, around which a new build in material will developed by the algorithm. The generative design itself, is a working space that offers the possibility to edit the geometric model, to define the constituent geometry for obstacle and must-be-kept geometry, to define the manufacturing options, materials, loads and constraints that should be supported by the final solution. Various criteria can be used for generative algorithm and the resolution for analysis is very important for the result, when computing resources are critical, or must be compromised with precision of the final topology.

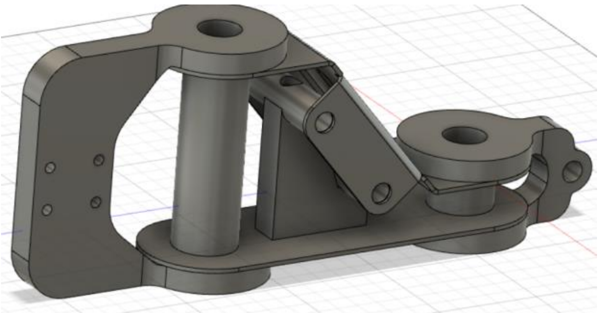
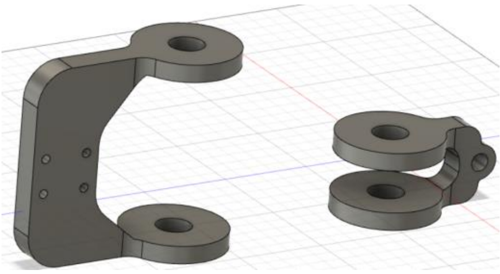
 

Figure 1 Figure 2

2.1.1. Creating the obstacles. In the generative design workspace, edit mode, two more bodies should be defined, beside the existing handles. These bodies will prevent the generated material to enter the functionally important holes in the mounting areas of the handles and the cylindrical pivot interior. Either a connector tool, or a simple extrusion can be used to define two cylinders, with the same diameter as the mounting holes, for each of the mounting handles. The calibration of this diameter is strongly related with the type of tolerated assembly at that level (figure 3).

2.1.2. Creating the preserves. As cylindrical parts are already defined, they will be selected as preserves, under the model components hierarchical model (figure 4).

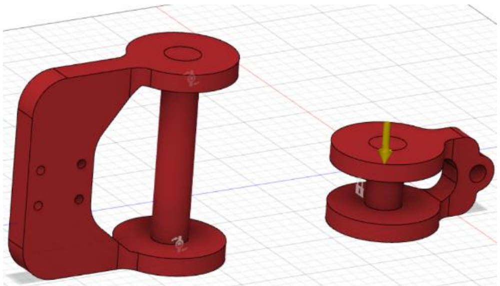
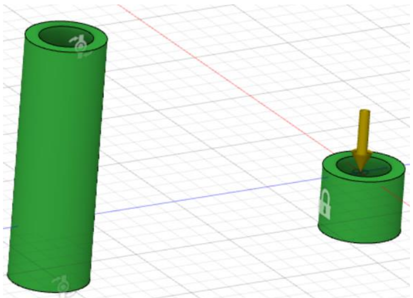
 

Figure 3 Figure 4

3. Materials and Manufacturing conditions

Under the design criteria, manufacturing section allows to define the manufacturing methods that will be constraining criteria for the generative algorithm. Basically, from the geometrical point of view, defining manufacturing conditions means new geometrical areas defined around the obstacles and preserves [3], taking into account the tooling and working directions for milling, overhang angle and minimum thickness for additive, ejection direction, minimum draft angle, minimum and maximum thickness for die casting. In addition to very well understanding the manufacturing processes, the machines and tooling, in order to optimize the computing resources (time and cloud credits), one should limit the manufacturing options choice for simulation to the ones that are expected to produce cost effective solutions. For example, if the number of items to be manufactured is a few hundreds, the die casting solution can be questioned, as the molds are, usually, very expensive. Also, imposed materials can be eliminatory for either of the manufacturing methods. In that perspective, a thorough choice of coupling material variations added from the library or designed, with specific manufacturing methods, could be a crucial time saver [4].

For this study, unrestricted, 5-axis milling and die casting will be chosen, along with aluminium alloy, generic stainless steel, cast iron and titanium. The intent was to explore more vast areas of optimization, in term of mass control (figure 5). The maximum thickness for die casting was imposed as 13 mm, while, for 5 axis milling, a minimum 10 mm mill diameter and 50 mm head diameter were set.

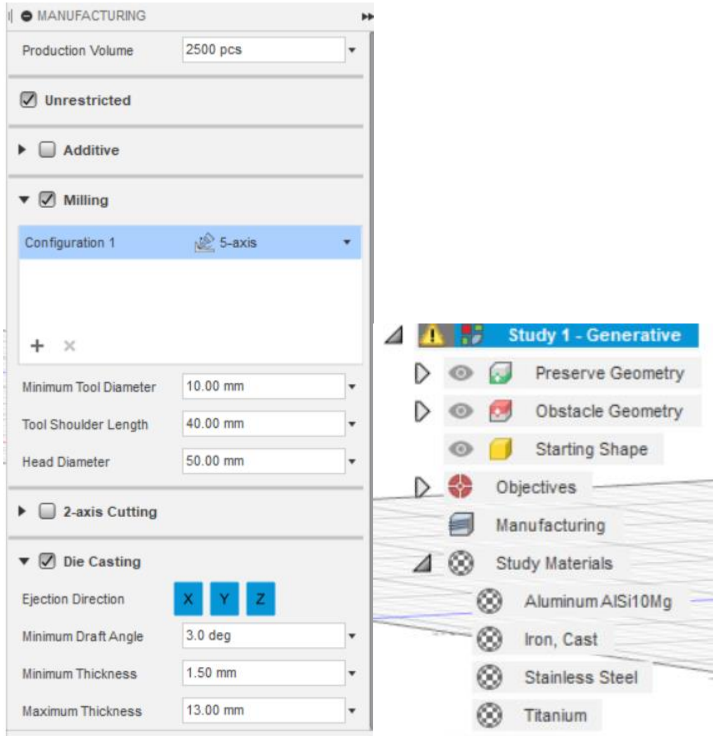


Figure 5

4. Loads and Constraints

Under the design conditions menu, structural fixed constraints can be defined on both the lateral of the cylindrical preserves. These will keep the bodies fixed during the simulation, with no degrees of freedom allowed for these surfaces (figure 6). The study resolution was set at 75%.

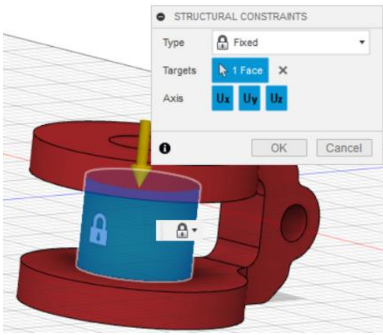


Figure 6

Loads will be defined as separate load cases, aside the existing gravity load. Normal forces will be added, in normal, median plane, as well as tilted 45 degrees back and forth, also normal to the large cylinder. A moment will be applied on the both directions of the two cylindrical bases of the large pivot (figure 7).

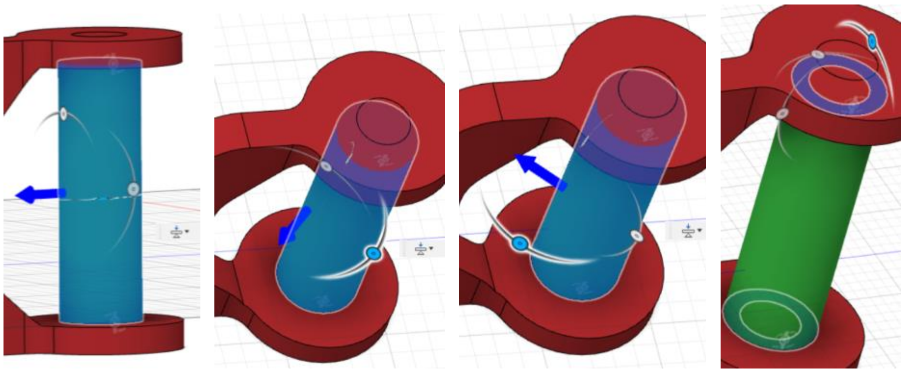


Figure 7

An important issue is the optimization criterion, as this is the core of the generative algorithm. For this case study, the mass optimization objective was imposed, with a safety factor of 4.

With all the limits conditions defined, the generative algorithm will be tested, for verification purpose, as a stable starting volume will reflect the feasibility of the study. The converged, completed variants will be offered as an output list, ready to be filtered and analyzed (figure 8).

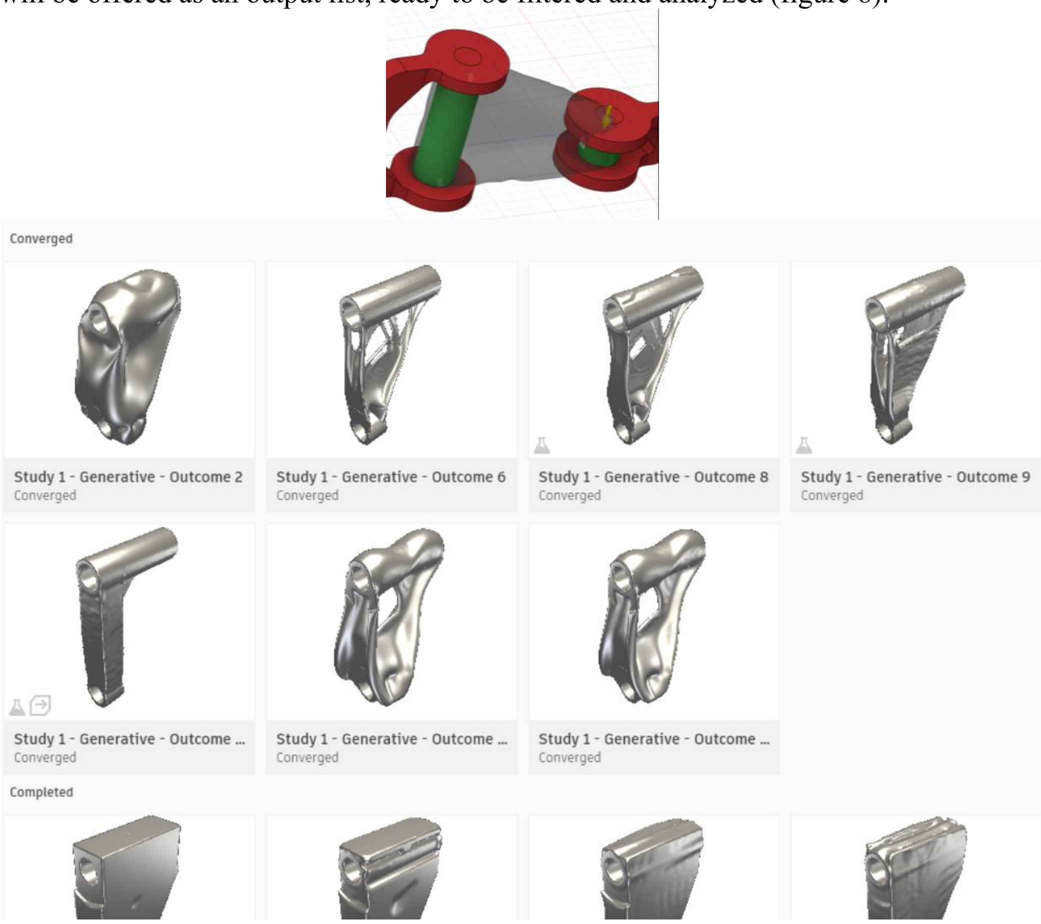


Figure 8

5. Filtering outcomes

Exploring all the outcomes is a complex task, as thorough analysis should be done in order to obtain a reasonable shortlist. This task is, also, time consuming, and filtering and visualization of the stress distribution throughout the obtained mass are the main tools the designer has, along with the mere prior experience.

In the presented case, there are several converged variants that have organic shape, and good mass index (outcomes 8 and 9, figure 8). But, at closer analysis, the slender tubes that strengthen the void areas are failing at buckling analysis, or, even, static structural stress, with lower safety quotients than the imposed 4. Above all, they might induce high cost manufacturing.

Outcome number 10, was considered the most feasible solution. This outcome is an iron casted solution, with smooth, plane or cylindric surfaces, good symmetry and less difficult to manufacture details (figure 9). The mass gain is up to 15% from the initial subassembly components replaced, the stress distribution is rather constant throughout the mass, with maximum displacement of 1.34 mm and a minimum factor of safety of 2,78 in a very small zone, at the rib tip, to be solved with further interventions on the initial BREP export of the solution (figure 10), via filleting.

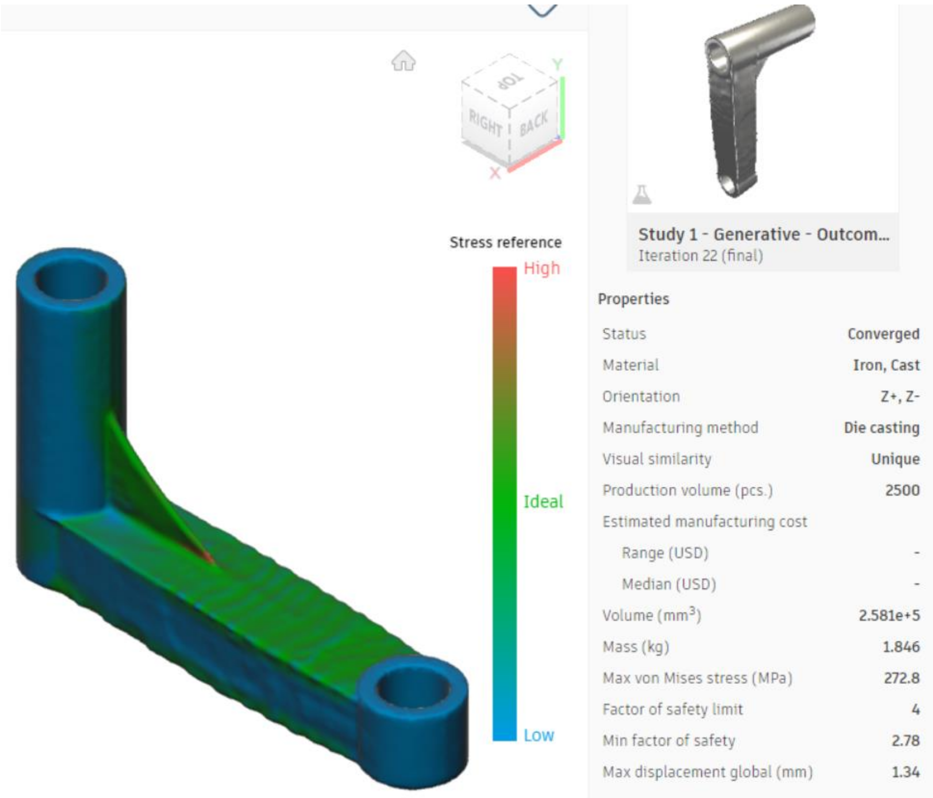


Figure 9

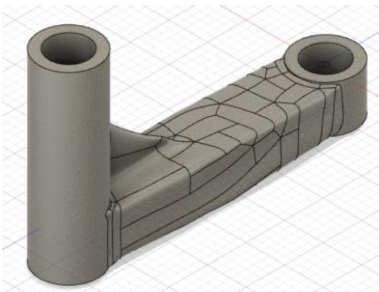
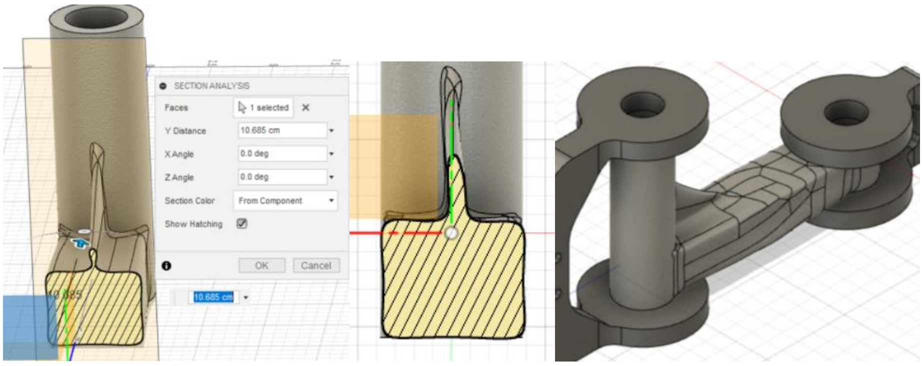


Figure 10

6. Editing the outcome for easy manufacturing

The winning outcome model needs several types of approaches, editing and stress analysis, iterated until a feasible, well validated solution is obtained.

In this case, an obvious uneven fold of the rib falls under the minimum, technological width for die casting, and should be resolved with shape editing tools. Also, the final straight line of the rib profile should be defined. Section analysis revealed the exact offset of the problem zones, from the mid cylinder plane (figure 11 a). The section was enlarged, and symmetry was established for the transversal profile of the rib. The result was inserted as a new component in the initial assembly, to verify the geometric compatibility, potential interferences, and degrees of freedom for the joints (figure 11 b).



a) b)

Figure 11

7. Conclusions

A generative study is a complex procedure, where both the setup and outcome filtering and selection are paramount for the final artifact. Manufacturing procedures to be considered as players in the study conditions imply a strong knowledge of the technology and cost inducing initiatives, as production line setup, supply and tooling. Meshing resolution can influence both the precision of BREP and mesh outcomes and the easiness of editing and finishing procedures, as a compromise toward computing time.

This study obtained a die casted mono-body solution, 15% easier than the components replaced, with simple surfaces, easy to imprint on a mold and easy to be extracted, with good stress and buckling behavior, with constant safety factor throughout the generated mass. Assembly costs are expected to be reduced up to 65 %, due to replacement of centering operations for sheet metal components and bulk support. Rapid prototyping solutions obtained, quicker validates the product and reduce the production time.

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