Generative design for assembly wrapping up

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Abstract. Design automation is a growing trend in the CAD world that reduces the amount of time it takes to complete a design and speeds up time to market. In practice, a design method known as generative design is one of the main way CAD automation is used. Generative design is a tool that generates designs for a given loads and constraints setup. Designers or engineers input design goals into the generative design software, along with parameters such as performance or spatial requirements, materials, manufacturing methods, and cost constraints. The paper presents a case study of an assembly to be wrapped via optimization criteria, in simpler, manufacturable product, using generative design that automatically produces variations based on automated computing. Using Autodesk’s Fusion 360, unique variations are produced, and a lighter and stronger product is proposed, after iterations based on specific criteria. The software explores all possible variations of a solution and quickly generates design alternatives. It tests and learns from each iteration. The present work offers an insight on the criteria and user input in specific moments of the automated design process.

1. Introduction

1.1. Working with defined assemblies

Woking with assemblies in various design, can bring some issues, regarding the design management, the representation complexity, up to manufacturing and assembly issues. Assembling is a rather cost expensive, both in design and production stages. Design for manufacturing and assembly principles are well known, still research and continuously embedded as tools or extension in parametric CAD software.

At the design level, usually, large assemblies are difficult to visualise, as part selection for editing and information extracting requires a lot of navigation tools manipulations. Design views from most of commercial CAD can simplify some tasks, but still, regeneration and visualization are challenging. Autodesk Inventor offers a solution for handling large, complex assemblies, with shrinkwrap concept, which replaces assemblies or subassemblies with a visual, bulky equivalent, for easy handling. There are two types of shrinkwrap: shrinkwrap and shrinkwrap substitute. The latter is used to reduce the memory, the open time. It will, basically take the subassembly and simplify it down to a part file and, then, will supress all the components in it. Shrinkwrap substitute is all about sharing, as the part file can be emailed, posted or communicated in any other way. The substitute can be spared of detail editing features, as fillets, chamfers, bolts, holes, pockets, filtering them by various parameters.
The output can be a single, bulky body, a multibody structure, a composite component and the result to be shared can be linked with the source file. Void or other structural details can be filled, if missed in previous selections, and the part file can be set for colour overrides, to maintain its initial colour assignments for the substructures.

This approach is for easy handling, when the shapes and roles of the components were previously validated in functional, structural and cost analysis.

1.2. Targeting optimized assemblies
For the cases where the appearance, structure, architecture of the concept is under question, optimization techniques are applied, to minimize the weight, maximize the strength, minimize the overall cost of the particular subassembly, maintaining the interfacing with the rest of the structure, as well as the functions, if not enhancing of optimizing the functions parameters [1]. Another level of wrapping is required, where the new design should not be a mere packaging of some components, but a whole, new solution, reverberating towards the manufacturing technology and assembly procedures.

This is what nature does, in long periods of evolution, adapting living organisms to better respond to ever changing environment. Generative design is an iterative process, based on a starting domain of possible space to be used for the shape and a set of boundary conditions, directly extracted from its functionality. The Generative Design process is multi fold and involves creating a parametric design space, evaluating performance via simulation, automatically generating design solutions through optimization algorithms, and evaluating the outcomes to find the best design options [2]. This paper presents a case study, solved with Fusion 360, in which these four facets of the generative design are mirrored. Material, geometry, manufacturing methods and algorithm are used as the representational mediums for the designer to choose from, to establish constraints, bearing in mind a basic design intent [3].

2. Generative design (GD) task analysis
GD goes beyond common design automation and offers a collaborative interaction between the CAD software and the operator. Optimized solutions offered as clustered outputs change the design workflow, and introduce new steps for interactive or advised decision, regarding the optimal, feasible shape for a new part [4].

The understanding of the function, loads and interfacing is paramount, when defining a generative design task. The initial design, often an assembly of standard and custom designed parts, is the starting point, from the geometric point of view. Decisions should be made about the design intent, the optimisation target, the initial cost, weight of the variant and the targeted values for the optimised solution.

The main concerns in this stage are:
- Identify the interface with the machine/ context assembly.
- Identify the moving parts, their role, loads, degrees of freedom and stop positions.
- Identify the geometry that should be preserved, not modified during the optimization.
- Identify the space available for the material new distribution.
- Identify the obstacles that should prevent the material distribution.

After a thorough examination of the starting topology, a generative study will allow to edit the model, introducing new “phantom” components, to help better organizing the space available for the distribution algorithms.

2.1. Defining the obstacles and the preserves
The study starts with a challenge proposed in [5], where a lifting bracket has a rotating arm, able to lift 500 lb of force. The analysis reveals that, the arm should be prevented to rotate under a certain angle, under the horizontal plane, in both directions and, the horizontal position is supposed to bring a significant increase of the load, as the mechanism will be dragged on a horizontal surface, thus receiving supplementary resistance, from the friction.
The rotating arm is sustained by a subassembly of steel sheet metal custom parts, standard bolts and standard rectangular profile (figure 1). The interface with the machine requires four linking zones, each being a rectangular, four bolted flanges, oriented at 30 degrees from the sagittal, vertical plane. This offers a nice symmetrical approach, when defining the various phantom components for obstacles and preserves, as well as for the case load definition.

![Figure 1. The central region of the lifting bracket, targeted by the optimization.](image)

The preserve geometry should keep the interfaces with the machine and with the active parts. As the scope is to replace the burden of several steel parts that sustain the arm, the interface with it should also be kept, i.e. the cylindrical articulation that offers the freedom of rotation around X axis. In consequence, five preserve bodies were defined and created, positioned as shown in green, in figure 2.

The obstacle geometry should cover all the space used by the arm during its rotation, the arm itself, the bolts and tooling to operate during assembly with the machine and to fix axially the arm in its articulation. The bolted connections were replaced with connectors and new solids, and shown, in red, in figure 3. One can observe that, behind the flange plates, new solids were created, to prevent material distribution in these areas, for tooling and mounting tuning.

![Figure 2. The preserve bodies.](image)  ![Figure 3. The obstacle bodies.](image)

2.2. Defining the design criteria
The next step in the setting up is to define the objective and manufacturing conditions for the new design. This a major step in setting the boundary conditions for the algorithms, as, for example, tooling directions, during milling, tool dimensions, supports in additive manufacturing, wall thicknesses are important parameters, along with the specific manufacturability of particular materials. This the moment when important compromises should be taken into consideration. One might want as many outputs as possible, to investigate as much technological available solutions for many shape and
material variants. This approach is time and computer resource consuming, as generative studies can be costly, using cloud resources, quantified as cloud credits.

This is, why, the designer usually agrees with the project manager or client, what are the manufacturing resources or conditions, what are the available materials and cost targets and shortlists the materials and technologies for the analysis.

Another issue is the refinement of the mesh that approximates the topology, a coarse mesh being less time costly, but, also, might offer coarse surfaces and miss some possible solutions.

The manufacturing conditions were set to explore the unrestricted solutions, 3-axis (with restricted access to ZY plane) and 5 axis milling (minimum tool diameter of 10 mmm, tool shoulder length of 40 mm and head diameter of 35 mm), and additive manufacturing, with an overhang of $75^\circ$ [6] and a minimum thickness of 4 mm. For this study, die casting was considered possible, but expensive, due to the total number of parts produced and the cost of the mould, thus, not included for output variants.

The objective of the study was to minimize the mass, with a safety factor of 4. The explored materials were Stainless Steel and Aluminium 6061. The meshing resolution was set to 75%.

2.3. The Design Conditions

Design conditions were imposed, using the function of the subassembly. The four outer faces of the flanges were fully constrained, fixed, as well as the interior of the central cylindrical supports for the rotating arm.

The forces and moment were defined, respectively, on the both side of the rotation quadrant, with a pace of 15 degrees, enhancing the force with 50% in the horizontal positions.

As there are possible small deviation from the symmetry of the loading, tilts in applied force were defined, for both vertical and horizontal position, with a ratio of 1/3 for the two cylinders that will sustain the arm, as the load could rotate or be applied in uneven was to the respective sides.

The load cases list, as defined in Fusion 360 tree, and some of the main loads applied, are presented in figure 4. Gravitational load is implicit. After the design conditions and criteria were set, the generative design algorithm is started in the preview mode, in order to check the existence of a valid space, circumscribing the topology problem, as a measure of validation for the correct setting up of the problem, as shown in figure 5.

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3. Selection and editing of the output results

The GD study offered 21 outputs (figure 6), that were filtered, and a thorough analysis of each solution was performed. The solution that offered a minimum factor of safety of 4 were selected, even though, an analysis on several other solution indicated that, sudden drop of safety factor values was in regions with stress concentrators, or slender sections, that might be corrected or easily edited.
A second filter was the maximum stress, with the same observation, that, some not shortlisted variants had some potential, as the maximum values of von Misses values were in pointy zones and could be dissipated with shape editors or simple fillets.

After the eliminating the too bulky or too slender structures, that failed either the mass either the safety factor criteria, two variants were shortlisted, one from aluminium (mass 0.14Kg, Max Von Misses stress 68.7MPa, max displacement 0.08mm, figure 8) and one from stainless steel (mass 0.417Kg, Max Von Misses stress 62.5MPa, max displacement 0.03mm figure 7). The steel variant was chosen for export in both BREP and mesh form.

**Figure 6.** The generative design outcomes.
Figure 7. Stainless-steel outcome.  
Figure 8. Aluminium outcome.

The design was primarily edited, checked for stress and buckling behaviour, then imported in the assembly and verified in the actual environment, with the rotating arm in position, taking all the intermediary rotational positions. No interference was found and enough space for manoeuvre and tooling was verified, as shown in figure 9.

Figure 9. The stainless-steel variant, assembled with the interface rotating arm.

4. Conclusions
GD is a method to explore organic, optimized shapes, with various setups. The design criteria and conditions are related with the compromise between the computing resources and the precision and feasibility of the results. If one wants a consistent list of manufacturable outputs, that will shorten the selection and editing time for the BREP of the new design, one must match properly the material and manufacturing selections, and choose an appropriate resolution, in direct relation with the manufacturing precision. The obtained solution is prone to cosmetic editing, to smooth the ridges and ease the manufacturing.

The subsequent editing of the selected outcome, usually, requires a design for manufacturing approach. The editing will seek to obtain a smooth surface, on which a curvature analysis will be performed, in order to check the manufacturability with the selected tools. Due to the symmetrical nominal load, a symmetric component is delivered, with smooth transitions ensured with a thorough section analysis.
Of great importance was the interferences check, when assembling the new component with the rotational arm. No interferences were found, enough space for tooling was also verified, due to the obstacle solid defined in the geometric definition of the interdicted space.

The chosen outcome brought an estimate of 27% mass reduction and replaced 5 sheet metal, complex components, plus 3 assembled profiles, in the support, with only one component. This will bring more cost reduction, ease and make faster the assembly. The safety factor is uniformly distributed along the regions of the stainless-steel part, which, also, is 32% more resistant as the initial sub-assembly, with, practically, little or no stress concentrators. The bulky architecture offers better stability and easy handling.

The generative design study completely setup, solved, exported and post processed a design and delivered the following:

- Generative outcome was solved and exported.
- Exported design file was post processed and validated with simulation. The outcome met and, even, exceeded the requirements. The validation is an iterative process, following the fine tuning of the final shape, obtained after editing the BREP model, considering the manufacturability of the artefact.
- Exported design was inserted back into the original assembly.

This case study offered the basis for understanding how the asymmetric load cases, defined as close to real-life deviation of applied forces, influence the final distribution of the material and how this is to be solved from the manufacturing point of view.

5. References

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