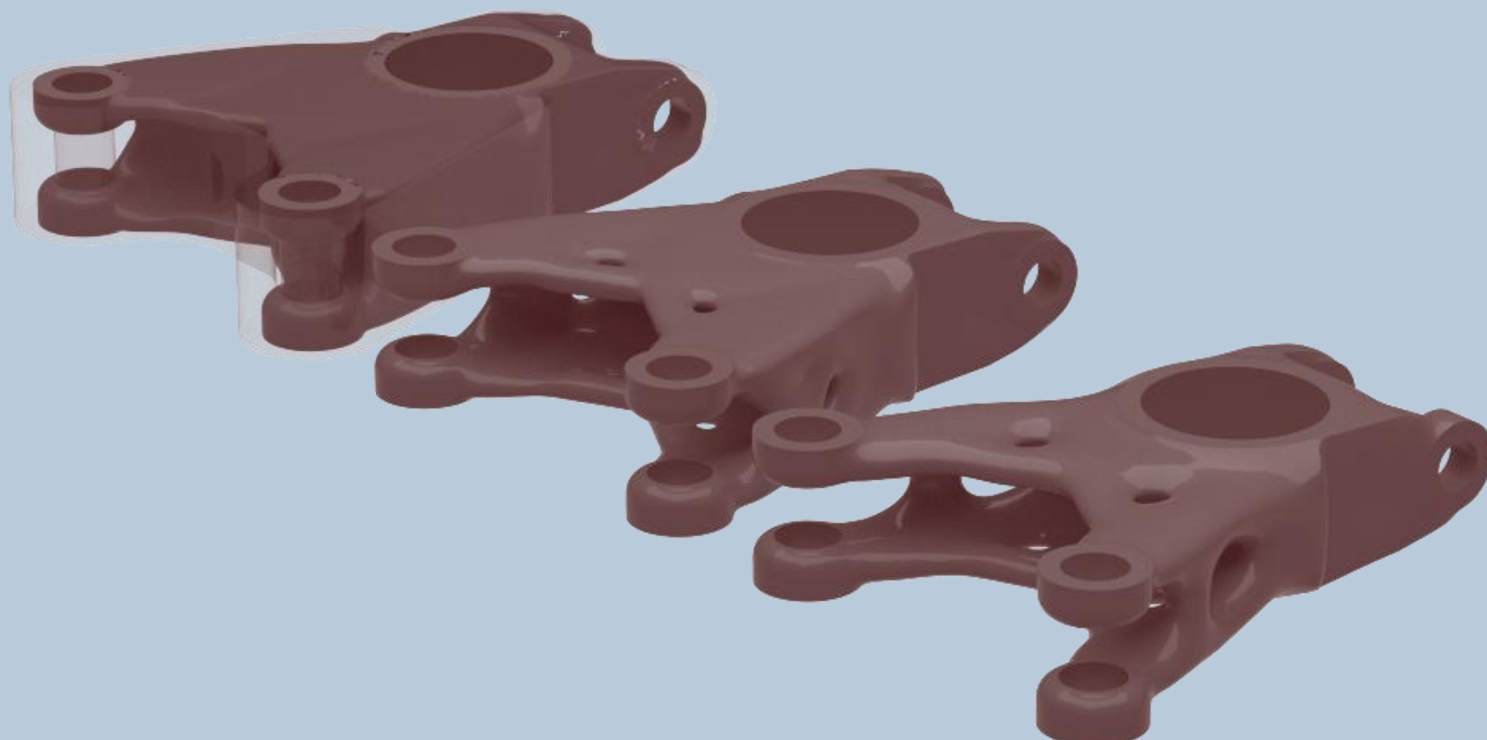
EMPOWERING ENGINEERS WITH GENERATIVE DESIGN AND FACET MODELING



LIFECYCLE INSIGHTS

INTRODUCTION

Designing products today is a tall task. Complexity is increasing as more and more technologies are integrated into products. The demand for collaboration is climbing as more and more suppliers become involved in the development process. Schedules are only getting shorter in a race to get to market as quickly as possible. Engineers, burdened with a plethora of responsibilities, barely have time to find a feasible design, much less a better one.

In this context, engineers often find they need more bandwidth. Fortunately, a new technology, Generative Design, offers some hope in this regard. Given a set of constraints defined by an engineer, this technology autonomously produces a number of alternative designs using algorithms such as topology optimization as well as those drawn from nature. Generative Design essentially acts as a software employee that presents its options to the engineer. As a result, engineers can consider many more alternatives than were previously possible. It has numerous applications in Concept Design and Detailed Design.

Incorporating the results of Generative Design, however, requires specialized geometry capabilities called Facet Modeling. Computer Aided Design (CAD) applications are only now starting to integrate such functionality alongside traditional Parametric Modeling and Direct Modeling. This is a crucial but oft overlooked set of tools that need to work tightly together.

The purpose of this eBook is to offer insight into all of these topics. It starts by looking at the constraints on today's engineers and the effect they have on the quality of design. Next, it delves into Generative Design, offering details on its use and technical considerations, as well this technology's application to Concept Design and Detailed Design. It finishes by taking a close look at the Two Application and Single Application solutions that are currently available. Throughout, it includes references to findings from Lifecycle Insights' studies.

There is no doubt that designing products today is a difficult task. However, new capabilities like Generative Design offer a means to expand an individual's bandwidth without much extra effort. The benefits are useful for both the engineer and the organization.

ENGINEERING CONSTRAINTS AND QUALITY OF DESIGN

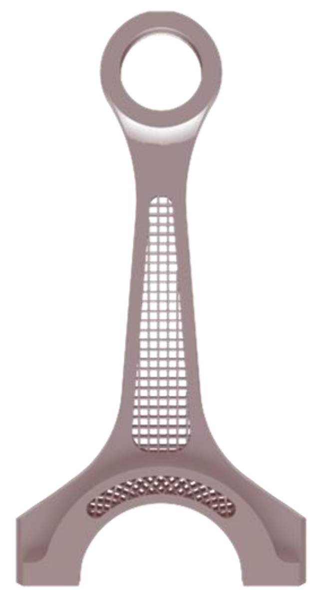
Every design project is a balancing act. On one side, the development of a project is constrained by a schedule, development budget, material cost targets, and functional requirements. On the other side is the drive not only to meet functional requirements, but also to exceed them to create more innovative and competitive products. In recent years, a number of trends have skewed this balancing act toward designs that are more conservative. This hampers companies' innovation efforts.

ENGINEERING WORK IS FUNDAMENTALLY VOLATILE

One factor that drives engineers to be more conservative is the reality that new development is fraught with risk. Design errors that get past design release can cause dire consequences for all of development, but especially engineers. Change orders that return to their desks create full-blown emergencies, wreaking havoc in the form of scrap, rework, and failed prototypes. Furthermore, design errors direct time, energy, and resources away from current design efforts, inserting delays in ongoing development projects. In fact, 60% of the respondents from The Simulation Driven Design Study have missed project deadlines due to failed prototypes.

GROWING TECHNOLOGY COMPLEXITY

Another factor skewing design towards a conservative bent is the increasing complexity of the technologies incorporated into today's products. Trends in electronics, including ongoing miniaturization, low power requirements, and the need for greater heat dissipation, makes it harder to accommodate the ever-increasing demand for computing power in products. The explosion of software on products raises integration issues, as those applications must seamlessly work with the electronic hardware and other systems on the products. With the emergence of the Internet of Things (IoT), development has become even more difficult as companies must figure out how to instrument their products with the right sensors, how to capture the right data, how to stream that data to the right storage, and then act upon that data. All of this converges with mechanical design to bolster complexity and increase difficulty in system integration.



COLLABORATING WITH MORE STAKEHOLDERS

Yet another factor to consider is the demand on engineers to collaborate more with more stakeholders. To keep pace with competitors, manufacturers have to integrate wave after wave of the latest technologies or be left behind. As a result, engineers have to collaborate with subject matter experts in niche areas. Additionally, it's not enough to find the design that meets form, fit, and function specifications. Engineers need to account for more. Today's products have significant operational and business constraints that affect the design solution. As such, they need feedback from the growing number of stakeholders, including those from procurement, suppliers, manufacturing, customers, service, and many more.

BALANCING MANY RESPONSIBILITIES

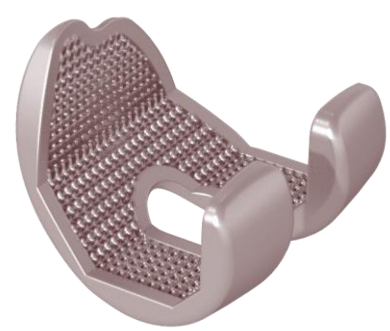
A factor that exacerbates these issues is the fact that today's engineers are already stretched too thin. Lifecycle Insights' Hardware Design Engineer Study quantified this challenge. From a field of thirteen core and extended design responsibilities, the study asked respondents to select which ones they fulfilled. On average, engineers tallied a total of 4.4 core design responsibilities, which included managing requirements, predicting product performance and more. Furthermore, on average, engineers tallied 2.9 extended design responsibilities, which included things like project management, collaborating with suppliers, and more. In all, that totals 7.3 responsibilities for the average engineer. Making design decisions is *only one* of those responsibilities.

SHORTER SCHEDULES, FIRST FEASIBLE DESIGNS

The final factor to consider is the ever-shortening schedule of product development. Compressed schedules force engineers to accept the first feasible design they find. In the worst case, these designs only marginally fulfill project objectives. As a result, the company is leaving 'opportunities on the table' to reduce product costs, create higher performing products, or completely fulfill customer requirements.

TAKEAWAYS

Due to a variety of factors, engineers have less time to design increasingly complex products today. Furthermore, design errors have serious ramifications, both for the company and for the engineers themselves. It is no surprise that they are developing more conservative designs.



GENERATIVE DESIGN IN THE DEVELOPMENT PROCESS

Today's engineers work under a set of pressures that drive them to be more conservative in design. To counter these pressures, engineers need more bandwidth to get more done. Yet, they are being asked to do more with less than ever. That is where a new technology called Generative Design can be applied.

GENERATIVE DESIGN: WHAT IS IT?

At a high-level, Generative Design is relatively simple. It is a capability of CAD applications that autonomously generates a number of design alternatives given a set number of constraints. This can be done without an engineer's guidance or interaction, freeing them up for other tasks. Once complete, the engineers can choose which designs they want to explore more completely. In all, this accelerates the design process without detailed attention from the engineer.

Generative Design leverages capabilities like Topology Optimization, which runs structural simulations and removes material not carrying loads. However, this is only one of the approaches that Generative Design leverages. It can also mimic behaviors seen in nature, such as replicating the growth of bacteria colonies or the evolution of bone structures to optimize weight-to-strength ratios. These approaches are used to explore the design space of a new product. Interestingly, Generative Design can produce designs that a human engineer might never have considered, opening whole new possibilities in design.

TECHNICAL CONSIDERATIONS

Generative Design starts simply enough. The input is a 2D or 3D model from Concept Design or Detailed Design. From there, the engineer specifies the constraints within which Generative Design can work. These might be boundary conditions, such as fixed geometry. However, they can also include geometric constraints, such as disallowing overdraft, or maintaining a certain geometric shape, such as keeping a cylindrical solid at a certain location. Given that Generative Design most frequently leverages Topology Optimization capabilities, which rely on structural Finite Element Analysis (FEA) functionality, other simulation items must be defined like material properties and loads.

As Generative Design works and material is removed, the software is actually eliminating some of the elements that have low stress or strain levels. From a modeling perspective, the output of this process is a mesh geometry generated from the tetrahedron elements of the analysis. Because the model is completely composed of these elements, which have flat faces, the outer surfaces of the geometry are also composed of planar surfaces. This result is called Mesh Geometry and can only be modified with Facet Modeling, not Parametric or Direct Modeling.

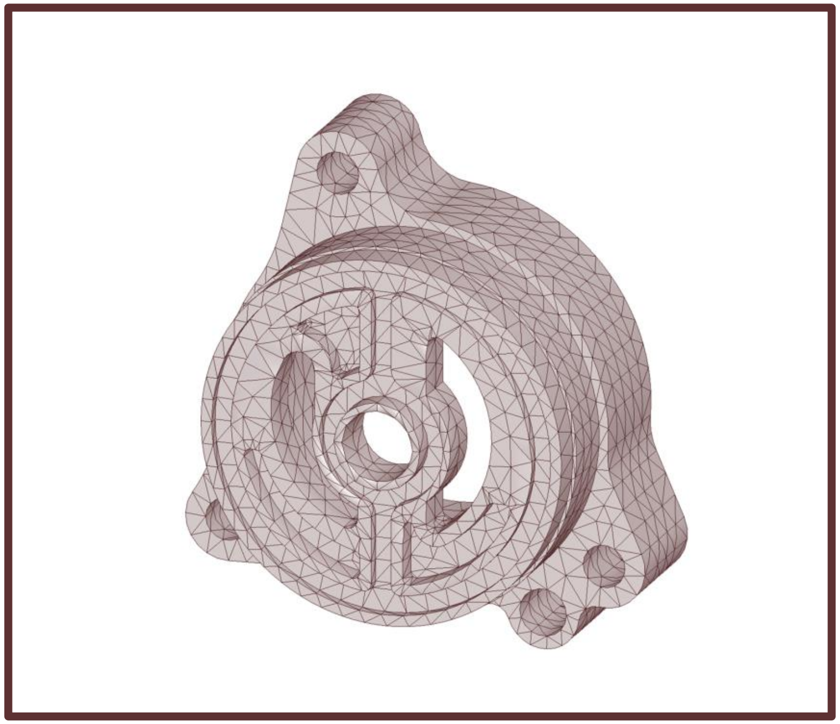
GENERATIVE DESIGN IN CONCEPT DESIGN

In concept design, engineers develop a range of ideas that could potentially fulfill the form, fit, and function requirements at hand. Initially, they look for designs that feasibly meet requirements. Once that first feasible design has been uncovered, many engineers move on to the next aspect of the design due to the need to meet the ever-shortening deadlines in development schedules. The problem with this approach is that they miss opportunities to reveal other designs that might better fulfill requirements. Moving beyond the first feasible design requires more exploration, experimentation, and iteration.

The digital geometric representations of these designs can vary widely. Some use top down design techniques to cordon off volumes and spaces for specific components. Others flesh out these ideas with 2D or 3D sketches developed from curves, lines, surfaces, and other simple geometry. However, at this stage, these representations are not usually fully detailed 3D models. Those are created during detailed design.

From a development perspective, Generative Design is highly applicable to Concept Design. At this stage, engineers have the most flexibility to explore alternative ideas for products. They can define the few constraints defined at this point and, using Generative Design, produce a wide variety of choices with little direct effort. Instead, engineers can almost take on the role of a manager who reviews the work of the Generative Design software. They can even set up trade studies, comparing the performance of these design alternatives. That, in turn, provides greater insight into the interplay between key variables and desired performance. Notably, these techniques can be applied to 2D sketches, abstracted 3D models, or fully detailed designs.

A key point is that the output of the Generative Design effort will be Mesh Geometry. Some iteration on this roughed out design is warranted to explore its feasibility. In this scenario, the use of Facet Modeling to manipulate the Mesh Geometry directly is highly useful, as it allows engineers to avoid the effort required to convert it over to the boundary representation (brep) geometry of Parametric and Direct Modeling. Given the resulting concept design must act as a starting point for the rest of development, it is crucial to be able eventually to transform this faceted representation into brep geometry. The capabilities of Facet Modeling are highly applicable here as well, as they ease the transition greatly.



GENERATIVE DESIGN IN DETAILED DESIGN

At this point in development, engineers take a vetted design concept and fully detail it for design release, verifying that it fulfills form, fit, and function requirements along the way. This requires them to explore options for different aspects of the design in an effort to improve performance. This is especially true of engineers who seek the right balance between competing requirements such as weight and structural carrying load, cost, and natural frequencies.

The digital geometric representation of the design at this phase is a fully detailed 3D model. These models are frequently built using Parametric and Direct Modeling capabilities that result in smoothly rounded geometry.

The opportunity to move past the first feasible design is great. More experimentation on different detailed geometry and different configurations on sizing parameters can dramatically affect product performance as well as cost and manufacturability. As was the case with concept design, more time spent experimenting with these variables and tracking requirements satisfaction reveals insights on their relationship. That allows engineers to fine-tune detailed designs in a way that better fulfills requirements.

From a development perspective, Generative Design is highly applicable to Detailed Design. Engineers can apply the technology creatively and expansively to assess alternative approaches to create details of the design. In fact, Generative Design may come up with options that an engineer may have never considered. This can be an invaluable tool to refine a design to find the right balance between competing requirements.

Integrating the output of Generative Design with Detailed Design models is imperative. Ultimately, engineers need to release these detailed designs to procurement or manufacturing to buy or produce components. This is where Facet Modeling can dramatically impact productivity with capabilities to smooth the transition from Mesh Geometry to brep geometry.

While some will need to transform mesh geometry into smooth boundary representation models, there may not be the need to do so in all cases. Engineers may need to make some modifications to Mesh Geometry, but otherwise keep it as it was finalized. This is especially true for organizations that are producing components using additive manufacturing, which also relies on Mesh Geometry. In these cases, the engineer can go directly to the 3D printer.

THE TWO APPLICATION SOLUTION

In Concept Design and Detailed Design, Generative Design is an incredibly powerful tool in the development process. However, the traditional technologies used to support Generative Design, an unintegrated couple of software applications, inherently have high amounts of friction in the digital workflow.

TWO GEOMETRY TYPES, THREE MODELING TYPES

In general, traditional geometry modeling takes one of two forms: Parametric or Direct. Parametric Modeling can be used to create a model feature-by-feature, using parametric dimensional controls. Direct Modeling modifies existing geometry by pushing, pulling, or dragging it. Both of these modeling approaches work with ‘boundary representations,’ in which the geometry is represented by flat or smoothly curved surfaces.

Mesh Geometry, by contrast, contains a cloud of points representing the outer surface of a design. Some CAD applications turn this into solid geometry by creating planar triangles or trapezoids and stitching them together into a ‘watertight’ solid. Facet Modeling lets engineers tweak the quality of the resulting mesh as well as modify that geometry by adding or removing material.

As noted earlier, there are cases where engineers need to develop smoothly rounded geometry as well as Mesh Geometry. In Concept Design, engineers need to work with the sketches and designated spaces alongside the Mesh Geometry of scanned components. In Detailed Design, they need to create detailed 3D models taking Mesh Geometry into account.

THE TWO APPLICATION SOLUTION

Traditional CAD applications used for building 3D models and other items often use some combination of Parametric and Direct Modeling, both of which result in boundary representations. Together, this powerful combination of modeling tools can be used quickly and easily to develop design concepts and detailed designs, and to produce physical components. Unfortunately, very few offer Facet Modeling alongside these conventional capabilities.

Because most CAD applications are unable to work with Mesh Geometry, engineers must turn to other solutions to get the job done. Some standalone specialty applications, typically ones that offer the laser scanning hardware, provide a CAD-like application that includes Facet Modeling. Theoretically, engineers can use both traditional CAD applications and these specialty CAD-like applications together. However, there are numerous drawbacks to this scenario.

LACK OF A SINGLE ENVIRONMENT

There are many cases in Concept Design and Detailed Design where engineers need to combine Parametric, Direct, and Facet Modeling ***interchangeably***. For instance, the user might work on facet data, then build a parametric feature, then modify something with Direct Modeling before using Facet Modeling again. If these three capabilities do not exist in a single software application, then designers and engineers simply cannot complete this kind of workflow. Instead, they need to find a means to move the design data between the traditional CAD application and the specialty CAD-like application.

EXCHANGING DESIGN DATA

If you are familiar with the exchange of geometry between CAD applications, then you are likely familiar with the issues here. Moving a model from one software application to another often results in misaligned or missing surfaces, lines, or points. This 'breaks' the model, because it no longer represents the design, and engineers must fix these sorts of problems every time geometry moves from one type of software to another.

Moving geometry back and forth between traditional CAD applications and specialty CAD-like applications is no different. This handoff is subject to the same issues. The result is more time lost for the engineer and a likely setback for the development project.

TAKEAWAYS

It is possible for engineers to use traditional CAD applications alongside specialty CAD-like applications to enable Generative Design, but not without significant friction in the digital workflow. It does not allow engineers to use Parametric, Direct, and Facet Modeling interchangeably, which constrains their design freedom. It also translates into a significant amount of time to fix design data exchanged between these two software applications. While Generative Design can provide powerful benefits in development, its applicability can be undermined by the time-consuming and painful work when using with two separate software applications.

THE SINGLE APPLICATION SOLUTION

In the past year, some CAD applications have expanded their capabilities to include Parametric, Direct, and Facet Modeling. The implications for Generative Design are key.

When engineers need to create boundary representation geometry from the results of Generative Design, the workflow gets simpler. All modeling capabilities are in a single environment, which means engineers always have access to the right tool for the situation at hand.

In another interesting case, engineers don't necessarily need to transform designs produced by Generative Design into boundary representation geometry. Facet Modeling provides the tools to change the design without those time intensive extra steps. This is especially true of components that will be produced using 3D printing, which is already dependent on Mesh Geometry.

An important point in all these scenarios is the activities that this new breed of CAD applications lets engineers avoid: *exchanging design data*. Because all of these capabilities exist in a single environment, there is no need to move 3D data, Mesh Geometry, or boundary representation, between different software applications. All of the work can be done in a single environment. Engineers need not waste time fixing geometry. They can focus on design, instead.

Overall, incorporating Facet Modeling alongside Parametric and Direct Modeling is a considerable boon to engineers who are looking to leverage Generative Design in their development processes. It removes much of the digital friction in the workflow, allowing engineers to focus instead on design.

SUMMARY AND CONCLUSION

Today, engineers are under tremendous pressure in development. Design work is fundamentally volatile as errors can cause disruptive delays in current projects. Increasingly complex technology is being integrated into products. Engineers must collaborate with more suppliers than ever. Schedules are only getting shorter and shorter. With a myriad of responsibilities, engineers often only have time to find the first feasible option instead of better ones.

GENERATIVE DESIGN IN DEVELOPMENT

Generative Design is a capability of CAD applications that autonomously generates a number of design alternatives given a set number of constraints. Once complete, engineers can choose which designs they want to explore more completely. This accelerates design without detailed attention from the engineer. Note that the output of Generative Design is Mesh Geometry, which can only be manipulated by Facet Modeling capabilities. This is especially important considering the resulting design needs to be used throughout the rest of the development process.

In Concept Design, Generative Design can be used to powerful ends. Engineers can apply it to explore a wide range of design alternatives early when requirements are the most flexible. In Detailed Design, Generative Design can be used to fine-tune a design so it meets the right balance between competing requirements such as weight and structural carrying load, cost, and natural frequencies.

TECHNOLOGY SOLUTIONS

Traditional CAD applications used for building 3D models and other items often use some combination of Parametric and Direct Modeling, yet lack Facet Modeling. Because most CAD applications are unable to work with Mesh Geometry, engineers must turn to standalone specialty applications that feature Facet Modeling. Engineers can use these two applications together, yet cannot use these capabilities interchangeably, and must work through data translation issues.

Alternatively, some CAD applications have expanded their functionality to include Parametric, Direct, and Facet Modeling in a single environment. These solutions allow engineers to avoid the problems associated with the two-application approach.

FINAL TAKEAWAYS

Generative Design offers a powerful way to expand the bandwidth of today's engineers. Nevertheless, this opportunity can be undermined by the issues of working with two applications for modeling. CAD applications that offer Parametric, Direct, and Facet Modeling, however, allow engineers to realize the full potential of Generative Design.

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