DIGITAL INDUSTRIES SOFTWARE

Design for purpose

Using Siemens' cohesive additive manufacturing lifecycle development workflow to increase sustainability

Executive summary
As we enter the world of Industry 4.0, technological advancements are becoming more sustainable. Sustainable manufacturing processes are the key to designing for purpose. Siemens Digital Industries Software is on the forefront of sustainable innovation by developing a full additive manufacturing lifecycle workflow that can rapidly turn ideas into reality. This paper will highlight the full lifecycle workflow that Siemens provides engineers to design for purpose.

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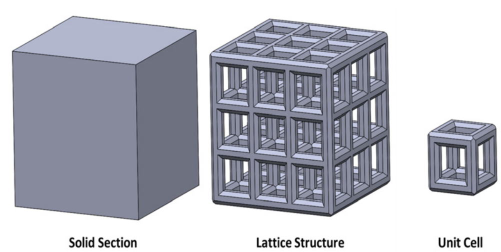
Sustainable innovation movement

At Siemens, we empower users to advance projects by providing new innovative tools to modernize solutions and processes. The first tool that empowers users is the NX™ software lattice structure design, which is a part of the Siemens Xcelerator, the comprehensive and integrated portfolio of software and services from Siemens. This is an optional add-on to NX that enables users to streamline complex lattice structure creation. Lattices are a repeating arrangement of 2 or 3D microstructures, which are inspired by natural crystalline formations. These microstructures contain a network containing beams (struts) and nodes (balls).



The breakdown of a simple model illustrating the differences between solid body, lattice structure and individual unit cell models.

Lattice structure techniques are growing in functionality and popularity due to the increase in additive manufacturing technologies. The tunable nature of lattices enables engineers to refine designs to match their application. Integrating lattices in designs enables significant mass reduction, which reduces cost associated with resources, tooling procedures and shipping and energy consumption. Although additive manufacturing decreases material waste by eliminating the need for additional tooling byproduct, lattice structures in design enable further material conservation due to the porosity of the lattices. Designs are engineered for performance due to lattices' low stiffness and their ability to withstand and recover large strains. They protect products by absorbing impact, energy and vibrations. The strength-to-weight ratio can be significantly enhanced and the structural integrity/fatigue life can be improved with virtual simulation and material testing of the lattice designs using Simcenter™ software Multimech integration and HEEDS™ software.

Siemens NX lattice structures

NX equips users with three command sets of lattice structures: graph-based structures, body lattice structures and triply periodic minimal surface (TPMS) structures. Each serve a unique purpose and possess individual benefits. Lattice structures with unit cells based on TPMS are free of self-intersections and have topologies generated by mathematical equations. Examples of these structures include the Schoen gyroid, Schwarz diamond and Neovius. TPMS structures are often self-supporting and provide great energy absorption. A few examples of TPMS structures can be seen in figure 1.

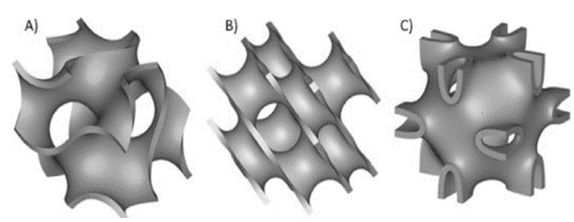


Figure 1. Triply minimal surface unit cells: Schoen gyroid (A), Schwarz diamond (B) and Neovius (C).

Body lattice structures enable users to create their own 3D repeating pattern in a part. This option enables design flexibility and easy customization with endless possibilities and combinations. An example of body lattice structures can be seen below in figure 2.

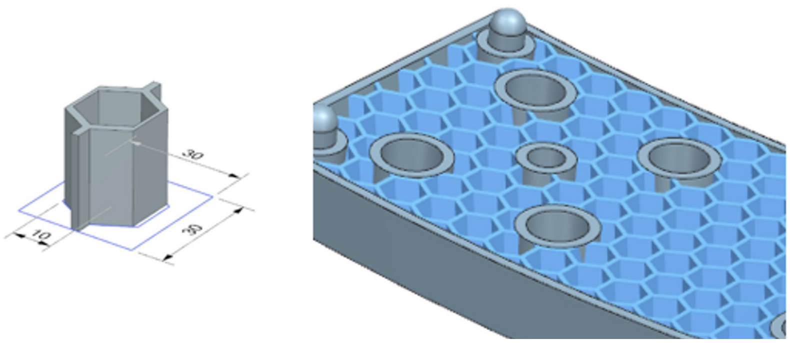


Figure 2. Body lattice applications that NX equips users with to design for purpose.

Graph-based structures are the most popular type of lattice, consisting of tessellating ball and strut configurations. There are many cell arrangements and each hold exclusive structural and thermal properties to innovate design. A few examples of graph-based structures can be seen in figure 3.

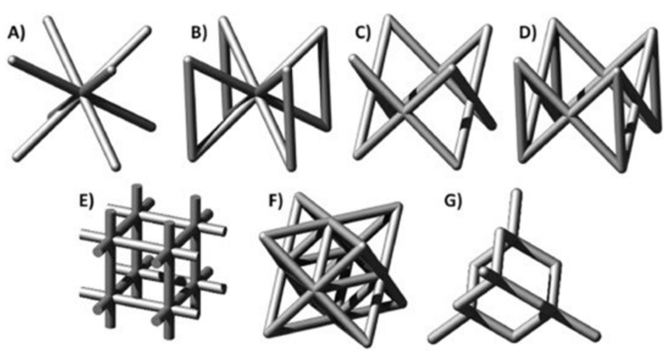


Figure 3. Graph-based lattice structures: BCC (A), BCCZ (B), FCC (C) and FCCZ (D).

Lattice structures impact on sustainability

Here is an example of how lattice structures can be implemented in manufacturing to optimize processes that are used to create parts. The part shown is an injection die mold that was designed using traditional machining practices. The part was redesigned for additive manufacturing to enable an eco-friendly industrial tool. Modernizing the design for additive manufacturing will reduce part weight and enhance structural properties, extending the lifespan of a product. This workflow gives engineers the ability to rapidly get products to market by increasing collaboration and decreasing file transfer errors. Part preparation uses NX capabilities such as synchronous and implicit modeling functionalities that simplifies designing and redesigning parts. Implicit modeling enables robust part designs in less time than traditional modeling tools. Shelling this part took minutes rather than hours by using implicit modeling capabilities.

Figure 4 illustrates the use of implicit modeling and NX design for additive lattice structures to innovate product designs. What used to take months to design now takes minutes by using these advanced optional add-on modules. Integrating NX design for additive empowers users to design for purpose and modernize manufacturing processes.

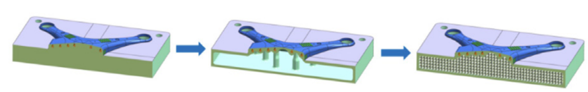


Figure 4. Implementation of implicit modeling and lattice structures in an injection die mold.

Micromaterial modeling with multimech

Integrating multimech for additive manufacturing

The second phase of the NX cohesive additive manufacturing product lifecycle development workflow is Multimech. With this software, engineers can predict how, when and why advanced materials fail at the microstructural level. Multimech is a fully integrated software that enables multiscale material modeling and simulation. It extends the flexibility and robustness of finite element analysis (FEA) to the microstructural level, strongly coupling the macro and micro-mechanical response. Integrating materials engineering in part design supports the acceleration of the product development lifecycle by predicting failure in innovative materials or shapes, such as lattice structures.

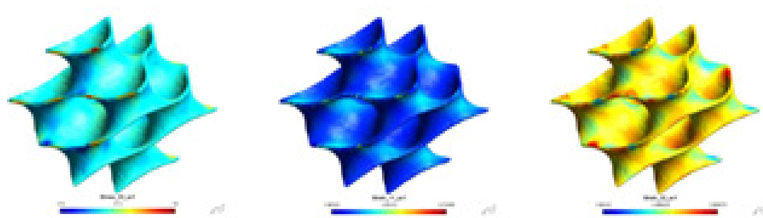


Figure 5. The stress and strains on a TPMS diamond structure generated with Multimech.

Engineers use Multimech to simulate and predict advanced material performance with three exceptional capabilities. The first is the automatic microstructure generation and optimization. Engineers can automatically generate the geometry and meshing of microstructural models. The only inputs required are basic design variables. They can also rapidly and easily apply various loading scenarios to gain insight in how the material will perform in various conditions.

The second capability of Multimech is used to understand manufacturing variability and imperfections. Simcenter enables engineers to import process-induced variation data and automatically convert it to microscale, including volume fraction and fiber orientation tensors to simulate injection-molded parts. The third capability of Multimech is to perform multiscale material modeling. This software enables engineers to zoom in on the material microstructure to identify the root cause of failure and see which damage mechanisms affect structural performance. Engineers can optimize material microstructure for the most cost-efficient performance.

Revolutionizing FEA

Multimech enables engineers to replace the vast amount of physical testing needed for certifying and implementing materials for all industry applications. Using Multimech accelerates the product development process by eliminating the need for physical material testing. This physical testing is still needed because new material models require using analytical formulations to predict the structural properties and safety qualities. However, with the introduction of smart materials and advanced engineered structures that cannot be changed on a microscale, this model is becoming obsolete. We start to become less predictive with analytical formulations when we observe how these materials fail and then fit them in predefined models. Multimech does not enable users to make predictions based on prior models. It allows them to reverse the process and building a material from the bottom up. Building it up from the physics of the microstructure enables engineers to be more predicative, by directly modeling the physics that occur on the material level.

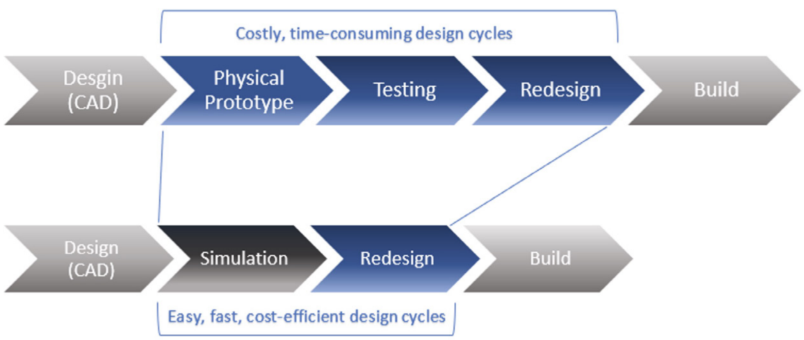
Doing this advanced material testing rather than physical observation increases validity. There is always some validation on the physical testing and verification, however it does not need to be done for every load case. Multimech enables users to replace physical testing by building ample confidence in their models for some load cases. Then, they can then predict how it will work for other cases.

Multimech integration with NX

Multimech can be used to add the lattice structure's advanced material properties. First, create a TPMS diamond structure using implicit modeling capabilities and import it in a finite element modeling (FEM) file to mesh the part to use in Multimech. Next, access the materials engineering tab to export the diamond structure to Multimech and create the material file format for analysis. Lastly, run a simple analysis test by applying a small amount of stress to the structure and analyze the stress and strain results. After completing the test in Multimech, save the material file to use in the next step of the lifecycle development workflow. Engineers can streamline development from months to days and decrease physical testing costs. Next, combine lattice structures and Multimech in virtual simulation to verify that additive manufactured designs perform equal to or better than traditionally manufactured parts.

Virtual simulation and testing

Virtual validation
The third step in this sustainable process is to validate product design with integrated simulation. Understanding how a component or product assembly reacts under stress or vibration is critical and as products and materials become increasingly complex, engineers need tools that go beyond linear statics analysis. Simcenter includes the structural solutions needed for a wide range of structural analysis problems in a single user environment. Engineering departments can consolidate analysis tools and only need to know a single user interface (UI).



Modern product design process provided by the integration of NX with virtual simulation software to reduce time to market and improve design longevity.

Siemens' structural simulation solutions help engineers accurately simulate both linear and nonlinear analysis. Linear analysis is used to solve static problems, such as determining if a structure will fail under a prescribed load and can be used to solve transient problems where loads change over time. Simcenter has a range of integrated linear analysis functionalities, including analysis for linear statics, normal modes and buckling. Engineers can use these capabilities to evaluate structural

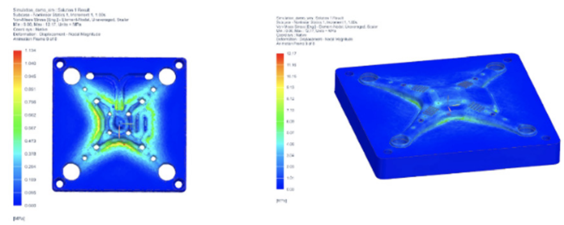


Figure 6. Stress gradient of a vertical simulation on the drone die mold.

performance for applications in a variety of industries. If deformations are large, linear material assumptions are invalid or contact is a factor, then nonlinear analysis is the appropriate simulation choice. Simcenter is used to solve a wide range of nonlinear analysis problems. Nonlinear implicit and explicit analysis solvers enable engineers to address problems as simple as a plastic catch or as complex as a car body roof crush analysis. Integrated explicit dynamic capabilities enable engineers to perform metal forming analysis or evaluate electronic hardware performance during a high-impact drop test simulation.

Simcenter also supports thermal simulation. Thermal management is a major consideration for a wide range of products, including industrial machinery, automobiles and consumer electronics. Thermal management solutions aim to maintain a product's temperature in an optimal performance range. This may require removing or adding heat, passively or in an actively managed fashion. Then, this can be evaluated using thermal simulation software. Simcenter includes comprehensive, best-in-class thermal simulation capabilities that enable engineers to understand the thermal characteristics of a product and tailor their thermal management solution for optimal performance.

Sustainable simulations

Computer aided engineering (CAE) provides virtual simulations and enables faster and more cost-efficient product development, manufacturing efficiency evaluations and simulation-as-a-concept demonstrations. This enables users to optimize resources and consume less energy. Virtual simulations provide sustainable designs of the manufacturing system and the product/service. Virtual engineering and simulations empower users to support sustainable manufacturing by providing a solution to resource scarcity, carbon emissions and customer attraction to environmentally friendly products.

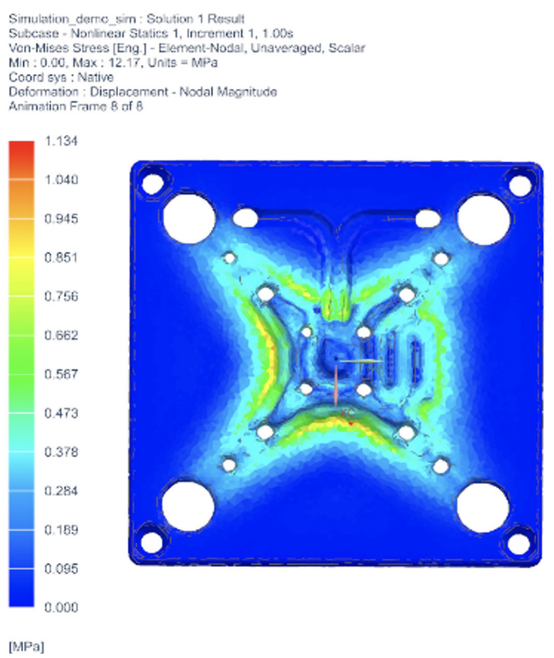


Figure 7. Stress distribution of the lattice structures located inside the drone die mold.

Continuing with the injection die mold that has been redesigned for additive manufacturing, the next step is to conduct a structural linear analysis to verify the new lattice structure design is as sturdy and design efficient as the original. To do this, create an FEM file in Simcenter to mesh the design to have an inner lattice structure portion and an outer solid shell. In this file, apply the material properties to each section. Next, import the FEM file in a simulation, apply fixed constraints to the bolt holes of the part and apply a force to the center of the design to simulate the real-life events. Once the loads and constraints have been applied, use the Multimech multiscale solver in the materials engineering tab to run the simulation at the micromaterial level. Lastly, run the traditional mold design in the same simulation and examine the outcomes.

Additive manufacturing is the key to sustainable innovation. Integrated simulation and testing enable engineers to streamline the product development cycle, increase design durability and sustainability and get parts to market faster. This reduces material usage, decreases energy spent on physical prototyping and machining and increases the ease of designing and testing in one work environment.

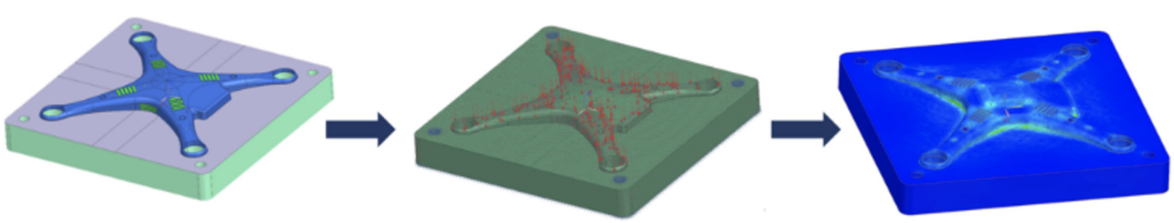
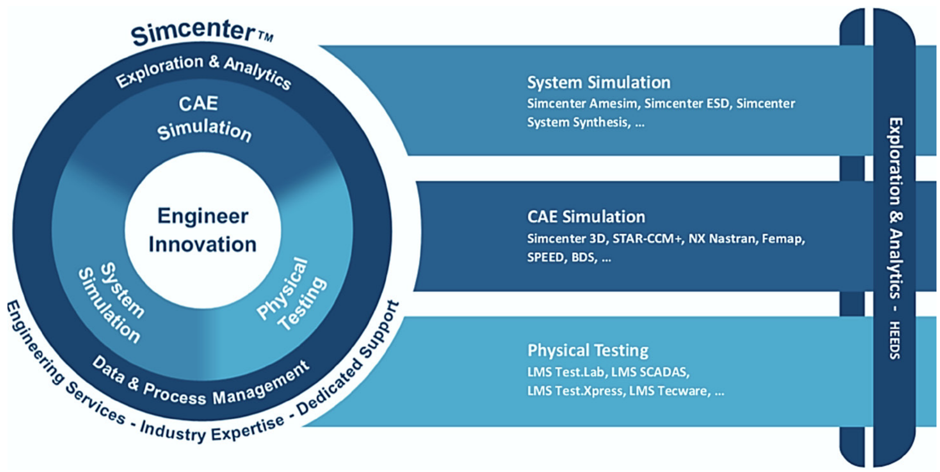


Figure 8. Process of conducting a virtual simulation on a drone die mold.

HEEDS design exploration and optimization



Accelerate product development

Today, consumers are willing to pay higher prices for ecologically friendly products. Advancing design methods can drastically reduce energy usage and abate material byproducts. Although this is the goal for many engineers, using HEEDS can make it happen.

HEEDS is a design exploration and optimization software that enables engineers to determine the most efficient and sustainable design. It enables users to drive product innovation and accelerate the product development process by automating analysis workflows. HEEDS maximizes available computational hardware and software resources. This software package explores the design space for innovative solutions while assessing new concepts to make sure performance requirements are met. HEEDS integration enables engineers to save time and resources to get products to market faster.

Simcenter integration enables users to enhance design by providing the most adaptive work environment. Users can seamlessly analyze designs in multiple software options using Simcenter and NX.

Instead of requiring expert technical skills and simplifying models, engineers and designers can use HEEDS to unlock innovation. HEEDS includes a proprietary design space exploration functionality to efficiently find design concepts that meet or exceed performance requirements. It automatically adapts its search strategy as it learns more about the design space to find the top solution in the chosen timeframe. Using HEEDS helps engineers effortlessly compare performance over a wide spectrum of designs that display desirable features and robustness. Instead of an entire team of engineers spending weeks to create optimized designs, HEEDS enables engineers to do it in hours.

HEEDS is used to visualize design performance trade-offs between opposing objectives and constraints. Results are analyzed and plots, tables, graphs and images are automatically created. The numerous capabilities that HEEDS offers enables users to create production-ready designs, by creating a comprehensive digital twin. The HEEDS automated workflow facilitates easy product development cycles and enables users to quickly integrate technologies without custom scripting. The data is automatically shared between different modeling and simulation products to evaluate performance trade-offs and design robustness. Quick optimization allows for efficient designs that are lightweight, structurally improved and easily manufacturable. This process reduces material waste and energy consumption throughout the lifetime of the part.

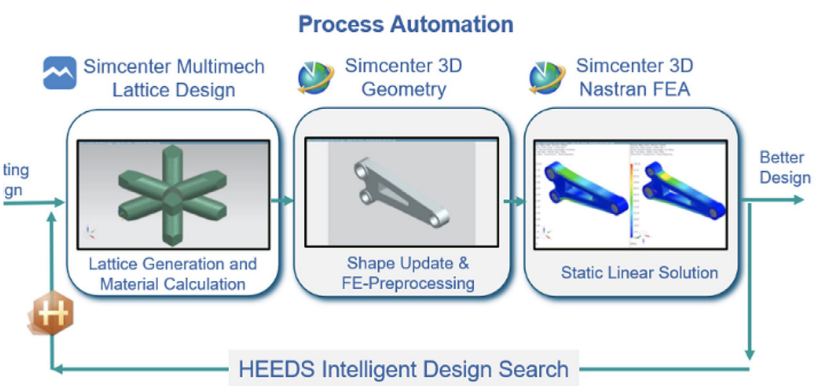


Figure 9. HEEDS process automation visual example.

Drive product innovation

Looking at the drone die mold part that has been redesigned with lattice structures for additive manufacturing, a HEEDS study can be run to explore 10 different design options. The changing parameter is the thickness of the lattice structures, ranging from 0.2 mm to 0.5 mm. To determine the optimal design, compare the von Mises stress outputs. The design that generates the least amount of stress will be chosen.

The workflow has three steps. First, generate the lattice structures with varying width. Second, analyze the lattice file generated in step one in Multimech and export to simulation when complete. Third, run the simulation on the drone die mold with the automatically imported material properties. To create a new HEEDS study, add portals (Simcenter, NX NASTRAN software and analysis portals) to generate the lattice and run the simulation. For each portal, add execution commands, input and output files, dependencies and environment variables. Study variables are identified and responses are created. Files containing the documented parameters are tagged so HEEDS can locate and record their values. The final step is to create the design set and response objective. For this example, ten designs of variable lattice structure thicknesses are evaluated to minimize stress.

This software delivers user-friendly process automation for straightforward and effortless configuration. With HEEDS, users discover better designs, increase productivity and lower material waste and energy usage.

Designing for purpose can be applied to nearly all designs and projects. The next section explains how to apply the integrated additive manufacturing lifecycle development process as a catalyst for sustainable innovation.

Sustainable innovation

Figure 10. Innovation in the shoe industry showing 3D printed lattice sneakers.

Ecological revolution

Design for purpose describes how engineers and inventors implement the global shift in ecological conscientiousness. With environmental conservancy being valued more than ever, consumers consider all aspects of a product and its company when making purchasing decisions. This worldwide revolution is occurring in every industry, particularly automotive, aerospace, energy and biomedical fields.

At Siemens, we empower users to advance projects by providing state-of-the-art tools to modernize designs and manufacturing processes. Our software is on the forefront of sustainable modernization, providing a complete additive manufacturing lifecycle workflow that rapidly turns ideas into reality. NX design for additive manufacturing, integration of Multimech, enhanced simulations and development of HEEDS empowers engineers to design for purpose.

Using this workflow on a drone die mold, increased energy efficiency, reduced material waste, enhanced the structure and promoted recyclability. The drone die mold demonstrates how easily manufacturing can be environmentally conscious.

Explore the possibilities

NX design can also be used for additive and integrated tools for front-end sustainable innovation. Globally, post-consumer shoes makeup 1.2 million tons of material waste, with less than five percent being recycled. As the value of the global shoe market (currently at $200 billion) continues to grow, sustainability must be a serious priority.

A single shoe can contain up to 65 parts and require approximately 360 steps in a manufacturing process.

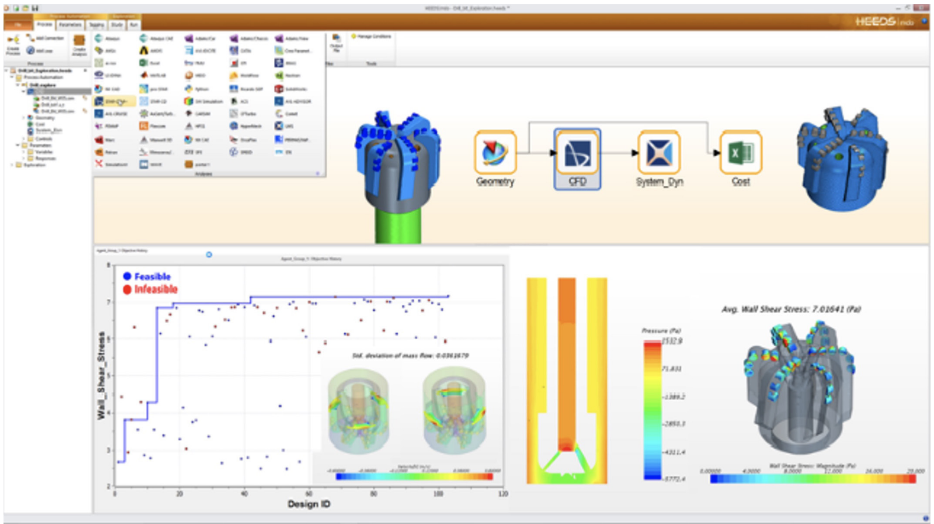


Figure 11. Example of a HEEDS study and analysis results.

Reframing the industrial shoe design process will help cut material waste and increase recyclability. With 3D printing technology, shoes can be customized based on an individual's footprint, including their running style, foot shape, performance needs and personal preferences. Advancements in our software enables users to rapidly produce designs, simulations and prototypes. Many companies are already exploring additive manufacturing to design for purpose, which shows the future of the shoe industry must be centered around sustainable choices.

Using NX capabilities such as design for additive manufacturing, lattice structures and implicit modeling, enables engineers to import biometric scans to model. In this case, the pressure map of an individual's foot can be imported to NX and a custom lattice design can be modeled for an exact fit. NX enables users to deliver lightweight components without compromising structural integrity. The integrated lattice tool makes it easy to embed lattice structures inside of a solid part or incorporate them in an overall design. The lattices are complex geometry represented as facets, which can be modified directly using Convergent Modeling™ technology.

The integration of Multimech enables users to automatically generate geometry and microstructural model meshing. Simcenter reliability accounts for manufacturing variability and imperfections to maximize product reliability. The software enables users to zoom in on the material microstructure to identify the root cause of failure and see which damage mechanisms affect the structural performance. Including Multimech and Simcenter simulations enable engineers to optimize material microstructures for the most cost-efficient performance.

HEEDS can be used to optimize design for stress and weight reduction, producing the most sustainable and innovative custom design. Engineers can use HEEDS to automate workflows to ease product development processes. HEEDS is used to integrate technology quickly and easily without needing custom scripting. The data is automatically shared between modeling and simulation products to evaluate performance trade-offs and design sustainability.

Figure 11. Concept of 3D printed sneaker to reduce material waste, increase longevity and decrease energy costs.

Call to action: design for purpose

Each phase of this workflow is more advanced and accelerated than ever before. It empowers users to design more sustainably and will help get products to market faster than ever before. Whether the goal is reducing waste, recycling plastics or decreasing energy usage, NX empowers users to design for purpose.

An example of sustainable innovation is a 3D printed lattice shoe design. This design is generated from the pressure map of a foot. Once designed, Multimech is implemented to provide a detailed material analysis of the 3D printing polymer filament. Lastly, simulations are conducted to determine the stress distribution when the shoe is worn.

Design for purpose is a call to action. Regardless of industry, it must be a goal to design more sustainably, manufacture efficiently and educate others to do the same.

Conclusion

The world progresses technologically in tangent with advancing sustainability. The key to designing for purpose is to implement sustainable manufacturing processes. Siemens recognizes this movement and is on the forefront of sustainable innovation by developing a full additive manufacturing lifecycle workflow that can rapidly turn ideas into reality. NX's design for additive manufacturing features, Multimech integration, enhanced simulations and continued HEEDS development are the four key components in this workflow. Siemens provides the tools needed to create limitless design possibilities.

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