New Development Principles for Plastic Components with Recycled Content

Achieving Sustainable Product Design Using Artificial Intelligence

The use of Artificial Intelligence (AI) is revolutionizing engineering by enhancing the quality, cost-effectiveness, and safety of products and processes. M.TEC Engineering, a pioneering company from Aachen, Germany, has developed an AI-integrated development process that boosts technical efficiency and addresses complex multiphysics challenges. Notably, a new application of this process is being implemented for designing components using recycled materials.

Artificial intelligence is used to optimize product and process parameters to ensure consistently high product quality. This makes it possible to use recycled materials for technically complex applications with minimal risk. © M.TEC Engineering

In response to stricter environmental regulations, rising raw material costs, ambitious sustainability targets, and growing consumer expectations, product development must evolve. Incorporating new digital tools, including AI, can help meet these demands by driving innovation and efficiency. But how exactly can AI help manage this pressure for innovation?

Given today's economic and environmental challenges, companies must find innovative solutions to save resources, establish sustainable production methods, and deliver safe and stable products at the same time. Uncertainties and increasingly complex requirements change the world of product development. Improving efficiency, reducing material and energy consumption, and ensuring the highest product quality are essential factors to meet the demands of modern industry and society.

For over 30 years, M.TEC Engineering has been a leader in product development, focusing on sustainable and highly efficient solutions. The company's AI-integrated process is tailored to meet the fast-paced, demanding, and volatile nature of modern product development. This approach not only pushes the boundaries of what is technically possible but also unlocks new potential, reduces costs, shortens development times, and enhances safety and reliability for customers.

By using AI in the development phase, M.TEC helps to make the use of recycled materials more viable and sustainable, paving the way for a future where innovation and environmental responsibility go hand in hand.

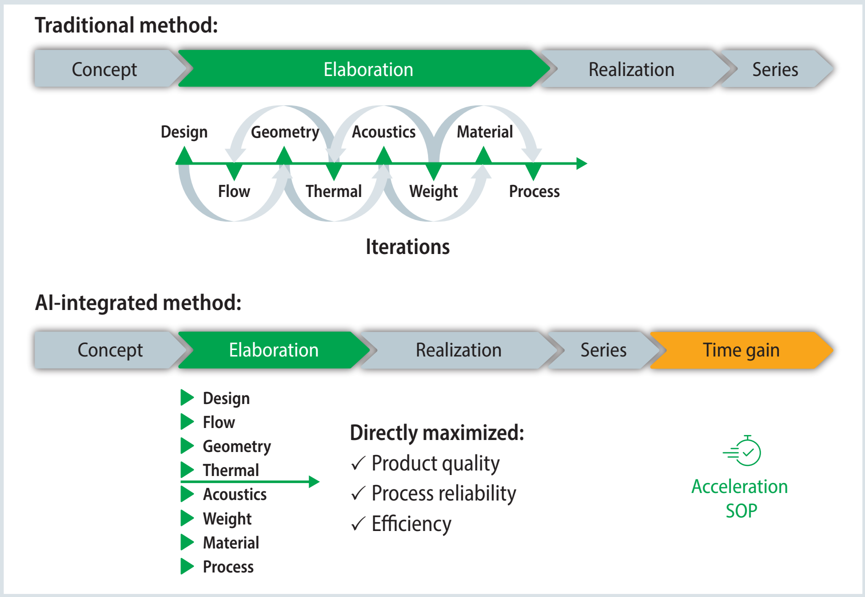

Fig. 1. Comparison of design processes without and with the use of AI. The simultaneous simulation of important requirements (below) accelerates the process. Source: M.TEC Engineering; graphic: © Hanser

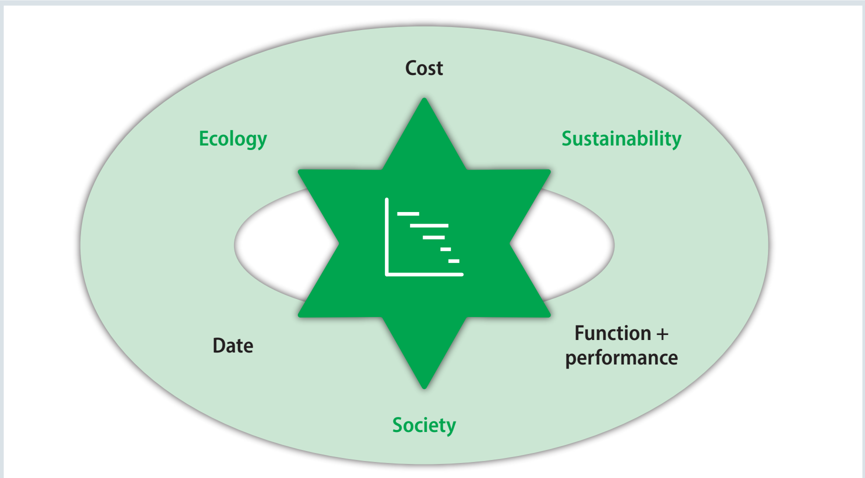

Fig. 2. Additional requirements for development projects in terms of sustainability. Source: M.TEC Engineering; graphic: © Hanser

AI-Integrated Development: Faster, More Efficient, More Sustainable

Long before the emergence of AI-based chatbots like ChatGPT, engineers at M.TEC began working on an AI-supported product development process. The technique opens up new ways to make the development process more sustainable, resource-efficient, and faster. Thus, the AI-integrated development process makes it possible to account for variations in material properties, which frequently occur when using recycled materials, and to optimize product and process parameters to ensure consistent product quality.

Unlike traditional development methods, which isolate individual physical domains, M.TEC's AI-integrated process uses multiphysics simulation to optimize products across the entire parameter space (**Fig. 1**). By handling high complexity and large data volumes, this method considers interactions and resolves conflicting goals, achieving the best possible dataset that human planners alone could not determine. These advanced technical solutions pave the way for accelerated innovation and sustainable development.

How can artificial intelligence make products and processes more environmentally friendly? What specific sustainability benefits does AI integration offer? Below, we summarize key sustainability factors in development and highlight a practical example of AI's impact on sustainability.

Sustainability Aspects in Product Development

Sustainability is increasingly central to product development (**Fig. 2**), driven by shifting consumer demands, corporate sustainability goals, and stricter regulatory requirements. Using recycled materials and optimizing material and energy consumption are crucial strategies for conserving resources and reducing carbon footprints. Consequently, development focuses on integrating circular economy principles, product durability, and reparability.

Looking at the material stream of post-consumer recyclates (PCR), it becomes evident that material properties can no longer be assumed to be constant in the future, as their source and composition can no longer be reliably guaranteed as they were before.

In this context, AI-supported optimization enables the precise prediction of processes, ensuring high product quality even with fluctuating material properties, thereby promoting the use of recycled materials in technically demanding applications. Additionally, processes can be optimized to be resource-efficient and energy-saving, and material usage can be minimized. This not only meets the current requirements of legislators and end customers but also aligns with the self-imposed goals of many manufacturers. »

Info

Text

Dipl.-Ing. Ulf Seefeldt is Business Development Manager at M.TEC Engineering GmbH, Herzogenrath, Germany;
u.seefeldt@mtec-engineering.de
Dipl.-Ing. Wolfgang Pelzer is Managing Director at M.TEC Engineering GmbH;
w.pelzer@mtec-engineering.de

Service

More information:
https://mtec-engineering.com/en

Fig. 3. At the 20th Automotive Award Night of the SPE, the vehicle support structure optimized with the help of AI was awarded in the "Enabler Technology" category. © M.TEC Engineering

Process and Warpage Optimization of a Vehicle Support Structure

The starting point for the following practical example was the process design for the production of an automotive cross member (**Fig. 3**) made from long glass fiber-reinforced polypropylene (virgin material) using shrinkage and warpage simulations. The process was designed using the in-house AI M.Opt, ensuring that there was no tool optimization necessary and reducing sampling time by 80 %.

As the project for BMW AG progressed, the goal was to use AI to calculate a parameter set that would ensure a stable process and consistently high product quality when using recycled material, despite the resulting fluctuations in material properties (assumed here: viscosity).

The development process began with the precise definition of requirements and the creation of a digital twin of the component. Detailed FEM (Finite Element Method) models were created to simulate the structural properties of the support structure.

A key aspect of the optimization was accounting for fluctuations in the material properties of the recycled materials used. Material viscosity was included as a variable in the optimization, with an assumed tolerance of ±20 % compared to the baseline value. Other studies indicate that the tolerance in viscosity for recycled materials can be significantly higher (up to ±50 %).

Multiphysics Optimization

The goal of the optimization was to find the parameter set that provides the least warpage with viscosity values fluctuating within a range of ±20 % compared to the nominal value. The main warpage was assumed as the measure of warpage, calculated as the average of all nodes. Initially, the total warpage (defined as described above) was determined using the process parameters of the series material, which would then serve as a reference value.

As an additional benefit, the AI identifies sensitivities in this case. It identifies the parameters that have a significant impact on warpage behavior, as well as those that play only a minor role. This allows for optimization of quality assurance in the creation of production control and inspection plans: In production, only the parameters that are truly meaningful and important are monitored.

In the next step, all 26 variable parameters were optimized simultaneously,

Fig. 4. Insulin pens as an example of the application of multiphysical optimization in complex engineering projects with conflicting development goals. © abidika – stock.adobe.com

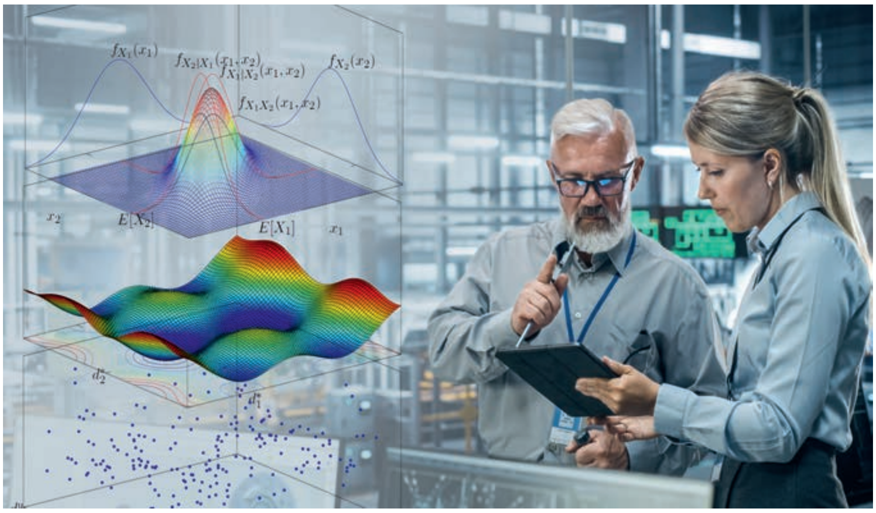

Fig. 5. A human being cannot cope with the effort involved in investigating the entire available solution space; AI is the only solution in this case. © M.TEC Engineering

with the minimum and maximum viscosity values assumed. This created a solution space of x^26, within which the optimum of this functional equation is sought (**Table 1**).

It was observed that a lower viscosity has a considerably greater influence on the shrinkage and warpage behavior than a higher viscosity.

In a further step, the tool dimensions were included in the optimization as variable parameters, i.e. geometry parameters were taken into account in addition to the process and material parameters. This further expanded the solution space (**Table 2**).

In general, it can be observed that the average warpage increased slightly in terms of level. However, a positive effect of such an approach can also be noted: the standard deviation could be significantly reduced. The assumed wide tolerance of viscosity could thus be compensated for through intelligent tool design.

The success of recyclates in new products can therefore be significantly supported by the use of AI in the development phase: risks become more calculable, and feasibility becomes visible earlier. The prerequisite for this is the exploration of the entire available solution space. A human cannot realistically perform this effort due to the complexity of the approach; in this case, AI is the solution.

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Medical Technology Application: Development of an Insulin Pen

AI-integrated development has proven its effectiveness in numerous practical applications, such as the optimization of an insulin pen (**Fig. 4**). In medical technology, where precision and safety are paramount, multiphysics optimization has been crucial for achieving consistently high product quality and process stability while reducing costs.

Developing the insulin pen, a complex medical safety product, involved balancing a range of sometimes conflicting requirements. Through multistage simulation, it was possible to find a balance between mechanical, thermal, and fluid dynamic requirements, reduce production and development costs, and consistently meet regulatory standards. The development process involved several steps:

- Defining specific requirements for the pen injector.
- Creating a comprehensive multiphysics model that accounted for mechanical, thermal, and fluid dynamic factors.
- Applying AI-based optimization to develop a design that met all these requirements.
- Validating the final design through real-world testing.

Conclusion

The AI-integrated development process as described represents a significant leap forward in sustainable product development. This is clearly demonstrated by the examples of the support structure and the insulin pen, where AI optimization reduced sampling time, material consumption, and resource use while enhancing product quality and process safety.

This approach not only facilitates the use of recycled materials but also helps reduce carbon footprints, implement circular economy principles, and achieve other sustainability goals. By adopting AI-driven processes, engineering can meet the current challenges of product development, enabling innovative and sustainable solutions for the future (**Fig. 5**). ■

Change in Viscosity [%]	Change in Warpage [%]
-20	-4.05
0	–
+20	0.97

Table 1. Change in warpage: Results of the analysis at minimum and maximum viscosity.
Source: M.TEC Engineering

Change in Viscosity [%]	Change in Warpage [%]
-20	-0.72
0	–
+20	-0.57

Table 2. Change in warpage: Results of the analysis with minimum and maximum viscosity and inclusion of the tool dimensions.
Source: M.TEC Engineering