Rethinking heat exchanger design through algorithmic engineering

Hyperganic has partnered with TRUMPF, the German industrial machine manufacturing giant, to radically accelerate the innovation of heat exchangers and their design process.

By Lin Kayser, Co-founder and CEO, Hyperganic

Hyperganic is a deep tech company that reshapes the way we create physical objects and machines. Engineers encode the laborious, human-driven engineering processes into computer algorithms using the Hyperganic software platform. As a result, this Algorithmic Engineering process scales with the amount of computational power deployed and not with the amount of working time spent on a design. The created objects are more complex, more functional and more customized to their use cases and often approach the complexity of natural objects. They are ideally suited for mass-production using industrial 3D printing (Additive Manufacturing, AM).

Nature as a paradigm

Heat exchangers are at the heart of modern heating and cooling, which account for 40% (13.2 Gt) of energy-related CO_2 emissions. As global temperatures rise, we race against time to find more efficient solutions.

Nature offers us valuable insights into how heat exchange governs the way natural structures are grown. For example, the circulatory and respiratory systems of some animals have countercurrent configurations to maintain optimum body temperatures and fluid levels in extreme environments.

Man-made heat exchanging structures, by contrast, are much more basic. The simple design of smaller scale shell-and-tube or plate heat exchangers that are used in our smartphones, cars or refrigerators no longer make the cut for our future needs.

Over the last two decades, our world fundamentally changed under the force of rapidly accelerating technologies. Additive Manufacturing offers a higher potential of design freedom to create structures that transfer thermal

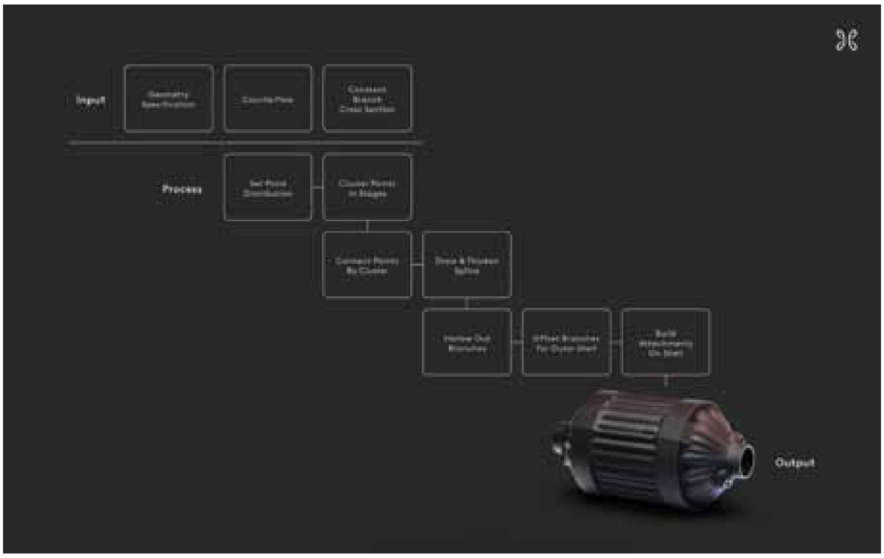
energy more effectively. Heat exchanger designs can be significantly more complex, resulting in higher thermal transfer because of larger surface area, yet at the same time have lower pressure drop through intelligent shapes, which reduces the power consumption. They are also often lower in weight, smaller in size, and even more reliable as an indirect result of being printed in one piece.
The challenge is to come up with heat exchanger designs in the first place. Today's CAD (Computer Aided Design) tools require engineers to create designs from scratch with little automation. The complexity of the object is fundamentally a function of the amount of work the human designer puts into it. When designing for Additive Manufacturing, the engineer's working time is the biggest bottleneck.

The power of algorithmic engineering

While many complex, additively manufactured heat exchangers have emerged in recent years, a scalable solution to create their designs remained elusive. Designs were created by hand, often repeating unit cells of known properties, that can easily be replicated. More complex designs could be imagined, but not practically designed, because of the amount of work required.
Many inspirations for the problems of heat exchangers can be found in nature, where cross pollination and tight integration of functionality govern the way structures are grown.
To tackle the challenge of coming up with a more scalable workflow, Hyperganic worked with German industrial machine company TRUMPF to build an algorithmic framework to generate heat exchangers. As a test case, a design for gas cooler for shielding gas that is used in the TRUMPF AM machines was considered and eventually executed.
In Algorithmic Engineering, the focus lies less on creating one single object, but on a process that can create a large number of possible variations, from which the best-performing object then can be picked. This enables the engineer to focus less on getting it right the first time and more on the principals involved in the design. Because there is less "fear of failure", the engineer can get closer to the limits of what is possible, because the objects can be recreated in seconds when new insights lead to different parameter inputs.

How it works in detail

The process begins with framing the design goals using mathematical and physical models on Hyperganic Core — Hyperganic's software platform for Algorithmic Engineering.
Such goals include maximized thermal efficiency, minimized pressure drop of hot fluid, a constant flow rate and a minimized length.
The benefit is that the engineer can now focus on achieving the goals through higher-level thinking that applies to all relevant heat exchanger designs, and not becoming lost in the time-consuming process of firming up details of one particular design.
The above design goals are then framed within the environment that the specific heat exchanger will operate in, which also dictates its outer appearance. In our case, we defined the boundary conditions of a target volume, an input diameter that had to be 50mm, argon as the shielding gas, and water as the cooling medium.



Heat exchanger design workflow.

The Fibonacci sequence is a naturally occurring pattern found in plants, flowers or fruits.

In order to achieve the highest number of equally spaced points within one circle, we took inspiration from the Fibonacci sequence that is found in the recurrent structures and forms of plants, flowers or fruits. In our case, the pipes are spread out very similarly to the way sunflowers arrange seeds at their cores.

The point distribution is then clustered and bundled into the main parent branch and turned into parameters. This is repeated as a staged process until an inlet with one point only is reached.

This data-structure was then used to route spline curves across the stages. After adding thickness to the spline curves and hollow them, the branching structure comes to life.

Once the coding part is in place, we basically have a black box that uses AI strategies to automatically execute the geometry generation process, create multiple design variations, and evaluate possible performance.

Efficient thermal cooling relies on an intricate network of cooling channels. Like how the body's blood vessels maintain a steady temperature, cooling channels in e.g. rocket engines pump liquid rocket propellant to cool down combustion chambers.

Algorithmic Engineering automates the routing of these geometries in the design of combustion chambers and highly-efficient heat exchangers – a task that would have previously taken engineers weeks of manual construction work is now automated with intelligent algorithms. A heat exchanger with a different diameter or a different number of cooling channels can be generated just by changing some of the input parameters. If different branching algorithms are more suitable, regenerating an object after implementation takes only a few seconds.

Challenges in designing heat exchangers algorithmically

We needed to ensure that the total cross section of the fluid domain is always constant at each stage of the heat exchanger intended to keep the mass-flow constant.

In order to address that, a mass-conservation law was quickly embedded in the algorithm, applying the constraint to the whole branching structure.

Another challenge was posed by the presence of local minima in the branching areas that caused challenges in terms of printability. We addressed this once again by updating our algorithms. Finally, the heat exchanger must be post-processed on a traditional CNC machine (a motorized maneuverable tool). Two lateral rings were created for the heat exchanger to withstand the pressure of the clamps holding it in place during that process.

What does this mean for our future?

This heat exchanger is just the first of a whole suite of objects and machines that can be algorithmically engineered. Multiple designs can be generated at once. This algorithmically designed heat exchanger has a surface area which is 14 times higher than a cylindrical tube of the same dimensions. The pressure drop goals were quickly reached; the overall heat exchange properties exceeded initial targets.

For future projects in the field of heat exchange properties, existing algorithms from past projects can easily be reused, speeding up the process even further. Hyperganic has since bundled much of the past work into a comprehensive heat exchanger framework, which covers fields as diverse as conformal cooling of jet vanes to passive heat sinks.

As more engineers get onboard with this new paradigm for design, more building blocks of algorithms will recombine and morph into objects that are ever more complex, sustainable and functional. This dramatic acceleration in innovation of physical objects will move us a step closer towards a more sustainable world.

About the Author

Lin is a serial entrepreneur who founded his first company 30 years ago.

In 2000 he started IRIDAS, which quickly became a leader in high-end image processing for the global movie industry. In 2011, IRIDAS was acquired by Adobe, where Kayser worked for 3 years as a Director. In 2014, he left to focus on Hyperganic, the company which builds software to design objects that are as complex, functional, elegant and sustainable as nature.