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KlimaStol: 3D-printed Cooling Chair for Mitigating Outdoor Heat Stress

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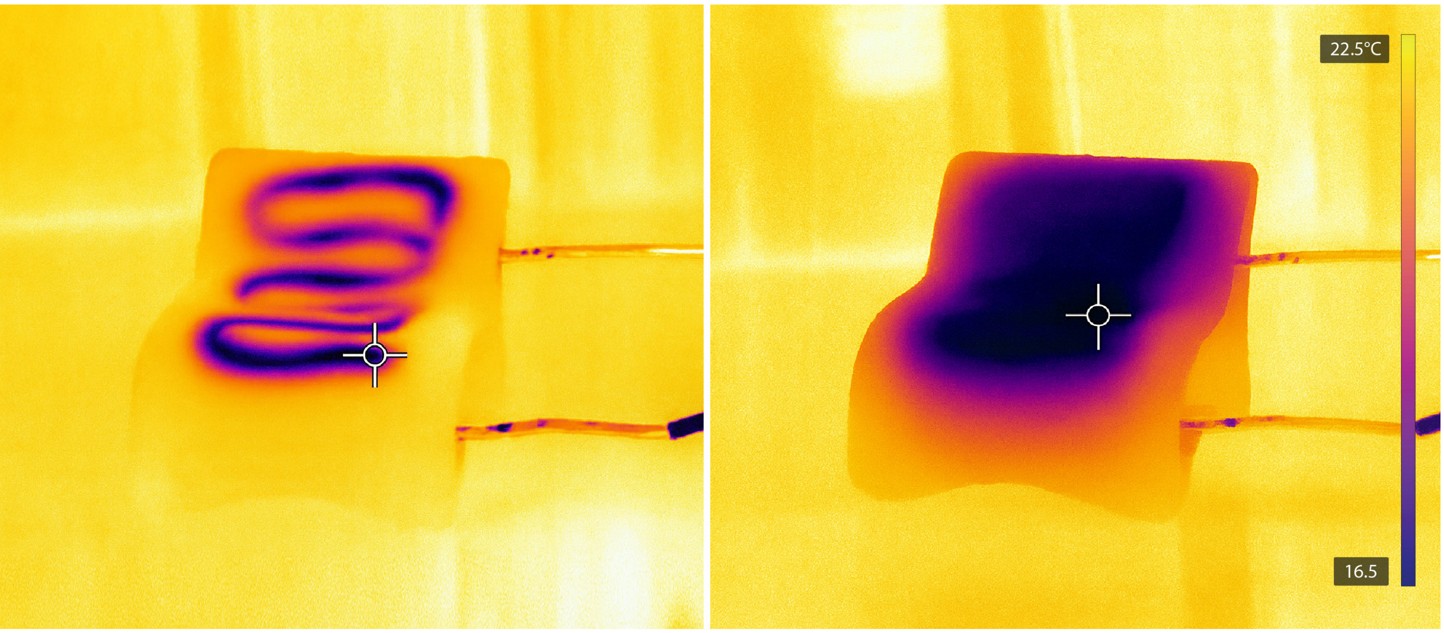


1 Infrared thermal images of KlimaStol show reduced surface temperature resulting from chilled water circulating through the pipe.

Heatwaves and Outdoor Cooling

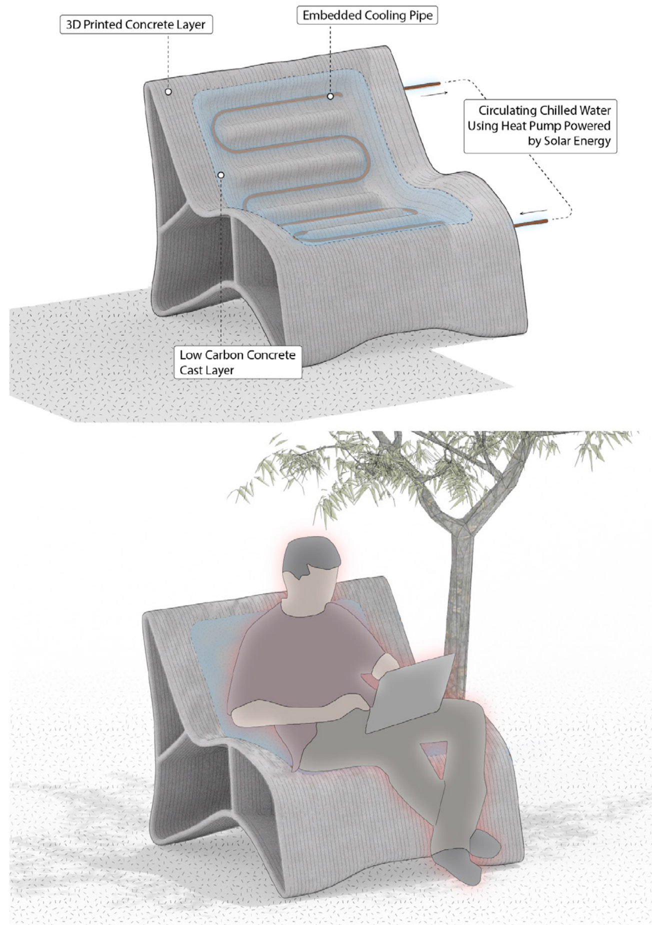
Heatwaves, one of the indicators of climate change, have increased in frequency in the United States—from occurring twice per year in the 1960s to six times annually in the 2010s and 2020s (EPA, 2024). In urban environments, heatwaves drive higher energy demand for cooling, often resulting in power outages. On a broader scale, dependence on energy-intensive cooling systems exacerbates environmental degradation (Ke et al., 2016). This vicious cycle ultimately undermines our capacity to adapt to climate change and, compounded by the lack of adequate alternative cooling strategies during extreme weather events, heightens public health risks (Jones et al., 2018). In response, this project highlights the design and fabrication process of a resilient cooling chair intended to reduce outdoor heat stress during the summer months.

Solar-powered Conductive Cooling Chair

Outdoor cooling shelters serve as critical infrastructure for mitigating heat stress in areas vulnerable to the health risks associated with heatwaves. In a previous prototype, we designed and installed an open-air cooling shelter that operates entirely on solar energy (Figure 2). Specifically, the shelter utilized a conductive cooling bench that enabled individuals to sit and rest while mitigating heat stress (Bae et al, 2025). As shown in Figure 3, the cooling pipes embedded within the bench created a chilled surface, allowing the human body to lose heat conductively upon contact.

2 Wood-based cooling bench from previous cooling shelter project.

3 IR image of chilled bench surface in previous cooling shelter prototype.



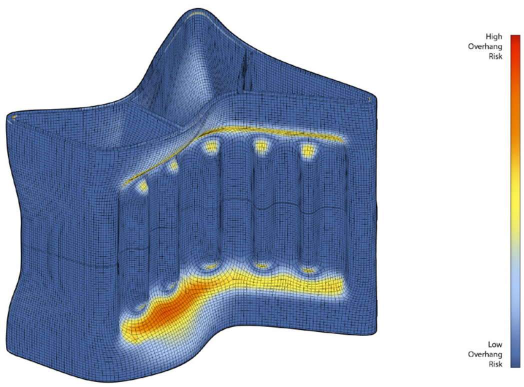
4 Demonstration of the conductive cooling system (top) and KlimaStol designed to maximize cooling performance (bottom).

However, due to the nature of conductive cooling—where its effectiveness is determined by the contact surface area with the body and the thermal conductivity of the material—the performance of this bench, made of wood and featuring a conventional form, was limited. Given the limitations of the previous bench, this project features the design exploration, material modification, and fabrication strategies involved in developing an innovative and resilient outdoor cooling chair.

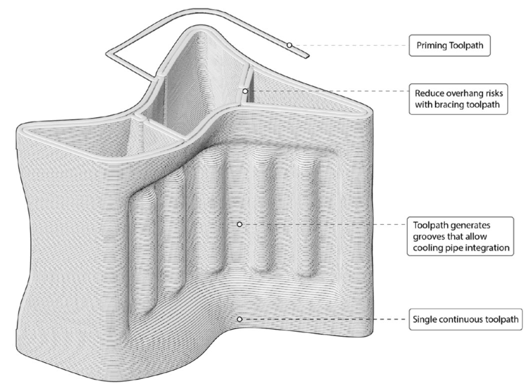
Ergonomic Design and Digital Fabrication

KlimaStol is a concrete cooling chair fabricated through robotic 3D printing. The chair is designed to accommodate a single user, with an organically shaped surface informed by ergonomic principles. This form maximizes the contact area between the body and the chair, thereby promoting effective conductive heat transfer (Figure 4, bottom). Additionally, the material used in this project is a low-carbon, high-thermal conductivity concrete developed in collaboration with material scientists. This material choice was intended to reduce environmental impact while enhancing the chair's thermal performance. Conductive cooling is achieved by embedding copper pipes within the seat and backrest, which are specifically designed with channels to accommodate the pipe layout. These pipes are encased in an additional layer of concrete, allowing chilled water—circulated by a heat pump powered by solar energy—to flow through the chair and enable effective heat transfer (Figure 4, top).

To fabricate the complex and functional geometry—such as the pipe channels and the human body-informed surface—we employed concrete 3D printing using a 6-axis robotic arm (Figure 8). Additionally, the complex mesh geometry was optimized to reduce overhang risks during printing (Figure 5). As shown in Figure 6, a continuous loop of toolpaths was designed to improve both structural stability and printability (PSL, 2025). As shown in Figure 7, the cooling pipes were installed along the pre-designed pipe channels in the completed chair, and an additional layer of concrete was cast over them to finish the construction.



5 Mesh geometry optimized to reduce overhang risks



6 Single continuous toolpath for robotic concrete printing.

7 Completed the 3D-printed chair and cooling pipe installation process, including the final concrete casting layer.

Heat Stress Mitigation

As shown in the infrared thermal images taken after the cooling chair was activated, the surface temperature along the cooling pipe dropped immediately (Figure 1). This was followed by a more uniform decrease in temperature across the entire chair surface, facilitated by the high thermal conductivity of concrete. As a robotically 3D-printed concrete cooling chair, KlimaStol demonstrates the potential of integrating sustainable energy sources with energy-efficient cooling methods. Its ability to reduce outdoor heat stress when placed in shaded areas of hot environments positions it as a promising form of resilient outdoor cooling street furniture.

ACKNOWLEDGMENTS

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IMAGE CREDITS

Figure 1-8: ©Thermal Architecture Lab

8 Robotic concrete 3D printing process of a geometric toolpath designed as a continuous loop to enhance printability.

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