Climate Active Bricks

How robotic fabrication technology can contribute to improving urban microclimates.

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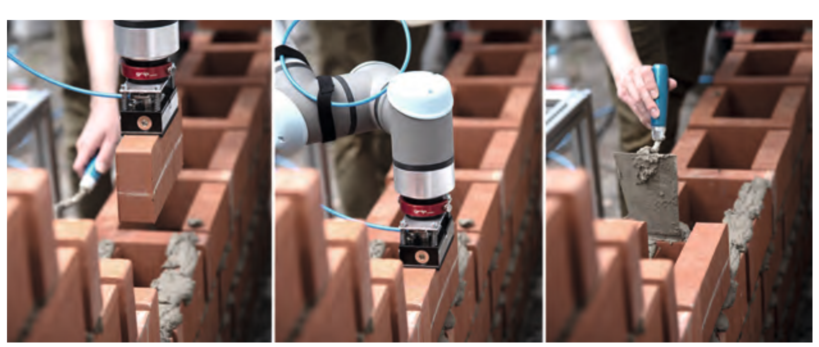
What role do urban microclimates play in our experience of cities?

On a hot summer day, one of the most refreshing experiences for a Munich city dweller is to enjoy a cool drink on the meadows of the river Isar or escape to the English Garden. According to the latest WHO projections, the frequency of extreme events driven by climate change will increase in future—and Germany will be no exception. This phenomenon can have severe effects on human health and wellbeing in urban environments. While recreational areas such as the English Garden or the banks of the Isar offer citizens the opportunity to recover from heat stress, such cooling areas only affect their immediate surroundings, i.e. the micro-environment. For buildings and urban exteriors with primarily sealed surfaces, other measures will be needed to improve the ambient climate. Architecture can help transform our urban realm into a space worth living in.

One of the main strategies to decrease heat stress inside cities is ample vegetation, for example along sidewalks. This has been proven to improve human comfort levels and encourages people to actively use public space. Another option, especially for dense areas where the amount of greenery cannot be increased, is to consider the shading of building structures or create surfaces with minimized exposure to solar radiation. During the Climate Active Bricks project, developed in August 2020 as part of a design-build summer school, we investigated whether we could apply digital design and robotic fabrication technology to directly improve the exterior facades of buildings. We explored whether customized, site-specific self-shading effects on the external facades of buildings might reduce exposure to solar radiation and thus decrease heat storage and radiation, thereby improving the ambient climate in urban areas.



Craftitude meets robotic fabrication: While a person mixes and applies the mortar, the cobot lays individual bricks according to the digital model. The consistency of the fresh mortar allows the robot to easily press the brick into place, whereafter the person removes any excess mortar and grouts the joint.

Re-imagining facade design

The Climate Active Bricks project was carried out in Munich's Kreativquartier, where we used a south-west facing facade to design, construct, and test the behavior of an architectural prototype, which was two-meter high and three-meter long at 1:1 scale. This prototype allowed us to explore how integrating the potential of computational design, climate simulation, and robotic fabrication unlocks the climate-active properties of bricks in exterior building envelopes. We also wished to expand the notion of integrated architectural functions in the exterior of building envelopes, for which we relied on Leon Battista Alberti as a historical reference. The social impact of architecture and consciousness of the urban realm were Alberti's major objectives. The Palazzo Rucellai in Florence, flanked by a continuous stone bench, visibly demonstrates his purpose, which is still evident today; This bench once served as resting place for visitors and passers-by and the façade's external formulation is thus an archetype of an integrated function.

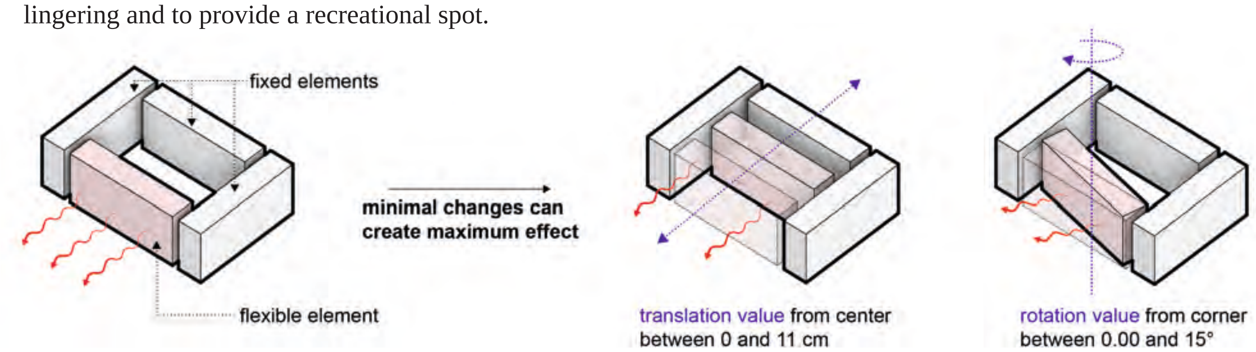
We developed the design of the facade prototype on the basis of the rat-trap bonded brickwork, a modular type of four bricks that are rectangularly arranged and laid on edge, thus creating a cavity in between. The rat-trap bond uses 40% less mortar and 20% fewer bricks without compromising strength compared to conventional brick masonry with a similar wall thickness. By rotating and shifting the front brick of the bond, we can create a self-shading structure and hence achieve a reduction in exposure to solar radiation and surface temperature compared to a conventional flat brick wall.

By performing digital simulations, we analyzed various designs that affect the exposure to solar radiation of brick constellations. Without any modification, the original flat front surface of the bond is, as any other flat surface, directly exposed to the sun. By shifting the front brick toward the back, the amount of exposed surface is reduced through shading by adjacent protruding bricks. To reduce solar reflection even further, we can rotate the front brick; this changes the angle of incidence and fall-out in reference to sunlight. The wider the angle with respect to the sun's location, the lower the value of the absorbed radiation, which results in a decrease in solar radiation and heat stress. To allow an existing tree to blend into our site-specific design, we followed Alberti's archetype and integrated a bench to invite lingering and to provide a recreational spot.

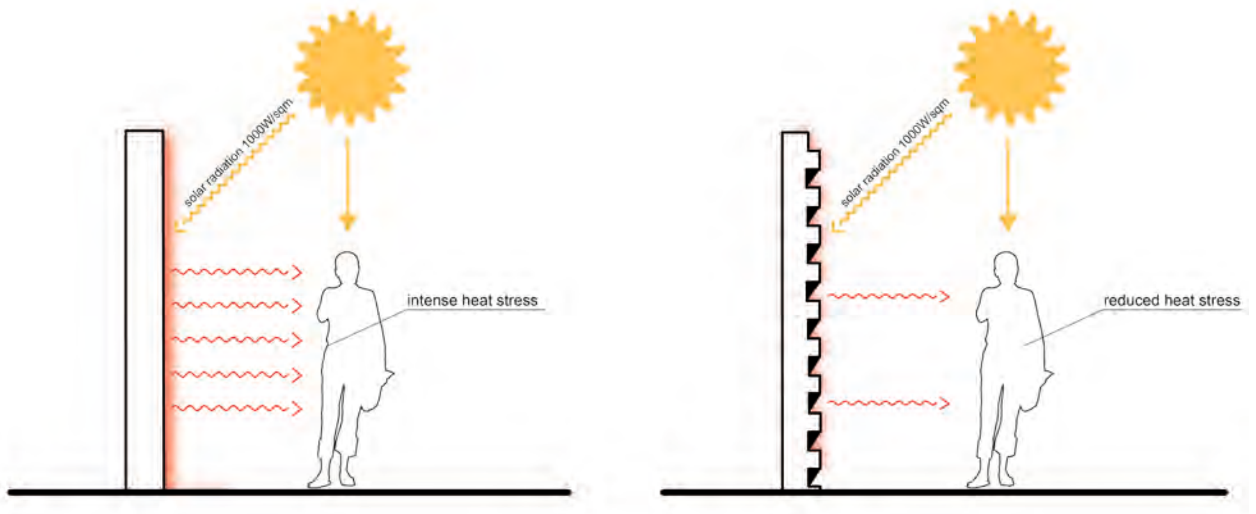
Cobots on building sites—it works!

A collaborative robot—a cobot—that can work hand in hand with people was brought on-site to do the brickwork jointly. The laying of the bricks into the customized rat-trap bond, in which each individual position was precisely defined by the digital model, was performed by the cobot. The mixing, packing and cleaning of the mortar joint, a process that requires great dexterity, skill and adaptation to external conditions—such as humidity, wind or air temperature—as regards the mortar setting, was carried out by a person (in this case, by students involved in the workshop). This enabled an intuitive workflow between the computational precision of the cobot and the realm of manual craft.

The wall was divided into individual sequences composed of step-like courses of brick within the reach of the cobot arm. Each of these pre-defined sequences was then built from an individual cobot location. Our digital model comprised priorly digitized survey points of the building site, which were then recorded on-site for each new cobot location by the robot arm. By matching recorded points with survey points, the cobot's exact current location could be estimated, enabling a seamless alignment of the bricks of the current sequence with the previous one.



Taking a rest at the *Climate Active Bricks* building envelope prototype.



Are our assumptions correct?

We measured the wall exposed to solar radiation during a hot summer day in Munich (August 10, 2020). The day provided cloudless solar radiation onto the brick wall and air temperature reached 32°C at peak time (14:00). As shown by the infrared thermal images, we were able to record a significant reduction in surface temperatures. The left part of the brick wall displays no self-shading geometry, which leads to a high level of absorption of incident solar radiation; thus, overall surface temperatures are over 42°C. However, thanks to the self-shading effect, the right part of the brick wall's surface temperature decreases by more than 40%. In the morning hours until 12:00, almost 85% of the brick surfaces are shaded, which results in lower solar absorption and, therefore, lower surface temperatures. The average surface temperature of bricks with self-shading geometry (right side) is a maximum 4.8°C lower than that of bricks with a flat geometry (left side). This implies that city dwellers would experience reduced heat.

You want enjoyable cities? Here is one way to achieve this

To make city life enjoyable, we should engage in highly informed design and construction processes that are carried out in cooperation and exchange with many disciplines. Climate Active Bricks is an attempt to bridge knowhow and expertise from the fields of architecture, robotic fabrication, and climatic simulation, leading to the creation of highly customized and site-specific architectural solutions. As the constructed prototype shows, the project is also an example of seamless links between simple and straightforward design ideas; and it harnesses the opportunities that technological innovations offer. This is intended to foster easier access to digital tools and, thus, the application of technology to architecture where it can be the most effective.

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Top: Flat surfaces of urban walls that are directly exposed to the sun tend to radiate heat and thus create heat stress for city dwellers. Decreasing the exposure of such facades to solar radiation, e.g., through self-shading effects, can help reduce the heat and thus improve the ambient climate for residents.
Bottom: Close-up of self-shading effect of facade built with *Climate Active Bricks*, shot on August 07, 2020, 13:02
The rat-trap bond, a brick wall masonry construction method in which bricks are laid on edge instead of the conventional horizontal flat position, thus creating a cavity (hollow space) within the wall, was used as the starting point of the design parametrization. While the side headers remain fixed, two parameters of the front stretcher—rotation and translation—could be modulated in order to create a self-shading effect and thus reduce the exposure of the entire surface to solar radiation.