The pavilion explored the possibility of reinforcing an initially inflated ETFE envelope with robotically applied carbon fibres, so that, post-fabrication, it could turn into a self-supporting compression structure. In this process, the transparent membrane transformed from a pneumatic mould into a watertight building skin.
The fibre layers were generated sequentially in tandem with the construction process, allowing the generative model to incorporate targeted production feedback. Each line represented an approximate robotic tool path that was modified during the fabrication process, based on sensor data, to adapt to the pneumatic base surface.

For the fabrication process the robot was placed in an inflated ETFE bubble. During the laying of the fibres on the inner surface of the inflated membrane, this soft pneumatic body gradually transformed into a structured compression shell.
Fibre Placement on a Pneumatic Body

Based on a Water Spider Web

Process-based biomimetics focuses on the transfer of biological principles to architectural construction. To realise the ICD/ITKE Research Pavilion 2014–15, presented here by Moritz Doerstelmann, Jan Knippers, Valentin Koslowski, Achim Menges, Marshall Prado, Gundula Schieber and Lauren Vasey of the Institute for Computational Design (ICD) and Institute of Building Structures and Structural Design (ITKE) research team at the University of Stuttgart, sensor-driven robotic fabrication was combined with advanced design computation and simulation. This enabled the construction of an architectural fibre structure on a pneumatic mould, drawing on the complex design of the web of a water spider.

The research for the ICD/ITKE Research Pavilion 2014–15 extended the fibre-composite processes of the 2012 and 2013–14 pavilions through the integration of a weatherproof skin based on a biological investigation of the diving bell water spider (Argyroneta aquatica). Contrary to the insights on morphological principles for fibrous structures gained from the biological role models used for the previous two pavilions, the water spider investigation focused on the process-based biomimetics utilised in the construction of its subaquatic nest.

Though it evolved from terrestrial arachnids, nearly all of the diving bell spider’s life is spent underwater, and it has thus developed an ingenious technique for building a submerged fibre-reinforced pneumatic habitat, which involves laying an initial set of fibres used to trap a pocket of air, then selectively reinforcing the pocket from within with spider silk to stabilise the dynamic structure. This concept not only creates an integrated fibrous system on the minimal formwork of an air bubble, but in the context of
the ICD/ITKE pavilion the biological processes employed by the water spider could be abstracted and transferred into robotic processes for the fabrication of a fibre-reinforced pneumatic shell. The research team therefore adopted this innovative construction methodology to explore the possibility of using composite-membrane interfaces for the pavilion envelope while simultaneously eliminating the unnecessary formwork associated with traditional fabrication methods.

The water spider is able to systematically reinforce its nest through a series of fibre-laying behaviours that constantly adapt to the changing shape of the pneumatic body during construction, and result in hierarchical fibre arrangements. To transfer this process to the design strategies for the research pavilion, a computational tool was developed to embed these fibre-laying behaviours into a digital agent that could traverse and adapt to a simulated inflated membrane to create

The total construction weighs only 260 kilograms (570 pounds), and uses 45 kilometres (28 miles) of carbon fibre.

Due to the dynamic nature of the pneumatic form, an adaptive robotic fabrication setup was required that allowed pressure sensor data from the custom effector to actively adjust the fabrication process. An iterative feedback loop allowed communication between the robot and the fabrication environment.
performative fibre arrangements. A crucial difference in this process, however, was the transformation the pavilion had to undergo from an air-supported structure during construction to a self-supporting shell after release of the internal air pressure. In addition, the pavilion skin needed to be constructed from various sheets of ETFE foil. The fibres responded to these requirements by serving various purposes within the structural system, by bundling into larger structural elements in response to loading conditions and seam layout, cross-linking into a fibrous network to form a performative composite system or space-filling for membrane reinforcement. The agent-based fibre-generation model thus created a point of convergence between the biological behaviour of the water spider and a behaviour-based fabrication strategy, a process that also represents a paradigm shift from traditional instruction-based fabrication towards behavioural robotic fabrication processes.

The materialisation of the fibre-reinforced pneumatic shell required the development of a novel and adaptive fabrication strategy; like the water spider nest, pneumatic formwork has dynamic geometry that changes shape during construction. A custom robotic end-effector tool was designed to extruded fibres, matching the speed of the robotic movements while negotiating the changes in the dynamic pneumatic substructure in real time. An integrated sensor system monitored the force of the effector on the ETFE membrane while applying fibres, and a robotic sensor interface was used to adjust the robotic behaviour. This fabrication strategy provided a high degree of flexibility and adaptability, attuned to the fluctuating conditions on site, for controlled placement of pre-impregnated fibres.

The prototypical pavilion showcases the potential of a process-based biomimetic investigation for adaptive fabrication strategies for fibre-reinforced pneumatic formwork within a computational design process. It also explores a cyber-physical production approach for such biologically inspired fabrication on the large scale of an architectural demonstrator. The total construction weighs only 260 kilograms (570 pounds), and uses 45 kilometres (28 miles) of carbon fibre. Its highly articulated skin integrates the composite structure and weatherproof membrane in one system with gradient degrees of transparency and rigidity, its fibre-reinforced ETFE surface revealing a unique envelope effect and spatial experience while also enabling increased structural performance for a thin shell spanning more than 7.5 metres (24 feet).

Finite element analysis (FEA) was used to determine the principal force directions and stress magnitude of the compression shell under several load cases. The data became an input for the agent-based design tool to output informed fibre-laying paths.

An integrative computational tool was developed utilising an agent-based approach to incorporate structural analysis, fibre orientation, material connections and fabrication constraints into the generative design of fibre-laying paths.