A cut above the Eiffel Tower

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This is the lighthouse in the estuary of Dnjepr, built by Vladimir G. Schuchov in 1911. Credit: Andrij Kutnyi / Technical University of Munich

Vladimir G. Shukhov, one of the most ingenious engineers of the 19th and early 20th centuries, developed revolutionary construction techniques. The Russian engineer built lattice towers up to 150 meters high using rows of twisted, intersecting bars -- an efficient, stable and elegant construction method. An international research team is now investigating his work. Andrij Kutnyi from Technische Universitaet Muenchen was the first scientist to gain access to Shukhov-built lighthouses in the Black Sea.

During the two and half weeks spent on a tiny man-made island with two lighthouse keepers, Andrij Kutnyi had to deal with poisonous snakes and watch his drinking water supplies dwindle as temperatures soared. Yet the architectural historian took it all in his stride. He was, after all, one of the first scientists to experience firsthand an early modernist architectural masterpiece – exactly one hundred years after it had been built. The 70-meter high lighthouse and its 25-meter high front beacon still guide ships along the range line from the Black Sea to the Dnieper River and into the Ukraine. Until five years ago, the lighthouse was part of a military exclusion zone. Ukrainian-born Kutnyi was granted access just in time for the lighthouse's anniversary.

The towers' steel lattices sweep elegantly up to the sky, easily supporting the lantern rooms despite their delicate appearance. The lattice design was invented by the Russian engineer Vladimir G. Shukhov (1853-1939) in what proved to be an unprecedented move in construction history. To create his structures, Shukhov arranged two parallel groups of rods in a circle and twisted these against each other to create the hyperboloid shape and "waist" – the same shape of cooling towers today.

This apparently simple arrangement has a number of key benefits. Firstly, it only requires minimum amounts of material. For a 350-meter radio mast in Moscow, which ultimately was never built, Shukhov planned to use just 2,000 tons of steel. In contrast, around 10,000 tons of steel went into the 300-meter Eiffel Tower. Secondly, it creates a lightweight structure that is surprisingly stable. The opposing curves in the lattice structure enable it to bear major loads.

Seven years after the inauguration of the Eiffel Tower at the World's Fair in Paris, Shukhov presented the first of his towers at the All-Russia Exhibition in Nizhny Novgorod. This was followed by a veritable building boom in water towers, oil and gas tanks and transmission towers. Due to the high strength offered by Shukhov's technique, Russia and the US used it to build radio towers on battle ships. And the structures are still in use today. The recently completed Canton Tower in Chinese city of Guangzhou, which – at 600 meters – is the sixth highest building in the world, is a hyperboloid structure. "Shukhov invented one of the most intelligent and effective design principles in the history of steel construction," explains TUM architect Kutnyi. And it was not the only revolutionary idea to come from Shukhov, the chief engineer of a major construction company. He also developed suspended roof structures, arch structures and grid shell structures. In many cases, these designs were not used again until the second half of the 20th century. The roofs of Munich's Olympic stadium are a prime example. "Shukhov is one of the most important pioneers in lightweight construction," reports Matthias Beckh from the TUM Department of Structural Design. Yet his structural work has been all but forgotten in the West. The lighthouses in the Black Sea are at most familiar landmarks to ships' captains.

Therefore, the first aim of the interdisciplinary research project, which brings together scientists from the University of Innsbruck and ETH Zurich, is to identify all of Shukhov's works. The researchers have already found numerous previously unknown projects. Many towers are in an extreme state of disrepair and in danger of collapsing. Yet the extent of the damage also reveals just how strong these structures are. One transmission tower was still standing although 16 of the 40 vertical bars at the base were missing. In this case, the engineers were able to kick-start renovation work. Other structures have already been destroyed. Recently, a Shukhov structure that the researchers had only just discovered was dismantled. The engineers' hope that their research will raise awareness of these structures and increase the chances of them being preserved.

In a second phase, architectural historians at TUM intend to measure and document the structures and reconstruct the engineering processes. On his first visit to the Dnieper lighthouse, Andrij Kutnyi discovered that the construction workers used a method that dates back to medieval times. The workers made notches in the individual pieces to number them before they were raised and assembled – a technique very similar to the methods used by medieval carpenters. "This numbering is very valuable information for us. We can use it to determine the sequence in which the tower was built," enthuses Kutnyi. The engineers already know that this tower is particularly special. At 70 meters, it is the highest tower to have just one "waist", as Shukhov built his other towers in several sections, each a hyperboloid shape in its own right.

The structural engineers at TUM will also be investigating the individual factors that make the towers so stable. This includes examining the parameters that determine the shape of a hyperboloid, as well as the interplay between geometry and load-bearing characteristics. The researchers plan to test models of the towers in TUM's wind tunnel. "Nobody knows how much of an impact wind really has on these complex structures," explains Matthias Beckh. "This makes it difficult to apply conventional engineering standards." The research project could lay the foundations for a renaissance in Shukhov's timelessly elegant structures – making them ideal candidates for new transmission towers that will be needed as the world moves towards more renewable energy sources.

Provided by Technische Universitaet Muenchen