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The Bog Characters:
A New Generation of High Voltage Power Pylons

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Abstract

An international competition victory brought PART architects and Bollinger+Grohmann engineers together to develop a unique design DNA for a new kind of power pylon. This collaboration resulted in the construction of two prototypes characterised by inclined linear members and rounded connections. The projects utilise parametric modelling to embody optimised structural performance while adhering to geometric constraints and design requirements. Despite initial challenges, these custom pylons offer a viable alternative to traditional designs, pushing the boundaries of infrastructure aesthetics and functionality. This paper explores a distinct and innovative design approach towards power pylons that merges technical efficiency with architectural creativity.

Keywords: power pylon, parametric design, structural optimisation, genetic algorithms, contextual design, infrastructure

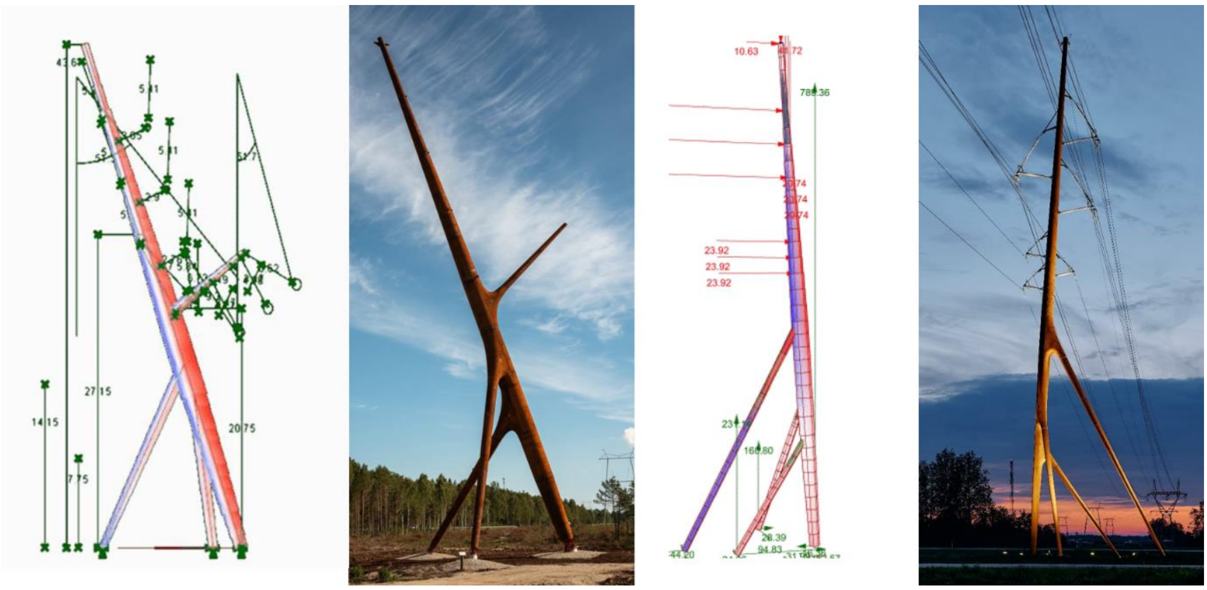

Figure 1: Left; *Bog Fox* as a model and as build structure, Rigth; *Bog Crane* as a model and build a structure with power cables [Image: Photos: Tõnu Tunnel, 3d Graphic: Bollinger+Grohmann]

1. Introduction: Rethinking Infrastructure Design

Power pylons are essential infrastructures that carry high-voltage transmission lines across vast distances. However, their design is often viewed as purely technical, with little consideration for testing new concepts or reacting to changing contexts. The few existing 'design pylons' are minimal monopoles or artistic landmarks that do not prioritise structural logic or efficiency.

In 2016, the Estonian power system operator Elering launched a competition for a unique one-off pylon design. PART architects won, sparking an interdisciplinary collaboration with Bollinger+Grohmann engineers. This partnership resulted in a new structural design DNA for power pylons, with two built examples and a third in development.

2. Architectural Competition

The Estonian Harku-Lihula-Sindi power line, with its three 110kV and three 330kV power phases, is crucial for energy security. It connects to Latvia, aiding the Baltic region in reducing its dependence on Russian energy and integrating with Central European and Scandinavian markets. Additionally, it supports renewable energy production in Western Estonia.

Energy transmission is a central issue in modern environmental discussions. Although electricity networks offer a cleaner alternative to fossil fuels, the construction of power lines often faces community opposition. The challenge is to make infrastructure projects more acceptable or even welcome, as suggested by The Economist's "Hug pylons, not trees" campaign. Rather than hiding these projects, we need to integrate them thoughtfully into communities and landscapes.

The Bog Fox pylon site is on the edge of the Kuistlema bog, a nature reserve, minimising disruption to nearby settlements. The goal was to create a distinctive and captivating structure that serves as a landmark for the Risti community and a gateway for Lääne-Nigula County.

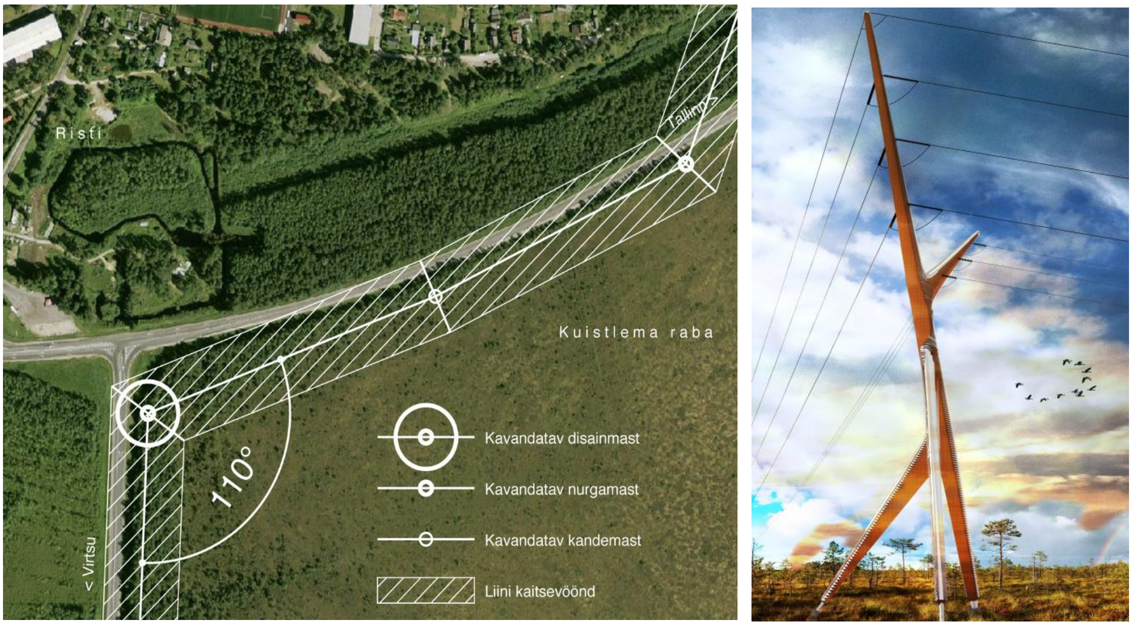

Figure 2:
Power line route corridor, location of the line towers and the designed power pylon, and the turning angle of the route [Kuistlema Bog] right: *Bog Fox* competition entry PART architects — timber structure with partial metallic skin for protection. [Image: PART Architects]

3. Design Philosophy

The design philosophy centred on integrating architecture, engineering, and contractor input to achieve the best outcome. Initially, the team aimed to construct the pylon using timber, minimising the number of elements to avoid moisture issues at joints. Consequently, a decision was made only to use four linear elements that could be prefabricated and assembled on-site. The rest was straightforward: at least three non-collinear elements with pinned connections to the ground were needed for a stable structure.

3.1. Version 1 – *Bog Fox*

3.1.1. Main Member & Inclination

The competition brief specified parameters such as maximum height, bounding box, footprint, cable clearances, and minimum height for the lowest cable point. The 45-meter maximum height was set by aviation regulations. The *Bog Fox* is a corner pylon with a 70-degree turn, resulting in a permanent sideways pull from the cables. This necessitated an inclined main shaft to balance form and force.

3.1.2. Legs

The legs were designed not to join at a single point but to shift these points apart, simplifying the geometry and allowing for easier transportation.

3.1.3. Smooth Transition

Smooth, thickened transitions between elements enhanced the structural connections by providing additional overlap areas for bolts in a timber version, giving the Bog Fox its distinctive organic and branching appearance.

Figure 3:
Assembly and erection process during construction [Image: Estfilm, Lauri Nagel]

3.1.4. Arm & Cable Attachments

With a minimum 5-meter cable clearance between electrical phases, placing all six phases (3x 330 kV phase wires and 3x 110 kV phases) on the main shaft would have required an additional 12 meters of shaft length. This extension would push the total pylon height beyond its height restrictions and place the lowest attachment point below the minimum height of 20 meters.

To address this issue, an extra arm was incorporated to maintain the necessary clearances for all power phases without exceeding the height constraints. This solution provided more space and flexibility for cable distribution, allowing room to explore various arrangements within the system.

3.1.5. Material

After carefully reevaluating various material options, weathering steel was chosen for its durability and ease of construction. The pylons are constructed using tapered circular hollow sections welded from rolled plates of weathering steel. A key feature of weathering steel is its ability to form a protective rust layer, known as "useful corrosion," which prevents further deterioration and reduces maintenance needs. This natural rust patina protects the structure and enhances its aesthetic, allowing the pylons to blend more harmoniously into the rural and forest landscapes.

Figure 4:
Transportation of individual pylon segments [Image: ©Estfilm, Lauri Nagel]

3.2. Structural Design Optimisation

All project parameters and relationships, like inclination, cable points and distances, height constraints, and leg points, were built into a parametric model that allowed for flexible exploration of various geometric configurations.

To find the optimal configuration, a genetic algorithm was deployed that mimics principles from nature and evolution in a simplified way. The algorithm controls the model by moving individual axes' start, end and connection points. Variations in inclination, leg position, member lengths, and point spacing affect the mast's load-bearing behaviour.

Karamba3D, a structural finite element calculation plugin, was employed to analyse the geometry based on given cable loads and associated load cases. Throughout this process, an integrated calculation routine optimised the sizing of cross-sections for each beam segment according to their present stresses and forces.

Octopus, a genetic algorithm for *Grasshopper*, ran through hundreds of form variations in search of an optimal structural solution. In doing so, it pursued solutions with better "fitness values," such as deformation, utilisation, and steel weight. The optimisation routine led to a structure with the smallest possible weight and a balanced system that embodied all necessary geometric constraints.

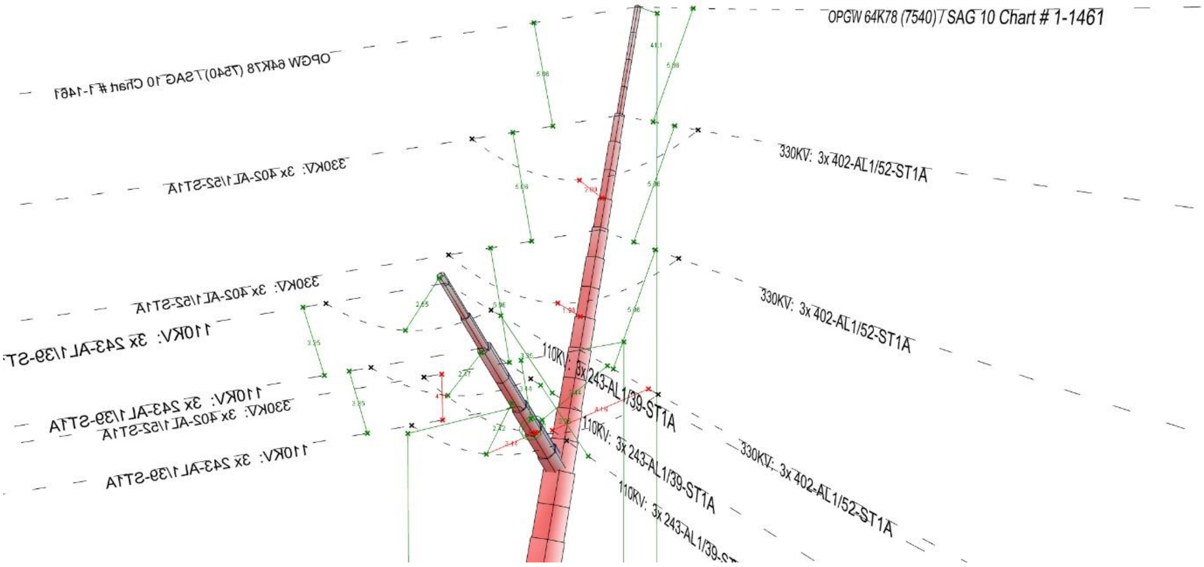

Figure 5:
A parametric model with geometric constraints and structural cross-section optimisation. [Image: Bollinger+Grohman]

3.3. Version 2 – *Bog Crane*

After receiving positive feedback from various sources, including national and international recognition and support from local communities, the client decided to embark on a second project focused on creating a carrying pylon.

The first pylon, *Bog Fox*, effectively utilised its corner geometry. Allowing all electrical wires to cut the corner maintained sufficient clearance between the phases and the structure, enabling a simple organisation of all high-voltage cables around the structure.

However, a carrying pylon with a straight-line routing does not benefit from such geometric advantages. This necessitated exploring alternative attachment methods and electrical insulator details to ensure the cables could be connected without interfering with the structure while maintaining necessary clearances.

To achieve this, special isolator elements were connected with laterally positioned V-shaped extension beams, meeting all inclined mounting points of the electrotechnical components. The connection points were arranged in a zig-zag pattern on alternating sides, ensuring safe distances and creating a more compact cable configuration along the main shaft.

Figure 6:
Attachment details of electric isolators and V-shaped mounting points [Image: PART Architects]

Despite the absence of asymmetric loads from cables, the analysis revealed that inclining the main member slightly towards the support legs resulted in shorter legs, slightly balanced load distribution, and improved structural performance. An additional leg element was introduced on the bottom to further limit deflections at the top by stabilising the structure further.

Instead of replicating the original Bog Fox design as initially intended by the client, the second pylon project, Bog Crane, adopted a modified approach. This resulted in a streamlined version with half the steel weight, demonstrating that unique solutions tailored to specific locations can be achieved by applying and adapting design principles. This approach maintained design consistency while optimising the overall process with each iteration.

4. Conclusion - Adaptability, Variety & Versatility

Despite their simplicity, the bog pylons—composed of a few inclined linear elements—offer a versatile and effective structural scheme. The underlying design logic can be adjusted to create various types of power pylons, each tailored to serve different functions within the power grid and specific contextual requirements. Variables such as orientation, inclination, thickness, height, distances, and the potential to add extra members allow for extensive customisation and problem-solving.

Improvements in automating the parametric design process enable the rapid development of new power pylon types and design possibilities. Ongoing research into this unique structural design language continues to expand its range of applications. Parametric computational design tools are essential for facilitating fast and flexible automated customisation while adhering to established rules and incorporating new requirements for specific contexts.

Rather than viewing the *Bog* pylons as mere design objects, they should be seen as a scalable design DNA adaptable to specific needs. Much like Greg Lynn's Alessi tableware, where using the right tool for the job is essential, these pylons demonstrate that unique and effective solutions can be achieved through tailored design. This approach has led to the development of a new generation of distinctive high-voltage pylons, with a third iteration underway and a fourth in the planning stages. As a family, these pylons could serve as models for future infrastructure projects, showcasing the potential for adaptable and versatile design solutions.

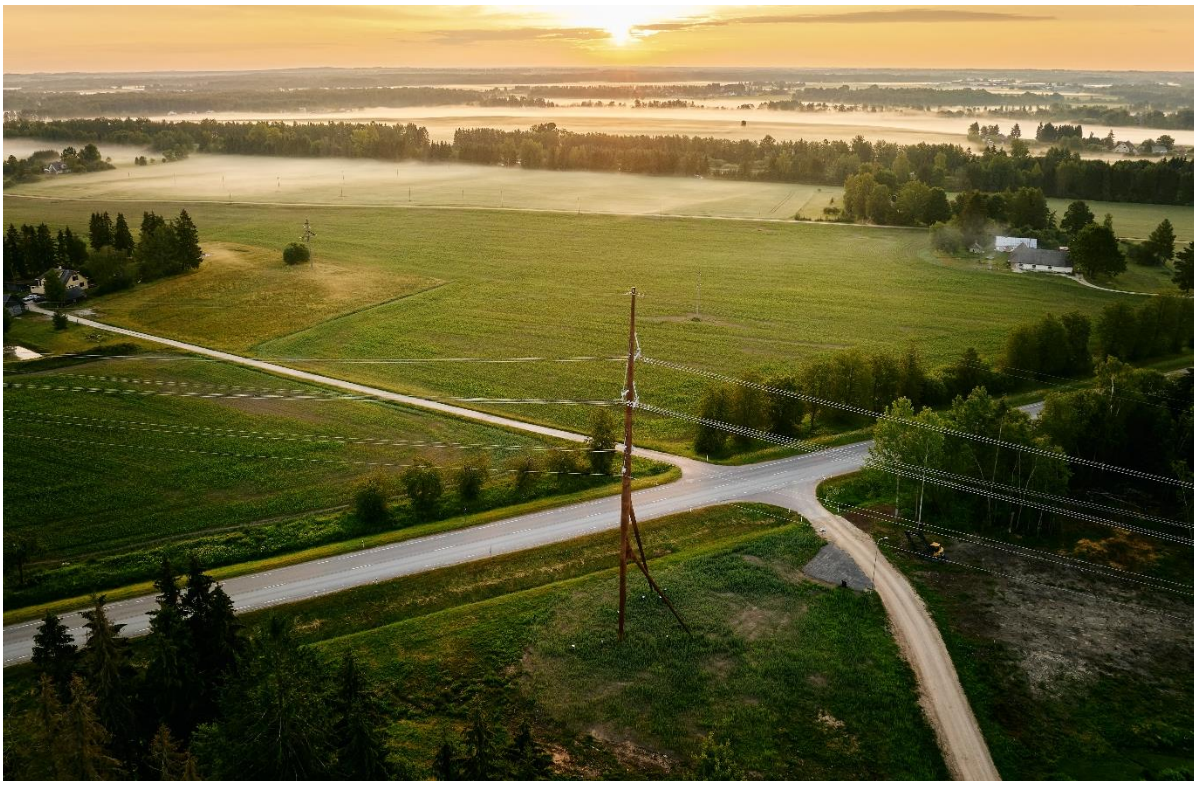

Figure 7:
Bog Crane, a prototype for a carrying pylon that is carrying 3x 330kV phases, 3x 110kV phases and 2x earth wires [Image: Tõnu Tunnel]

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