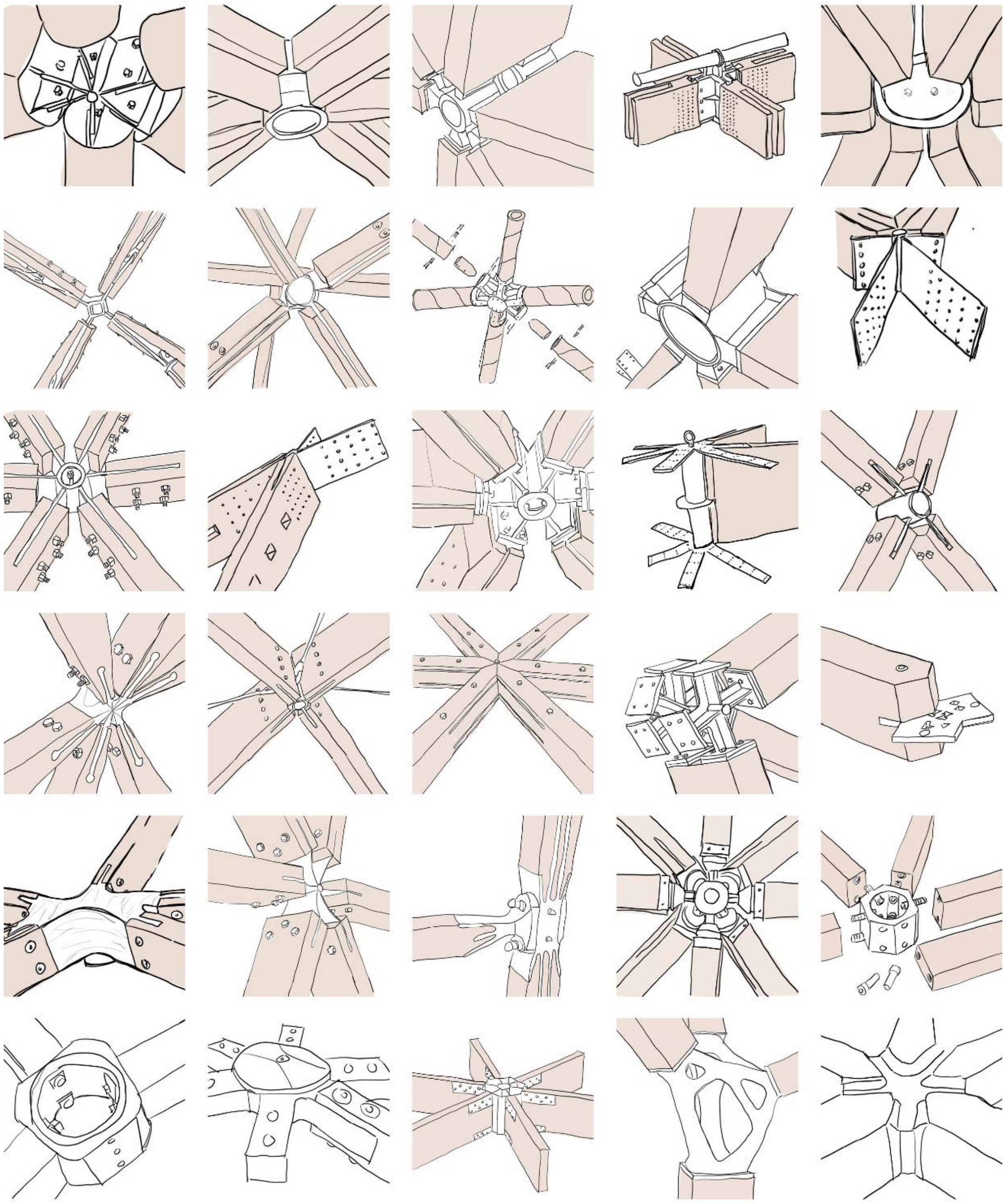

Figure 1. 30 nodes from built projects, authors drawing

Category: paper

Nodes

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This PhD-project studies the design of structures consisting of nodes and members connected at the nodes. More in detail, it explores timber gridshells with aluminium nodes. The project aims to shed light on design options and provide proposals for explicit design to inspire further exploration of shell structures bridging architectural and structural concerns. A substantial part of this project is to design and develop new node principles. In this paper a framework of built gridshell nodes is presented, categorizing the main parts of the nodes. Building on this, a selection of node-principles that are not found in the framework is deducted and drawn as design proposals. The following paragraphs describes the technical and theoretical background of gridshell nodes and discusses their aesthetic or tectonic potential.

Gridshells can be slender and material-efficient structures with variation in spans and forms. They can be constructed with visually interesting patterns that together with the detailing and materials explain the structural behavior of the architectural forms. There are at least three types of gridshells. *Smooth*, where members are pre-curved and connected with nodes or lab joints. *Kinematic*, where the members are bent into shape. And *discrete*. In general, a discrete gridshell is made from two main parts: members, straight with varying lengths, and nodes that connect the members. Design of gridshells relies on good collaboration between the disciplines of architecture, engineering, and manufacturing. Decisions on shape, topology, and cross-section, together with the node design are all interconnected and play a huge role in how a gridshell works as structure, how it appears visually and how it is manufactured. (Chilton and Tang 2016). In terms of digital design of gridshells, the members are usually modelled with a discrete mesh segmentation or a subdivided NURBS-surface, where the “mesh edges” or “sub-division lines" represent the members, coupled with form-finding and optimization methods.

Nodes are key elements in a gridshell regarding structural performance as well as costs, assembly, and visual appearance. To save manufacturing costs, it can be crucial to use bulk materials for manufacturing. Proprietary node-systems often combine mass production or bulk material, with customization through machining or welding. Bulks can come from profiles (cylinder, tube, or rectangle), castings (spheres, cups or plate-like), or plates (*thick*, with thickness as tall as the member height, or *thin*, typically one machined plate or several pieces welded together). The node can be considered consisting of two main parts: (1) a kind of "gripper" connecting the timber member to the node-element, and (2) the "core of the node" where the geometry of the members connected by the node meet. Due to conditions and preferences for manufacturing and assembly, there are many design options for these two parts. Nodes which are quite straightforward to design and manufacture are “splice-nodes”, typically a hollow cylinder with welded vertical splices and bolts, however, this often results in gaps where the members meets the cylinder and/or a cylinder proportionally large compared to the members, which may not be visually appealing.

As described, gridshell nodes are about joining materials. When discussing the links between materials, structure, and shape from an architectural point of view, “tectonics” has become a keyword. The origin of the term is Greek, where *téktōn* means a carpenter, joiner, or builder (Frampton 1995, 3). Through the history of architectural theory, the term has later been used in somewhat different meanings. Gottfried Semper describes the four technical arts, where tectonics, an art which originated in timber carpentry, describes the art of assembling stiff, plank-like elements into a rigid system (Semper 2004, 623). According to Semper, the joint, or knot, is the oldest and most original construction part (Semper 2004, 219), and it is out of the connections that the beauty of architecture emerges. Kenneth Frampton uses tectonics in a more general meaning, describing a kind of approach to architectural design which is also is a qualitative property (Frampton 1995). According to Frampton, tectonic can be a way to reveal the essence of a building and a structure should therefore be logical and understandable. To archive this clarity, an articulation of the joints is crucial.

In short, tectonics is about exploiting qualities embedded in the different materials and combining and connecting parts and materials in interesting and meaningful ways. Different materials can represent interesting contrasts where the one strengthens the characteristics of the other. While timber can be characterized as natural, soft, and warm by color as well as by tactility, aluminium represents an industrialized precision that can appear in many ways, ranging from sharp and shiny to round and smooth. This project works with the tectonics of gridshells, expressing the structural system as well as the different materials. Gridshells are by default readable structures, consisting of almost pure structure. Gridshells with timber members and aluminium nodes possess a huge potential for tectonic articulation. And the node, the joint that binds the parts together, is key to the appearance of any gridshell.

Design Driven Research

This PhD projects work is described as a kind of research by design, which can be explained as the general concept of producing new knowledge through the act of designing (Hauberg 2011, 51-52). The output in research by design can be the object itself, but in this case, the main output and purpose is the knowledge gained through designing. A realistic design task is needed to study the competing issues of aesthetics, structure, manufacturing, and assembly in the design of gridshell nodes. Therefore, several cases are selected for exploring gridshell nodes. Smaller pavilions and theoretical cases are used, but as the main case, a known building is selected, more precisely, the roof covering the British Museum Great Court completed in 2001. The method consists in examining the steel gridshell-structure of British Museum redesigned by the combination of timber members and aluminium nodes. The overall shape, grid-member-dimension, and particularly the nodes and the connection between node and member will be examined. Nodes are examined with focus on the aesthetic and tectonic potential, as well as structural integrity, manufacture, and assembly, as described in the main section.

Repeated nodes, like in a geodesic dome, can be drawn manually, but when it comes to free form gridshells, manual drawing of nodes is very inefficient. Instead, the relations between nodes and members in a free form gridshell should be established digitally. A digital parametric design workflow handling these geometric relations are more efficient and expedient and the chosen framework for this is through visual programming in Grasshopper.

Keywords_ Gridshell, Nodes, Joints, Tectonics

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