Digitally fabricated active-bending beams for the rapid assembly of temporary structures

Conference Paper · September 2018

2 authors:

Efilena Baseta
TU Wien

Klaus Bollinger

Digitally fabricated active-bending beams for the rapid assembly of temporary structures.

Efilena Baseta, Klaus Bollinger, University of Applied Arts Vienna, Austria /

Introduction

The construction industry has not exploited the full potential of the new technologies that the digital era offers. Thus, construction remains a labour intensive task. Focusing on transportable, temporary structures, such as tents, an efficient construction method is active-bending. This method exploits the elastic bending of thin elements in order to create curved forms. Nevertheless, the bigger the desired curvature, the smaller the cross-sectional height should be. This results to lower stiffness of the final structure due to the slenderness of its parts. In order to solve this problematic, research has been conducted on hybrid active bending structures. In the latter structures, additional elements, such as membranes and cables, are combined with the bending elements in order to stabilize them and increase their stiffness (Gengnagel et al., 2013). This technique has been proven possible for up to 30 m span structures. However, the installation process can become complicated since an equilibrium of forces needs to be achieved (Lienhard; Knippers, 2013). Besides that, the structural calculations of the aforementioned systems can be intricate.
Given the above, the presented research proposes an alternative construction system for temporary structures based on active-bending. The aim is to create an independent relation between the maximum curvature and the stiffness of such structures, relying on digital fabrication techniques. Past research, ZipShape, had focused on the materialization of curved geometries through digitally fabricated constrained systems (Schindler, 2008). However, its assembly and scalability have been proven intricate. In addition, ZipShape aimed for fixed final geometries, rather than transformable ones. On the contrary, the aim of this research is to create a system that facilitates the erection and the reusability of temporary structures.

Research

The proposed system is a multi-layered beam which is flexible when it is flat, and thus susceptible to deformations, and stiff when it is bent on a predefined curvature. The flexibility relies on the relative slip between the layers, while the final increased stiffness relies on the constraining of the slip. This simple principle has been materialized by introducing gaps between the joinery details of two consecutive layers. By differentiating the gap lengths, the curvature of the final stiff curvature can be controlled. One locking point per beam, where all the layers are fixed, is required in order to facilitate the slip towards the correct direction. From the above becomes apparent that the more the layers of the beam the stiffer the final bent shape becomes. Thus, scalable linear elements can be constructed flat and easily assembled in a curved configuration. By removing the boundary conditions, the element returns to its flat configuration. The reversibility of the elements allows for applications in temporary gridshell structures (Baseta et al., 2018).
The behaviour and the functionality of the system depend on the joinery detail between the consecutive layers. In this paper, two main geometries will be presented: a) the zig-zag and b) the rectangular. The zig-zag detail allows controlled bending in one direction and unconstrained bending in the other direction. On the contrary, the rectangular detail, allows controlled bending in one direction and constrains bending in the other direction. Variations of these two types can lead to structural optimization of the detail, such as rounding corners and increased contact area. Moreover, the distribution pattern of the joinery detail along the element can increase the structural performance, optimizing the fabrication time. (Fig. 1)
Current research proves that fibre composites, as well as metals, are the most appropriate materials for bending active structures (Kotelnikova-Weiler et al., 2013). Wood, as a natural fibre composite, has been chosen for this research as a low-cost solution with sufficient structural performance. Various tests and prototypes, with various cross sections, have been conducted to prove the functionality and scalability of the proposed system. For the fabrication of the aforementioned prototypes, CNC milling with two different machines have been explored: a) a Kuka robot for the small cross sections (15x20 mm), and b) a Hundegger K3 for the larger cross sections (40x60 mm).
The fabrication with the Kuka robot allows the machining complicated details. For the tests of this research, a milling bit of 6 mm diameter was used to mill laths mounted on a wall. This resulted in filleted corners for the zig-zag specimens where the laths were milled from the sides. However, sharp corners were achieved at the rectangular specimens where the laths were milled from the top. A further limitation for the specific fabrication setup was the maximum length of milling which equals the radius of the robot (approximately 3 m). It has been noticed that the quality of the milling depends on the cantilevering of the robotic arm. (Fig. 2)
The fabrication with the Hundegger K3 was challenging and aimed to prove the potential of the mass production of the proposed system. The beams with the zig-zag detail were initially milled from the bottom. Their production process was problematic and resulted in breakages when the beam was cantilevering inside the machine. In order to reduce the vibrations, two beams were milled simultaneously from both sides of one bigger beam. The latter beam was subsequently sliced in two pieces with an electric saw. The incompetence of the K3 to clamp the zig-zag beam resulted in bad finishing and inaccuracies. However, the beams with the rectangular joinery detail were produced smoothly with a good finishing. (Fig. 3)
Two gridshell prototypes, produced with the aforementioned fabrication techniques, have been conducted; one suspended and one cantilevering. Both prototypes have been fabricated from flat elements with equal cross sections and have been shaped into double-curved surfaces by uniform gravitational loads. (Fig. 4)

Conclusion

In conclusion, the proposed multi-layered beam allows the creation of bending-active structures with controlled stiffness, without limiting the maximum curvature and without the addition of external elements. The behaviour of the system depends exclusively on the geometrical configurations of the joinery details and the material properties. Thus, curved beams can be easily erected from flat elements, since the construction manual is embedded in the joinery details. Two CNC milling process have been used for the digital fabrication of wooden laths and obtained accuracy of the scale of a millimetre. The gridshell prototypes proved the controlled deformation of the double-layered active-bending elements, as well as the scalability of the system. Further steps of the research include the realization of a temporary larger scale gridshell structure which consists of industrially fabricated elements.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 642877. The fabrication with the Hundegger K3 would not have been possible without the support from the Blumer Lehmann AG (Gossau, Switzerland) and its leaders Kai Strehlke and Martin Antemann. The fabrication with the Kuka robot was part of the course 'Digital Design and Full Scale Fabrication '17' in the University of Applied Arts Vienna. Philipp Hornung representing the Angewandte Robotic Lab and the Wood Technology Laboratory led the robotic fabrication.

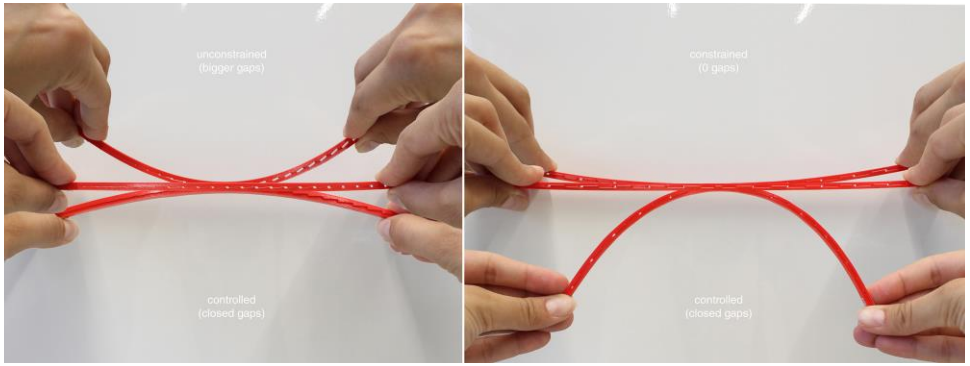

Fig. 1: Bending behavior of linear element with zig-zag (left) and rectangular joinery details (right).

Fig. 2: Fabrication with Kuka robot. Top: zig-zag detail; Bottom: Rectangular detail.

References

Gengnagel, Christoph; Alpermann, Holger; Lafuente, Elisa: Active Bending in Hybrid Structures. In: Günther H, Filz; Rupert, Maleczek; Christian, Scheiber (ed.): FORM – RULE | RULE 2013 – FORM. Innsbruck 2013.

Lienhard, Julian; Knippers, Jan: Considerations on the Scaling of Bending-Active Structures. International Journal of Space Structures, 28 (3-4), 2013, pp. 137-148.

Schindler, Christoph: ZipShape - A Computer-Aided Fabrication Method for Bending Panels without Molds. Proceedings of the 26th eCAADe - Architecture 'in computro' - Integrating Methods and Techniques. Muylle, Marc (ed.). Belgium 2008, pp 775-782.

Baseta, Efilena; Preisinger, Clemens; Antemann, Martin; Strehlke, Kai; Bollinger, Klaus: Geometry-induced variable stiffness structures. Proceedings of the IASS Symposium 2018 - Creativity in Structural Design. Sigrid, Adriaenssens; Caitlin, Mueller (ed.). Boston 2018.

Kotelnikova-Weiler, Natalia; Douthe, Cyril; Lafuente, Elisa; Baverel, Olivier; Gengnagel, Christoph; Caron, Jean-François: Materials for Actively-Bent Structures. International Journal of Space Structures, 28 (3-4), 2013, pp. 229-240.

Fig. 3: Fabrication with Hundegger K3. Top: zig-zag detail; Bottom: Rectangular detail.

Fig. 4: Gridshells formed by gravitational loads. Left: Suspended; Right: Cantilevering.

Keywords

Active-bending, Digital fabrication, Flexible wood, Wood joint systems, Temporary structures.

Biography

„Efilena Baseta is an Architect Engineer, studied at the National Technical University Athens, with a Master degree in Advanced Architecture from IAAC. Since 2014 Efilena is a co-founding partner of Noumena, a multidisciplinary practice that merges architecture with technology. During 2015-2016 she collaborated with IAAC as the coordinator of the Visiting Programs. Efilena is currently a Marie-Curie researcher at the University of Applied Arts Vienna.“

www.noumena.io

„Klaus Bollinger has studied Civil Engineering at the Technical University Darmstadt. Since 1994 he has been assigned Professor for Structural Engineering at the University of Applied Arts at Vienna. In 1983 Klaus Bollinger and Manfred Grohmann established the practice Bollinger + Grohmann. The office provides a complete range of structural design services for clients and projects worldwide.“

www.bollinger-grohmann.com