Modern timber design approaches for traditional Japanese architecture: analytical, experimental, and numerical approaches for the Nuki joint

Demi FANG*[a], Julieta MORADEI[b], Jan BRÜTTING[c], Aliz FISCHER[b], Daniel K. LANDEZ[a], Benshun SHAO[b], Nick SHERROW-GROVES[b], Corentin FIVET[c], Caitlin MUELLER[a]

[a] Massachusetts Institute of Technology (MIT), Cambridge, MA, USA
*Corresponding author: dfang@mit.edu
[b] Arup, San Francisco, CA, USA
[c] Swiss Federal Institute of Technology (EPFL), Fribourg, Switzerland

Abstract

The use of timber in modern structural systems has increased worldwide in recent decades. However, mass timber connections are dominated by steel fittings and fasteners. Conversely, historic timber structures use timber-only joints characterized by their interlocking geometries, called joinery connections. These joints have historically demonstrated the potential for rapid construction and deconstruction for sustainable design. However, investigation on the widespread applicability of these historic joints in modern construction is limited. Existing analyses of joinery connections typically involve one or two of analytical, experimental, or numerical approaches for a single joint. A systematic assessment of the joints' structural performance, verified across all three analysis approaches, remains to be documented for a variety of joint types and geometries.

This paper builds on two previously separate research initiatives from Fang and Mueller [1] and Moradei et al. [2], both presented at the 2018 IASS Annual Symposium. As a first step in this long-term collaborative effort to document the structural behavior of joinery connections, this work fully investigates a single joint geometry via analytical, numerical, and experimental methods. The selected joint is the *Nuki* joint (Fig. 1), a simple mortised column with through-beam tenon. The analytical approach builds on state-of-the-art embedment stress models, while the experimental approach takes advantage of digital fabrication to reduce variations introduced by hand fabrication. Results from both approaches are used to calibrate the non-linear finite element model and analysis of the connection. Furthermore, the difference in behavior between prototypes of various beam thicknesses (B_w) is examined to calibrate across analysis approaches. This work not only sets out a workflow for digital fabrication, physical testing, and structural analysis for more complex joinery geometries, but also discusses the challenges and relevance of its application towards a reference library of joinery connections for modern timber construction.

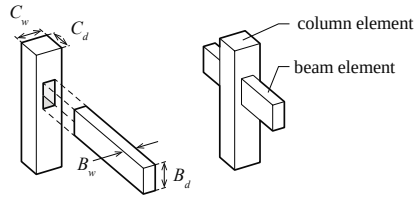

Fig. 1. *Nuki* joint with parametric dimensions.

References

[1] D. Fang and C. Mueller, "Joinery connections in timber frames: analytical and experimental explorations of structural behavior," in *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium*, Cambridge, MA, USA, 2018.

[2] J. Moradei, J. Brütting, C. Fivet, N. Sherrow-Groves, D. Wilson, A. Fischer, J. Ye, and Cañada, "Structural Characterization of Traditional Moment-Resisting Timber Joinery," in *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium*, Cambridge, MA, USA, 2018.