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# EASILY CONSTRUCTABLE BAMBOO FOOTBRIDGES FOR RURAL AREAS

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## 1. Introduction

The present study investigates an original approach for sustainable footbridges in rural and underprivileged areas assembled out of prefabricated bamboo members. Bamboo is a natural material with excellent mechanical properties and in abundance in many parts of the world, particularly in many areas of interest. Additionally, bamboo structures are eco-friendly and align with the goal for green and sustainable development. However, in the construction industry, the usage of bamboo culms is still limited, mostly because of the shortage of design codes and standards.

The proposed bottom-up approach aims to empower local communities (similarly with) offering a design solution that it is easily constructible and scalable. In a nutshell, the present study proposes "Do-It-Yourself" (DIY) bamboo footbridges mimicking the "IKEA" paradigm. Thus, the proposed footbridges can be assembled by non-experienced personnel from (pre-fabricated) full culm structural members and steel connections following simple instructions. The present study reports the first phase of this research which concerns the design, prototyping and experimental validation of (full-scale) bamboo footbridge models. A particular objective of this paper is to highlight the challenges of the design and the construction process, and to identify points that merit further research.

## 2. Structural Design and Building Codes of the proposed bridge model

The structural system of the proposed bamboo footbridge is a well-documented Pratt truss braced at both upper and lower levels (Fig. 1). From the standpoint of this research this structural form offers the following advantages: (i) simple and easy assembly, (ii) modular structure, and (iii) lightweight structural members. The three-dimentional ful-culm bamboo connections are realized with steel plates, stud bolts, nuts, and washers (Fig. 1b,c). The main advantages of the proposed connections are that: (1) they are of measurable quality and offer a high level of reliability, and (2) they accommodate the natural irregularities of the geometry of the bamboo culms along the circumference (e.g. in terms of the shape of the section, the diameter and the thickness) but also along the culm (deviations from the straight line). To improve the resistance of the bamboo culms to lateral crushing near the connection areas, the ends of the bamboo culms are filled with mortar. Subsequently, in order to increase the resistance of the bamboo culms against splitting, and to reduce splitting cracks, steel hose clamps are selectively installed at the connection areas, to provide confinement.

This study uses culms of two bamboo species, namely Bambusa Pervariabilis (or Kao Jue) and Phyllostachys Pubescens (or Mao Jue). Both of the physical and the mechanical properties of the bamboo used are specified through a series of tests in the Structural Engineering Laboratory of HKUST.

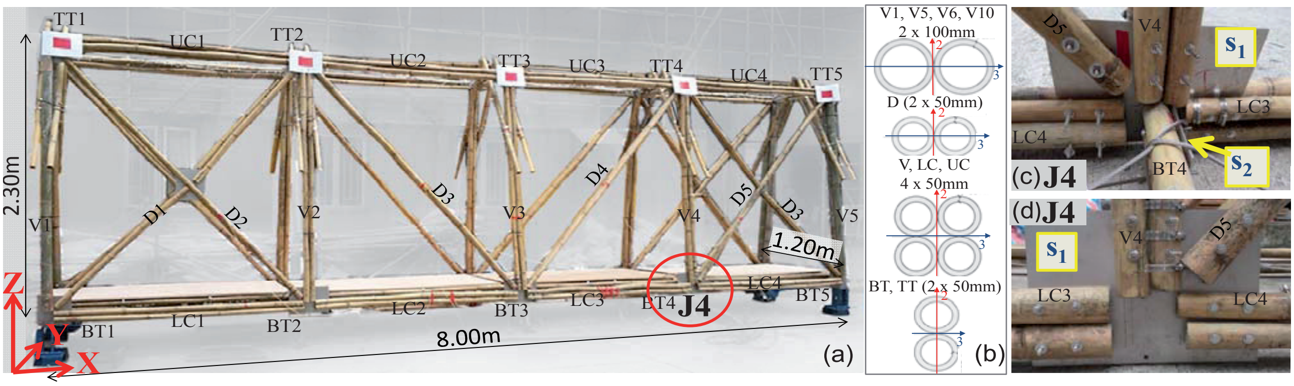


*Fig. 1. (a)The physical model of the proposed footbridge, (b) the orientation of the bamboo sections, (c) the inside view, and (d) the front side view of the of the proposed connection at J4.*

In the absence of more specialised codes for bamboo footbridges, this study defines the applied loads based on the specifications of Eurocodes 1 and 0 for the actions on footbridges, and the load combinations, respectively. The member verifications and the design checks follow the Building Code of Colombia, since it is one of the few codes globally that include rules and provisions on the use of bamboo as a building material. Due to the lack of designing codes for full-culm bamboo connections, the design of the bamboo-to-steel plates connections through stud bolts follows Eurocode 5, which provides specifications on the design of bolted timber-to-steel connections. The design of the steel parts of the connections is based on Eurocode 3.

## 3. Experimental tests of the proposed bridge models and assessment of the design

This study examines experimentally and numerically the performance of the proposed footbridges under vertical loading. The construction process can be divided into two stages: (i) the prefabrication of the bamboo culms, and (ii) the assembly of the bridge. The assembly of the prototype was completed within a single day without the use of machinery or substantial experience in construction to ensure the simplicity of the construction process.

Two full-scale prototypes (i.e. models A and B), are built and tested. The performance of the prototypes was monitored by LVDTs and strain gauges placed along the culms. For the validation of the experimental results we perform sequential static numerical analyses of models A and B. In general, the analytical results are in good agreement with the experimental measurements for the elastic range of the response. In model A, the total loading of 11.62kN is applied. Under full loading, model A suffered no damage, and reached a maximum vertical deflection of 10.8mm. The model B, collapsed under a total vertical load of 20.5kN. Ultimately, the failure of the bridge is due to the failure of the bamboo culms at the joints.

## 4. Conclusions

The present study investigates an original solution for green and sustainable footbridges as a remedy to the overwhelming lack of bridges in the underprivileged world. The present study focuses on the design, the construction, and the experimental validation of simple truss bamboo bridges, and it brings forward several important knowledge gaps in the design of bamboo structures.

The experimental testing of full-scale prototypes reveals the importance of safe and reliable connections. The dominant failure modes of the examined steel-to-bamboo connections are splitting perpendicular to the (bamboo) fibers and sliding of the bolts along the bamboo culms. The formulas that estimate the load-carrying capacity of the steel-to timber connection with bolts, cannot predict the splitting failure of the bamboo members. On the contrary, the tensile opening stresses perpendicular to the fibers developed herein at the critical bamboo culms can be validated from the corresponding dowel-bearing tests. The results show that hose clamps provide substantial radial confinement to the bamboo cross-section, preventing the splitting and increasing the load-carrying capacity of the bamboo members. The development of reliable full culm bamboo connections however, beckons for further experimental and theoretical research.