12th World Bamboo Congress

Taiwan, 18-22 April, 2024

www.worldbamboo.net

Augmented reality application in bamboo construction: The case study of "Kepiting Bamboo"

Kristof Crolla*, Garvin Goepel

Building Simplexity Laboratory, The University of Hong Kong, Department of Architecture, Hong Kong SAR

Abstract

"Kepiting Bambu" is a bamboo architecture project that was built in the Balinese jungle in the spring of 2023 as part of a bamboo build & design course hosted at Bamboo U. It involved the construction of two experimental permanent dormitory structures that explore the integration of augmented reality (AR) technology into bamboo craft and construction, expanding the practical solutions available for local builders. The objective of the design research case study was to optimise construction processes through the use of a novel notational system that allowed onsite collaboration by both experienced bamboo craftspeople and novices. This paper highlights the role of AR in facilitating efficient communication and enhancing craftsmanship throughout the construction process. The workshop's methodology includes AR in all construction and fabrication sequences without the use of any conventional 2D annotations. The article discusses the successful integration of AR technology into the construction process, enabling rapid adaptation by local craftspeople. The collaborative learning environment and the ease of technology integration were notable outcomes. While some participants initially pursued hyper-precision, AR's suitability in accommodating bamboo's natural variability and non-standard geometries became evident. The project demonstrated that AR is invaluable for tasks involving irregular patterns, making non-standard design solutions practically achievable in reality. This workshop exemplifies how technology can enhance traditional craftsmanship and open new possibilities in bamboo architecture design.

Keywords Extended reality-based construction, Augmented Craft, Bamboo, Bending-active shell structures, post-digital

**Corresponding Author: Kristof Crolla, Building Simplexity Laboratory, The University of Hong Kong, Department of Architecture, Hong Kong SAR*

1. Introduction

Kepiting Bambu

"Kepiting Bambu", or "Bamboo Crab" in Balinese, referring to the projects' particular roof geometry, consists of two permanent dormitory structures that were built in Bali's jungle in 2023 as part of a bamboo construction workshop conducted at Bamboo U (see Figure 1 and 2). The workshop focussed on the integration of augmented reality (AR) technology in bamboo craft and construction to expand its locally practically feasible solution space. The workshop aimed to expose participants to the possibilities this opens up for bamboo architecture design. The workshop's objective was to optimise and test the construction processes of the pre-designed geometries by providing easily understandable construction information to both expert bamboo craftspeople and participants with no prior experience in bamboo construction. This paper summarises the key aspects and findings from the workshop and highlights the role of AR in achieving efficient communication and the enhancement of craft.

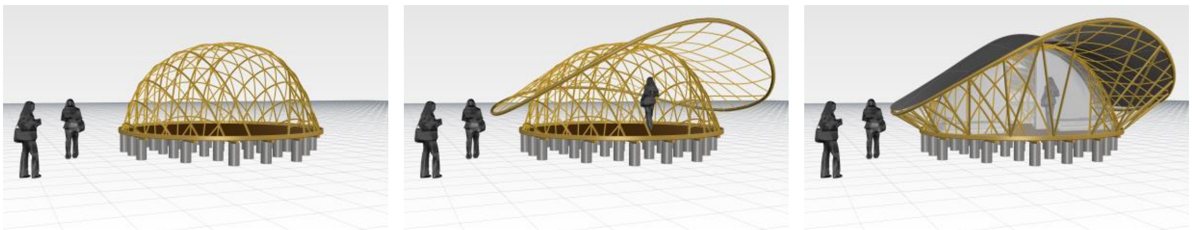

Figure 1. Project design and installation sequence, incorporating two equidistant bending-active bamboo grids made from bamboo splits

Figure 2. Completed main structure of one dormitory unit.

2. Background

Mixed Reality (MR), as conceptualized by P. Milgram and H. Colquhoun in 1999, establishes immersive environments where real and virtual elements coexist (Milgram and Colquhoun 1999). As articulated by X. Wang, Augmented Reality (AR) extends reality by seamlessly incorporating virtual spaces into the physical workspace, allowing users to store and interact with digital content within their real surroundings (Wang 2009). Wang and Dunston further emphasized that AR enhances the user's real-world view by leveraging their visual and spatial abilities, in contrast to Virtual Reality (VR), which immerses users entirely in computer-generated virtual worlds (Wang and Dunston 2006). VR and AR occupy opposite ends of the spectrum, with VR creating wholly virtual environments and AR merging computer-generated 3D models with the physical context while preserving the user's awareness and ability to interact with reality (Jahn et al. 2018). Despite widespread discussions within the research community about the potential of AR, its integration and adoption in architectural design have been sluggish. One contributing factor is the scarcity of powerful, readily accessible, and adaptable tools. This bottleneck began to loosen with the emergence of hardware products like Microsoft's 2016 HoloLens (Kipman 2016), originally envisioned for gaming and entertainment but later repurposed for engineering, construction, and design applications in the second-generation HoloLens (Microsoft HoloLens 2019). Similar to the introduction of smartphones in 2007, these innovative open-ended hardware devices preceded several years of application development to fully realize their potential. This study aims to explore the potential and possibilities of integrating AR/MR technologies into the construction of non-conventional architecture, with a specific focus on bamboo. The authors thereby combine gained knowledge of their bamboo projects such as the ZCB Bamboo Pavilion, constructed in Hong Kong in 2017 (Crolla 2018, 2017), a bamboo split installation in Taiwan (Crolla and Goepel 2020) and their research and implementation of AR technology for the construction of bamboo structures (Goepel and Crolla 2021, 2020).

3. Materials and methods

AR-driven Construction

Step 1: Siting

Both bamboo structures were sited in wild, natural, and highly irregular jungle terrain with no access to utilities other than electricity. Although a rough location had been pre-assigned during the design phase, their final precise location was determined onsite in collaboration with the stakeholders through holographic projections using several HoloLens devices. By placing fiducial markers and manipulating them collaboratively, the exact location, orientation, and rotation of the pods were decided, considering site conditions like accessibility, view orientation, direct solar exposure and more. This AR-enabled process significantly reduced the time required for configuration compared to conventional measurements as those were incapable of fully capturing the complexities of the site's natural environment (see Figure 3).

Figure 3. AR display of design intent for in-situ decision-making of orientation and exact localisation.

Step 2: Foundations

Once the project location was finalised, skilled craftspeople used digital information that was holographically projected through HoloLens devices onto their field of vision to position the centre points of the concrete pile foundations (see Figure 4). Despite language barriers, digital instructions were quickly understood, allowing the marking to take place swiftly, followed by the subsequent concrete pouring and installation of the bamboo flooring.

Figure 4. Labelling foundation position and installation of the floor

Step 3: Ring beam installation

A ring beam, consisting of interconnected bamboo splits and fixed to the bamboo flooring, was installed, guided by AR, to serve as an anchor for the bending-active grid structure that defined the primary structure of the projects (see Figure 5). Identification points marking the intersection points of this grid structure and the ring beam were marked up following holographic guides to allow the accurate positioning of the grid during its in-situ bending in later steps.

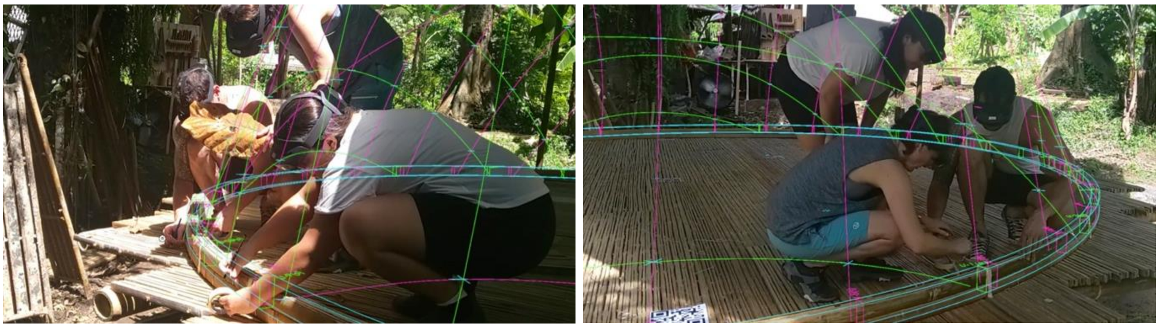

Figure 5. AR labelling of ring beam

Step 4: Equidistant, bending-active bamboo grid

The primary structure consists of a bent, equidistant grid made from bamboo splits. Following AR-guided marking of intersection points onto the splits, the flat grid was assembled using wire connection on the pod floors under the guidance of AR instructors, who directed participants to allocate specific beam IDs to their respective locations (see Figure 6). Once assembled, participants lifted and centred the grids onto temporary support scaffolding, guided by AR instructions (see Figure 7). AR supervision facilitated identifying and correcting any deformations, ensuring the physical bamboo geometry matched the digital design as it was fixed to the base's ring beam. A secondary grid was laid on top to define the roof surface.

Figure 6. AR labelling of the grids' bamboo splits

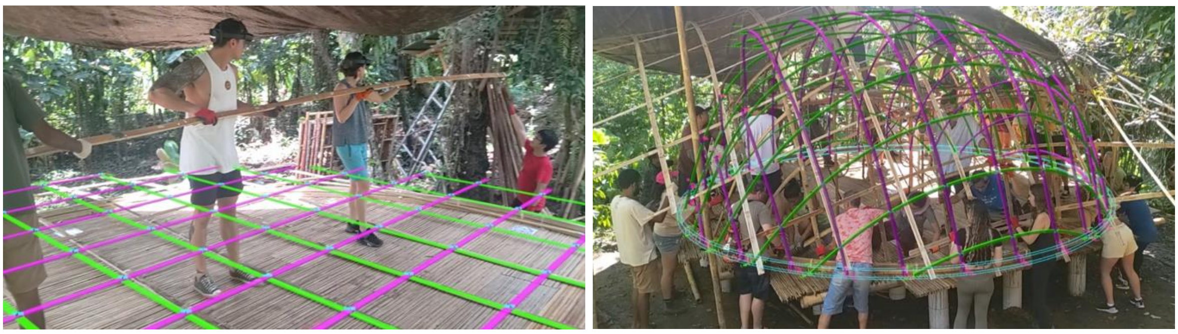

Figure 7. Assembly, bending, and popping up of the grid (Bottom: Jumpa Zoe, March 2023, © Bamboo U)

Step 5: "Lidi Bundle" roofline

The roof line was designed to be held up by a "Lidi Bundle", a flexible ring beam made from bundles of tied-together bamboo splits. Participants wearing a HoloLens adjusted the prefabricated bundle's height and location in alignment with the digital twin representation. Bamboo poles were temporarily fixed to the ground and scaffoldings to fine-tune the bundle's position (see Figure 8). Support positions were marked by tape, allowing craftspeople to adjust bamboo supports without additional measurements.

Figure 8. Installing the "Lidi Bundle" roofline

Discussion

Training sessions were organised at the start of the workshop to familiarise certain participants with the Extended Reality operating devices, holographic instructions, and software required for independent use. These trained individuals then assisted their peers, thus contributing to a collaborative learning environment. This workflow worked well, which illustrates the ease of technology integration in labour-intensive construction workflows. Local bamboo craftspeople involved in the project rapidly adapted to their now AR-driven tasks, which could now be completed far more quickly that traditionally would have been possible. It was necessary for the design team to create and maintain a nimble procedural holographic drawing generator to make sure feedback from the site could instantly be processed to produce updated most suitable holographic content and notation styles. Participants initially exhibited a tendency to strive for hyper-precision in the marking and assembly processes – a quality with which current technology still struggles, especially in irregular natural environments where "Simultaneous Localisation and Mapping" (SLAM) technology struggles. Bamboo architecture, however, by its very nature, has a high tolerance towards material, craftworkership, or dimensional tolerances, as the variability of the natural materials doesn't lend itself to hyper-precision anyway. Hence AR was found quite suitable to be integrated into this tectonic system. While the project demonstrated that for certain highly repetitive tasks, AR might be redundant, for tasks involving non-standard geometries or irregular patterns, its guiding potential proved to be vital. This proves that AR can be a great tool to make non-standard design solution spaces found on-screen now practically possible in reality.

Figure 9. Workshop Team inside Grid shell structure

Figure 10. Current construction progress of structures

Conclusions

In conclusion, "Kepiting Bambu" represents a pioneering exploration into the fusion of AR technology with bamboo craftsmanship and construction. The project's significance lies in its successful integration of AR as a transformative tool in bamboo architecture, paving the way for innovative design solutions and more efficient construction processes. The workshop conducted at Bamboo U showcased the practicality and adaptability of AR, enabling participants, including both experienced bamboo craftspeople and newcomers, to collaborate seamlessly. The use of holographic projections, particularly in determining precise site locations, reduced configuration time and overcame the complexities of the natural environment. Throughout the construction phases, AR-driven guidance ensured the accurate placement of concrete foundations, ring beams, and equidistant bamboo grids. AR instructors played an essential role in coordinating the assembly and alignment of bamboo components, ultimately achieving a fusion of physical and digital design elements. The project illuminated the potential of AR in enhancing craftsmanship, particularly in the context of non-standard geometries and irregular patterns. It showcased that AR is not redundant but rather indispensable for tasks demanding precision in unconventional settings. This pioneering effort serves as an exemplar of technology's role in harmonising traditional craftsmanship with contemporary design. By effectively bridging the gap between the digital and physical worlds, AR has expanded the horizons of bamboo architecture, making non-standard design solutions found on-screen a practical reality. "Kepiting Bambu" demonstrates that AR is not just a tool but a catalyst for innovation in construction and design, holding promise for future developments in sustainable and efficient architectural practices.

Author declaration

It is hereby confirmed that the manuscript has been read and approved by all the named authors and there is no conflict of interest. All regulations of our institution/institute/company including intellectual property rights have been followed and there are no impediments to publication.

Acknowledgements

Workshop team: Tutors: Dr Kristof Crolla, Dr Garvin Goepel; Programme Director: Orin Hardy (Bamboo U); Course Assistants: Cécile Durand, Rodrigo Novais Istchuk, I Putu Juliadi ("Pak Putu Abang", carpenter), Jeplin Kaban ("Pak Epin", carpenter), I Ketut Darmadi ("Pak Donal", carpenter); Participants: Tualagi Nokise, Carly Althoff, Anke Fuerer, Rachel Ponder, Rohan More, Amar Gurung, Angelo Bayonito, Julia Frendo, Natalie Choo, Guilen Cannesson, Dipta Priyatna, Steven Verde, Corentin Haëner, George Bakardijev, Eleni Vournas Cedar and Tallis Robarts

Conflict of interest

The authors declare there is no conflict of interest

References

Crolla, K. 2018. Bending Bamboo Rules: Beyond Century-Old Typologies. Journal of Architectural Education 72, 135–145. https://doi.org/10.1080/10464883.2018.1410669

Crolla, K. 2017. Building indeterminacy modelling – the 'ZCB Bamboo Pavilion' as a case study on nonstandard construction from natural materials. Vis. in Eng. 5, 15. https://doi.org/10.1186/s40327-017-0051-4

Crolla, K. and Goepel, G. 2020. Designing with Uncertainty - Objectile vibrancy in the TOROO bamboo pavilion, in: D. Holzer, W. Nakapan, A. Globa, I. Koh (Eds.), RE: Anthropocene, Design in the Age of Humans - Proceedings of the 25th CAADRIA Conference - Volume 2, Chulalongkorn University, Bangkok, Thailand, 5-6 August 2020, Pp. 507-516. CUMINCAD. https://doi.org/10.52842/conf.caadria.2020.2.507

Goepel, G. and Crolla, K. 2021. Augmented Feedback - A case study in Mixed-Reality as a tool for assembly and real-time feedback in bamboo construction, in: Realignments: Toward Critical Computation-Proceedings of the 41th Annual Conference of the Association of Computer Aided Design in Architecture (ACADIA). Presented at the ACADIA. http://papers.cumincad.org/cgi-bin/works/paper/acadia21_232

Goepel, G. and Crolla, K. 2020. Augmented reality-based collaboration - argan, a bamboo art installation case study, in: 25th International Conference of the Association for Computer-Aided Architectural Design Research in Asia. Presented at the ACADIA, Bangkok. https://doi.org/10.52842/conf.caadria.2020.2.313

Jahn, G., Newnham, C., Berg, N. and Beanland, M. 2018. Making in Mixed Reality. Holographic design, fabrication, assembly and analysis of woven steel structures, in: Recalibration: On Imprecision and Infidelity (ACADIA). Presented at the Recalibration: On Imprecision and Infidelity (ACADIA), Mexico City, pp. 88–97.

Kipman, A. 2016. Announcing Microsoft HoloLens Development Edition open for pre-order, shipping March 30 | Microsoft Devices Blog [WWW Document]. Microsoft Devises Blog. URL https://blogs.windows.com/devices/2016/02/29/announcing-microsoft-hololens-development-edition-open-for-pre-order-shipping-march-30/ (accessed 2.13.23).

Microsoft HoloLens. Introducing Microsoft HoloLens 2, 2019. https://www.youtube.com/watch?v=eqFqtAJMtYE

Milgram, P. and Colquhoun, H. 1999. A Taxonomy of Real and Virtual World Display Integration 1–16. https://doi.org/10.1007/978-3-642-87512-0_1

Wang, X. 2009. Augmented Reality in Architecture and Design: Potentials and Challenges for Application. International Journal of Architectural Computing 7, 309–326. https://doi.org/10.1260/147807709788921985

Wang, X. and Dunston, P.S. 2006. MOBILE AUGMENTED REALITY FOR SUPPORT OF PROCEDURAL TASKS. Presented at the Proceedings of Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montreal QC Canada, pp. 1807–1812. http://itc.scix.net/paper/w78-2006-tf275