Toward an Ontology-Informed Framework for Robotic Timber Construction

Ali Nakhaee[1,*], Diellza Elshani[1] and Thomas Wortmann[1]

[1]Institute for Computational Design and Construction (ICD), Chair for Computing in Architecture, University of Stuttgart, Germany

Abstract

This extended abstract presents early outcomes from a PhD project focused on improving interoperability and automated reasoning in robotic timber fabrication through the development of a domain specific Timber Building Design Ontology. The ontology captures essential concepts in timber construction such as materials, spatial configurations, structural roles, and fabrication processes in a formal and machine readable format. Developed using a modular architecture and formalized in the Web Ontology Language, it is designed to integrate with regulatory and fabrication systems. Initial evaluations through an industrial use case demonstrate the ontology's effectiveness in enabling structured data exchange and supporting automated compliance checking within digital design to fabrication workflows.

Keywords

Timber Construction, Ontology Engineering, Knowledge Graphs, Semantic Web, Robotic Fabrication, Interoperability

1. Introduction

Timber construction has emerged as a sustainable alternative to conventional materials, offering reduced environmental impact, high material efficiency, and compatibility with prefabrication. Engineered timber products such as cross-laminated timber (CLT) and glue-laminated timber (glulam) have expanded the possibilities of structural timber design [1]. At the same time, robotic fabrication is enabling precision, scalability, and resource efficiency in timber construction workflows [2]. Despite these technological advances, robotic timber fabrication still suffers from fragmented data and limited interoperability across design and fabrication stages [3]. Manual checks for regulatory compliance and fabrication readiness create bottlenecks and hinder automation. To overcome this, we propose a unified semantic framework—centered around a Timber Building Ontology—that enables data integration and supports automated reasoning through knowledge graphs.

2. Method and Results

The Timber Building Design Ontology is developed using a modular and domain driven ontology engineering methodology. This approach begins with the identification of domain requirements through expert interviews, architectural literature, and technical documentation from the industry partner Gropyus AG. Competency questions are formulated to define the scope and ensure that the ontology meets practical use needs in robotic timber fabrication.

The knowledge gathered is then structured into conceptual models that reflect key aspects of timber construction, including material specifications, spatial configuration, structural logic, and fabrication procedures. Ontology modules are designed to separate concerns clearly and to allow targeted extension

LDAC2025: 13th Linked Data in Architecture and Construction, July 09–11, 2025, Porto, Portugal

*Corresponding author.

ali.nakhaee@icd.uni-stuttgart.de (A. Nakhaee); diellza.elshani@icd.uni-stuttgart.de (D. Elshani); thomas.wortmann@icd.uni-stuttgart.de (T. Wortmann)

0000-0002-2761-1878 (A. Nakhaee); 0000-0003-2902-341X (D. Elshani); 0000-0002-5604-1624 (T. Wortmann)

and reuse. These modules are formalized using the Web Ontology Language within the Protégé ontology editor to ensure consistency, logical clarity, and machine readability.

Throughout development, ontology engineering best practices are followed, including iterative refinement, terminology alignment with domain standards, and the use of reasoning tools to check for consistency. Evaluation is conducted by applying the ontology in a real world industrial use case related to automated compliance checking, developed in partnership with Gropyus AG. The ontology is embedded in a knowledge graph to enable structured data representation and to support querying and validation of timber building designs against regulatory and technical requirements.

This method ensures that the resulting ontology is both theoretically grounded and practically applicable, supporting semantic data integration and the automation of early stage design and fabrication processes.

3. Conclusion

This work presents the Timber Building Design Ontology, a modular, OWL-based framework developed to support robotic timber fabrication. It formalizes key concepts such as material properties, spatial arrangements, structural roles, and fabrication processes using established ontology engineering methods.

Validated through an industrial use case with Gropyus AG, the ontology demonstrates its ability to represent timber design semantics and support automated compliance checking. Embedded in a knowledge graph, it improves data integration and consistency in design-to-fabrication workflows, offering a reusable foundation for digitally integrated timber construction.

Acknowledgments

This research is funded by the German Federal Institute for Research on Building, Urban Affairs, and Spatial Development on behalf of the Federal Ministry of Housing, Urban Development, and Building, through the Zukunft Bau research funding program (Grant No. 10.08.18.7-24.25).

Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT-4 for grammar correction and refinement. All content was reviewed and edited by the authors, who take full responsibility for its accuracy.

References

[1] S. Liang, H. Gu, R. Bergman, S. S. Kelley, Comparative life-cycle assessment of a mass timber building and concrete alternative, Wood and Fiber Science 52 (2020) 217–229. doi:10.22382/wfs-2020-019.

[2] H. J. Wagner, M. Alvarez, A. Groenewolt, A. Menges, Towards digital automation flexibility in large-scale timber construction: integrative robotic prefabrication and co-design of the BUGA Wood Pavilion, Construction Robotics 4 (2020) 187––204. doi:10.1007/s41693-020-00038-5.

[3] L. Skoury, S. Treml, N. Opgenorth, F. Amtsberg, H. J. Wagner, A. Menges, T. Wortmann, Towards data-informed co-design in digital fabrication, Construction Robotics 158 (2024). doi:10.1016/j.autcon.2023.105229.