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Design Tool Development for Multi-Criteria Optimization of Hybrid Timber Structures in Multi-Story Application

submitted by

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Abstract

Design Tool Development for Multi-Criteria Optimization of Hybrid Timber Structures in Multi-Story Application

Midrise multi-story timber buildings are seeing resurgence in construction activity due to an increased understanding in timber engineering, new massive wood products, and environmental construction trends. With this resurgence there are a number of different hybrid construction methods that are used to produce the final structure. By ascertaining a set of design criteria in the schematic and preliminary design phases it is possible to optimize a choice of element based construction solutions. This process reduces upfront design investments and leads to controlled and consistent results.

Three main work packages were conducted in the initiation of the project. A survey of architects and engineers was conducted to determine which design criteria buildings should be optimized to. Then an evaluation of different multi-criteria optimization methods was performed with a weighted sum model being adopted for ease of use and functional results for the decision maker. Finally construction elements for multi-story hybrid timber buildings were modulated and designed from literature and existing structures. These construction elements were then graded according to a set of criterion developed on a numerical scale to normalize both qualitative and quantitative criterion. Grading criteria, the weighted sum optimization matrix and the construction elements were combined to create a multi-criteria optimization tool.

Verification and validation were undertaken in cycles of trial testing the matrix with different problem tasks. The matrix was first trialled in designing a set of prototypical buildings, which was easily accomplished. Then the matrix was compared to existing buildings with design criteria obtained from designers of the original building. Throughout this process the matrix was updated to improve functionality. Major discrepancies were rectified producing a operational multi-criteria optimization matrix for multi-story hybrid timber structures.

Keywords:

Multi-Story Timber Construction, Multi-Criteria Optimization, Design Tool, Weighted Sum Method, Schematic Design.

Summary

Multi-story timber projects are quickly gaining market acceptance around the world. This is not only because they are becoming cost effective competitive solutions, but also because they are often deemed as higher quality products architecturally. With a spur of innovation there are many methods to construct multi-story hybrid timber projects. It became clear that a preliminary design tool was needed to help determine which construction methods best-fit different criterion and design preferences. The development of this tool covers design considerations that architects, engineers, developers and design-builders would consider in early stages when selecting the design concept for their building. Multi-criteria optimization with the weighted sum method is performed across 25 criterion, 6 component categories, and 31 systems to determine a ranking of preferred construction systems. The tool was then compared to existing buildings with their designer's input.

Criterion and construction elements needed to be developed to produce a boundary outline from where the building design systems can operate. A survey of experts was used to aid in developing the criterion needed for building design, while literature was consulted to design basic element based systems that could be used for the structure of the building. A grading criterion had to be developed for elements to determine a normalization of both qualitative and quantitative terms. Various methods of multi-criteria optimization were considered, and a simple weighted sum method was selected for ease of use, lack of heavy pre-programming required on the user's part and pareto optimality conforming results. The matrix was then used to produce prototypical-building results for basic confirmation of functionality. Furthering the validation process the matrix was compared to existing structures by having building designers fill out design criteria for their project. The workflow outline is illustrated in figure 1-1.

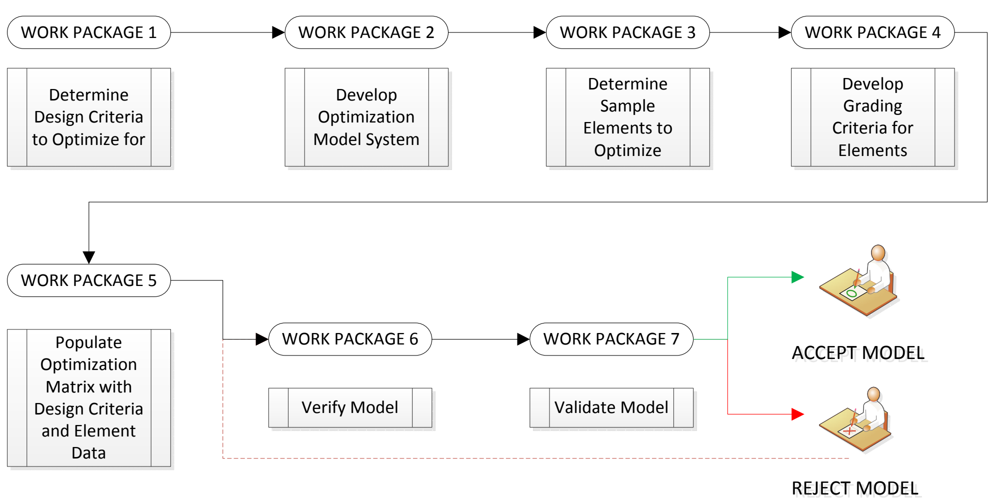

Figure 1-1 Workflow Outline

The optimization matrix was completed and implemented successfully. The optimization matrix is capable of specifying most typical design solutions for multi-story timber and helps to explain where there is such a variety of solutions available. Different design input criteria clearly result in different preferred systems for construction. When the matrix was tested in comparison to real world buildings it was found that there was an average overall discrepancy of 2.3% with a average range of acceptability of 73.3%. The combination of sixty-six data points allowed the comparison of model results vs. the real building solutions. Linear approximation was conducted resulting in an R^2 value of 0.77 as seen in figure 1-2. This indicates that the matrix operates in the realm of functionality, however determining the exact level of accuracy of such a matrix is difficult as most designs are still performed taking into account some level of intangible human error.

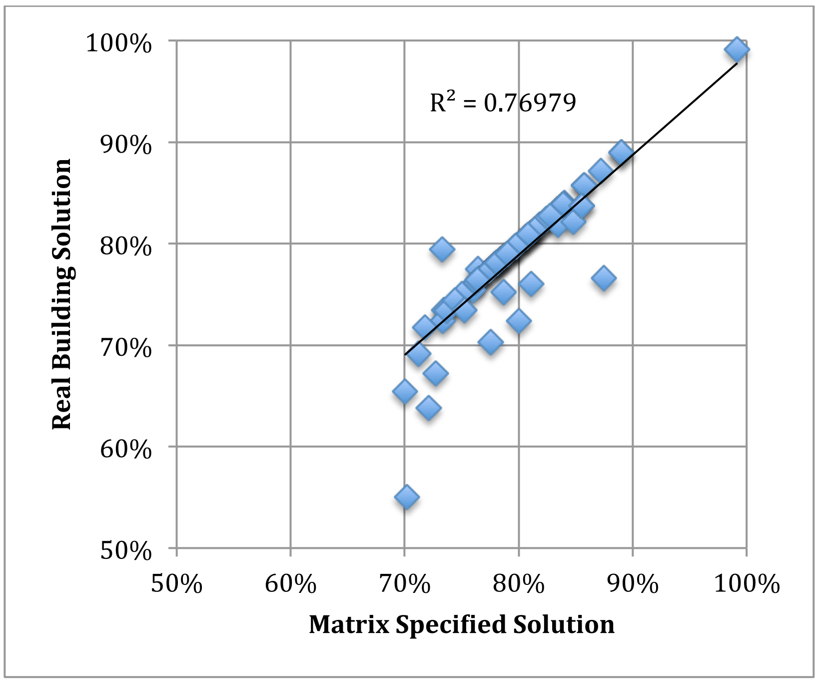

Figure 1-2 Matrix Solutions vs. Real Solutions, Linear Fit

There are a number of areas for further development with the optimization matrix and the apparatus that surrounds the matrix. Different versions of optimization systems could be selected however they all have significant drawbacks in ease of use for the user. A greater collection of construction elements and categories could be produced in further depth to better represent real world potentials. Finally more time should be spent with designers of real world structures to establish their exact design criteria and ascertain them on a comparable scale across projects. By doing this in depth and reviewing the results on a larger spread of projects the optimization matrix could be substantially improved. If results from this work are two disjointed between projects it would hopefully indicate areas or methods to rectify this situation for cross comparison on similar terms.

The design tool as an optimization matrix proved functional in determining systems for use in preliminary and schematic design. The top ranking systems output from the matrix are then considered with deeper analysis for further stages in project development. The final matrix is simple and quick to use in determining solutions for hybrid timber construction systems. Further implementation of this system should be sought through regional wood construction associations or with other large industry partnership leaders. It has been deemed that it is possible to optimize preliminary design of hybrid timber structures through a variety of systems. Continued research in a number of implementation tactics for such a system is advised.