Recalibrated: An interdisciplinary, studio-based study of massive timber for student housing

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ABSTRACT: The demand for sustainable buildings is continually evolving to be more comprehensive in its scope. In addition to focusing on energy performance and efficiency of usage, designers are increasingly emphasizing a life-cycle approach that recognizes the energy embodied in construction materials and processes. This trend is paving the way for new massive timber products, such as Cross-Laminated Timber (CLT), which offer minimal carbon footprints and compelling advantages in constructability. Following a period of rigorous testing, CLT will be recognized for the first time in the 2015 IBC. Additionally, new CLT producers are emerging in North America. What remains is the education of architects, engineers, and contractors who are often reticent to embrace new and unique building technologies.

This paper describes the work of the 2013 Graduate Comprehensive Studio, which was challenged to design campus-housing solutions for underserved graduate student populations. Recognizing the opportunity to introduce massive timber to next generation designers, and guided by the conviction that project constraints promote ingenuity, we asked students to utilize prefabricated CLT panels as the primary structural material. The size and scope of the project program was ideally suited to CLT, whose economy derives from repeatable geometries and rapid on-site construction with small crews.

The Studio was administered by three architecture faculty with complimentary areas of expertise. Additional industry guidance was provided by professionals experienced with CLT, and a representative from the university’s housing department acted as our client. Finally, the studio operated in close collaboration with three Civil Engineering students and their advisor who were concurrently engaged in researching CLT and its capabilities.

This paper presents a selection of findings related to the effectiveness of CLT for innovative student housing solutions. It also considers the merits of this interdisciplinary studio setting for material-based exploration, and describes funded research spurred by this initial project.

KEYWORDS: Massive Timber, CLT, Interdisciplinary Studio, Student Housing

INTRODUCTION

In the Spring of 2013 a unique, interdisciplinary design studio was devised to address two contemporaneous University interests. From a programmatic standpoint, there was a stated desire for dedicated campus housing options for graduate and married students. From a research standpoint, members of the University’s administration along with an exploratory team of faculty were engaged in planning a new institute focused on advanced wood and timber technologies. Taken together, these catalysts led to a dynamic, research-driven studio experience with deep and on-going impacts in the practices of two departments, and in the broader discourse related to massive timber structures.

1.0 PROJECT BACKGROUND

1.1. Alternative student housing

An ongoing redevelopment plan for the northeast corner of our campus anticipates a significant increase in housing options for upper-class students. The new development aims to retain a greater number of students in campus housing while adding retail, dining, and other recreational programming. However, it will not address the persistent lack of campus housing for graduate students, married students, and other alternative populations. This was not an oversight, but rather a calculated decision. Early versions of the new master plan were careful to include dedicated housing for the graduate community, but planners encountered high cost estimates, and were thus faced with the prospect of higher rental rates. This presented a challenge to staying competitive with the private market.

In his opening presentation to our Studio class, the director of University Housing described the economic advantages of the private developers. In particular, he stressed that the University’s commitment to consistency, durability, and longevity (50+ year life-span) requires higher quality materials and construction than are seen off campus. This equates to higher material costs and longer, more expensive construction periods. Ultimately, the campus planners steered away from graduate housing on the new site in favor of higher density development, a scenario they felt was more suitable for undergraduate living.

With this history in mind, the Comprehensive Studio was challenged to think critically about the University's conclusions and the various assumptions made about graduate and married student housing along the way. Working in pairs, the students were charged with re-balancing the economic equation, and ultimately found success by combining the following strategies:

- Pursuing dense, multi-family arrangements without assuming that they are ill-suited to graduate and married populations
- Utilizing pre-fabrication to maximize quality and limit on-site construction time
- Designing for energy and water efficiency and thereby limiting operational and infrastructure costs
- Proposing alternative programming that prioritizes the unique opportunities associated with the given sites (and the larger University setting) rather than mimicking the amenities found in off-campus complexes

As the course progressed, student teams were given a series of opportunities to present these strategies to a diverse team of faculty members[1], as well as collaborators from the Civil Engineering department[2], and our project partner in University Housing[3]. The students, in turn, received a broad range of critical perspectives to help refine and develop their design and marketing concepts (e.g. Fig. 1).

Figure 1: Student presentations. source: (photos by author 2013)

1.2. Massive timber

Our state boasts a large timber industry ($759 million harvested per year) and its pine forests represent a significant and renewable natural resource (SC Forests, 2014). Additionally, our campus itself features close to 17,500 acres of contiguous forestland whose operations have been certified under the Sustainable Forest Initiative (SFI), a leading third-party certification program. Citing these resources and the potential for our land-grant University to contribute to economic development in the state, members of the Board of Trustees and upper administration were interested in expanding wood-focused research. In the months leading up to the 2013 Comprehensive Studio, a small group of faculty from Architecture, Civil Engineering, Forestry, and Materials Science responded by laying out plans for the new Wood Utilization + Design Institute. The WU+D Institute aspired to involve each of these constituent disciplines in collaborative, full life-cycle research aimed at advancing the use of wood products in sustainable and resilient construction. The Comprehensive Studio presented an ideal vehicle for developing a model of design-focused collaboration. With this in mind, we chose to explore the topic of Cross Laminated Timber (CLT), an advanced massive timber system with untested potential for Southern Pine utilization in our region.

Developed in Europe in the early 1990's, CLT is a pre-fabricated structural panel that can be used for walls, floors, and roofs. The material, which comprises laminated layers of boards (typically softwood), derives its stiffness and dimensional stability from the alternating grain direction between layers. The timing of the studio course coincided with the release of the U.S. CLT Handbook, a design guide culminating from performance-based testing by FP Innovations (Douglas, et al. 2013). Seizing the opportunity to introduce massive timber to 33 student designers while examining and applying the design guidelines outlined in the Handbook, we asked students to utilize prefabricated CLT panels as the primary structural material in their proposals. The size and unitization (200 units) of the project program provided an ideal test application for CLT and the new guide.

Figure 2: CLT material study from "treaty oak" project. Source: (Barrett and Martin 2013)

1.3. Collaborative structure

The Comprehensive Studio course requires M.Arch students in their final semester to develop and document rigorous design solutions to a complex project. The project combines an exploration of the intuitive, poetic, and humane aspects of architecture with a thorough integration of building systems and other technical and functional considerations. Students work in pairs for the duration of the semester, and they are typically divided into distinct sections, each directed by individual faculty members.

However, in the case of the 2013 Comprehensive Studio, the teaching faculty decided to keep the 16 student teams together and instruct them through rotating consultations. This arrangement allowed each student to benefit routinely from the wider spectrum of knowledge offered by the diverse instructors, whose complementary areas of expertise included: affordable, zero-energy housing; architectural history + theory; and structural systems + advanced timber technologies. The latter of these instructors attended the first American CLT Symposium[4] early in the semester and returned with expanded knowledge in the areas of acoustical and fire performance, as well as new case studies.

The 2013 Studio also operated in close collaboration with a group of three Civil Engineering students and their faculty advisor, who were simultaneously engaged in studying CLT in their own Directed Studies course. Following the initial site analysis and concept-forming stages, these project consultants spent time each week with the student design teams. They evaluated the working drawings and made recommendations for panel sizes and span directions. They discussed shear wall configurations and evaluated size and placement of framed openings. They also worked with certain teams to develop hybrid solutions, combining steel, concrete, or glulam members where necessary. In conjunction with the consultation received, the design teams were expected to clearly articulate the load paths of their CLT structures, and were asked to produce detailed structural diagrams and assembly drawings. In return, the consulting engineering students received 16 unique and challenging case-study designs for which to run analysis and calculations. They developed for themselves a strong understanding of the material capabilities and limitations of CLT, and identified areas for future research, including the testing of Southern Pine panels and the potential for longer-span solutions. Most importantly, both sets of students were necessarily involved in the types of collaborative, problem-solving conversations that they would expect from their future professional practices.

Additional support was provided to both sets of students by Crawford Murphy (architect) and Frank Ungert, PE, both professionals in our area with experience designing and building with CLT. Murphy and Ungert opened the semester with a detailed presentation concerning CLT, its production, and its advantages for rapid on-site construction. They compared the weight of CLT (25-37 lbs/ft^3) to normal-weight precast concrete (150 lbs/ft^3) and described the resulting opportunity for foundations of reduced size (Douglas, et al. 2013). They also echoed the life-cycle benefits and carbon sequestration being touted by CLT advocates in the softwood lumber industry. Following the presentation, Murphy continued to be involved as an industry resource and guest reviewer for the remainder of the semester.

2.0 PRE-DESIGN

2.1. Market analysis and site selections

Working with the University's planning department, the studio faculty identified four diverse sites on or near the campus that were most suitable for a future graduate and married-student housing program. Each student team then performed detailed site and market analyses, including a close critical inspection of the University's most recent housing survey, prior to selecting a site for development. Students recognized that the University's earlier studies of economic viability had been based on fairly narrow market assumptions, namely that graduate and married students required the same square footages and specific amenities offered by off-campus competitors. Each team re-examined the survey data through the lens of the given sites. Rather than trying to compete with the amenities established by private developments, students focused on the unique and positive opportunities associated with the sites themselves – from outdoor recreation to campus connectivity, and from quiet settings to the potential for creative LIVE / LEARN programming (e.g. Fig. 3). For example, would graduate students be content with a smaller bedroom and shared laundry facilities if, in return, they were able to walk to and from class, share a community garden, and have on-site day-care for their children? Since the course was comprised of graduate students (many with families), the Studio served as an ideal testing ground for the various programming and lifestyle proposals. In this sense, design and market assessment were linked seamlessly and performed in parallel.

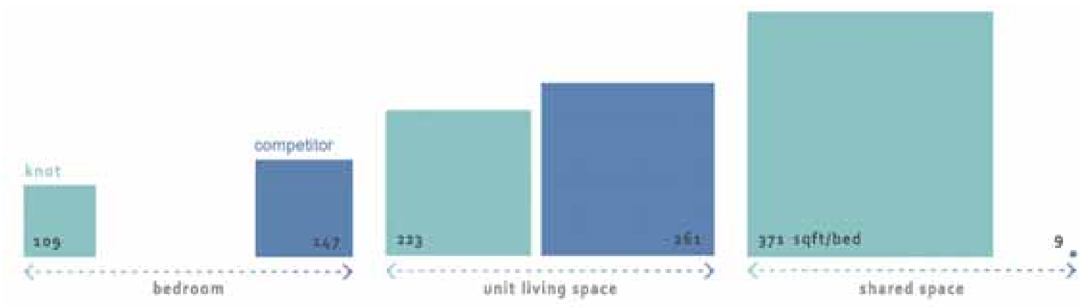

Figure 3: Space allocation comparison from "knot" project. Source: (Atria and Kim 2013)

2.2. Program and code assumptions

In keeping with the ideal size and scope identified by the university's housing department, the project program required housing for approximately 300 students and family members in up to 200 dwelling units. The division of single bedroom versus multi-bedroom units was left up to each student team and derived from their own demographic assessment (e.g. Fig. 4). The assignment also required students to propose and design some form of on-site mixed-use programming. Proposals ranged from daycare facilities, to cafés, to support spaces for outdoor recreation programs.

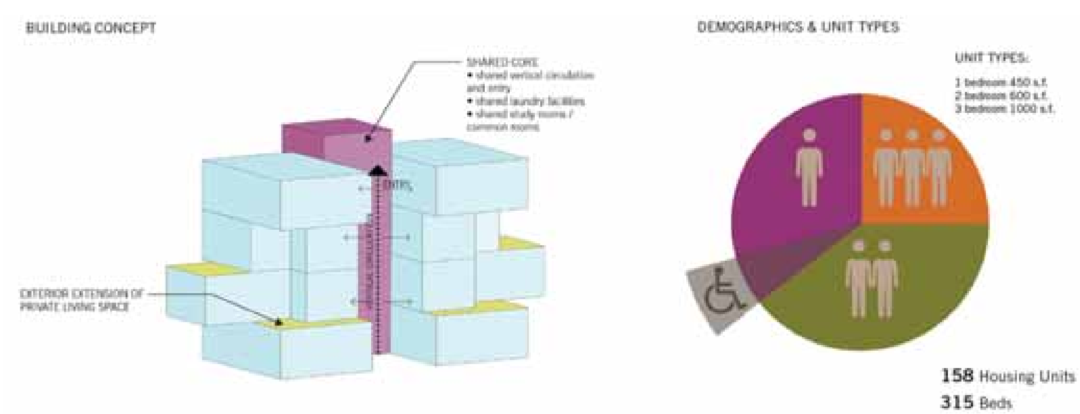

Figure 4: Program organization from "spectrum" project. Source: (Knorr and Yarborough 2013)

For the purpose of the project, the Studio assumed an R-2 residential occupancy and Type III construction based on the definitions outlined in the 2012 International Building Code. More recent advances in North American testing and documentation have led to direct recognition of CLT in the forthcoming 2015 IBC, wherein it will be accepted for Type IV (heavy timber) construction. However, at the time of the 2013 Studio, the assumption of a Type III A classification made the most sense, given the co-assumptions that the University would require sprinkler systems and that CLT exterior walls would perform comparably with fire-retardant-treated lumber. This meant that the students faced a maximum building height of five stories with a possible increase to six stories if using a non-combustible podium at the ground floor, a strategy that is widely employed in wood-framed structures.

3.0 PROJECT DEVELOPMENT

3.1. Load paths and panel capacities

Taking advantage of the complimentary areas of expertise at work in the Studio, systematic and integrative project development was conducted over the course of the semester, including efficient unit plans, thorough structural and mechanical schemes, rigorous sustainability strategies, and detailed construction / assembly drawings. All of this while being careful to carry forward the initial concepts about lifestyle and the potential programmatic advantages associated with campus living (e.g. Fig. 5).

Figure 5: Floor plans and smart-wall concept from “knot” project. Source: (Atria and Kim 2013)

Through their discussions with the consulting engineers, the Studio grew to recognize the formal potential of stiff, lightweight wall panels, which can act as deep beams in cantilevering scenarios. As a result, some proposals explored overhanging and projecting volumes and their associated details (e.g. Fig. 6).

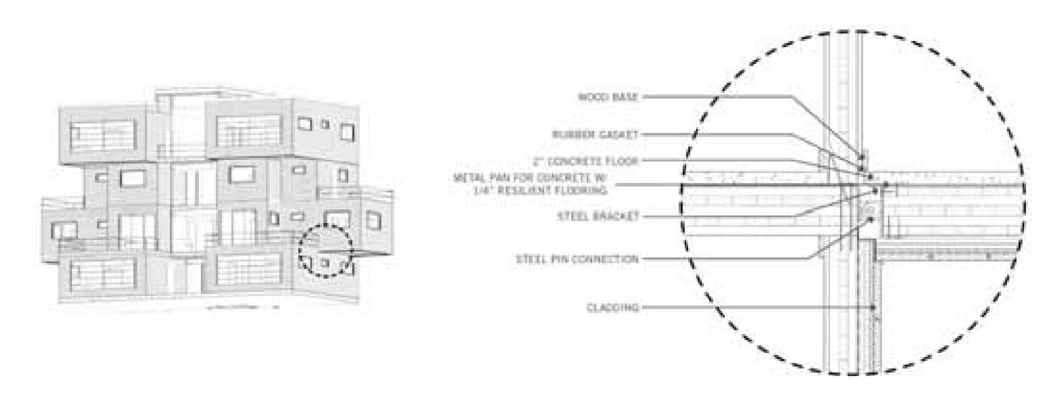

Figure 6: Cantilevered room detail from “spectrum” project. Source: (Knorr and Yarborough 2013)

Other students were confronted with the span limitations of CLT floors and roofs, and were thus required to include additional supporting elements such as steel or glulam beams and occasional columns in order to achieve the openness they desired in the living spaces (e.g. Fig. 7). These extra elements, and the time and complexity they add to construction, introduced the need for an all-in-one, long-span alternative – a concept that would be revisited in later studies (see section 4.1).

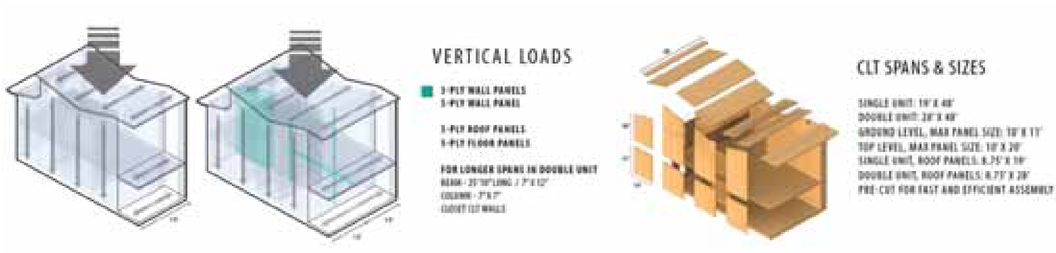

Figure 7: Load Paths and panel sizing from "seed" project. Source: (Boulier and Boykin 2013)

3.2. Acoustical design

Acoustical considerations presented another design challenge to the students. The IBC requires a minimum Sound Transmission Class (STC) rating of 50 for walls and floors between dwelling units, as well as a minimum Impact Insulation Class (IIC) rating of 50 for floors. However, according to the CLT Handbook, bare CLT floors and walls fall well short of these requirements, particularly in their IIC measurements. The actual STC rating measures from 32 to 34 for 3-ply walls and 39 for 5-ply floors, while the actual IIC measures from 23 to 24 for 5-ply floors (Douglas, et al. 2013, 9.13). Thus, sound dampening measures need to be employed for floors and walls between units. Working from tested assemblies presented in the Handbook, as well as various other case studies, the students proposed detailed sound attenuation strategies using furred-out walls, raised floors, and dropped ceilings (e.g. Fig. 8). Each of these scenarios necessarily add time and expense to construction.

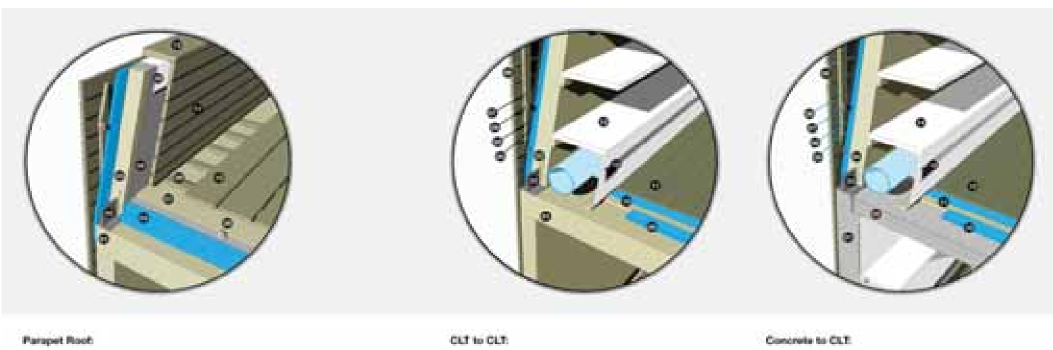

Figure 8: CLT details and acoustical floor treatment from "treaty oak" project. Source: (Barrett and Martin 2013)

4.0 FOLLOW-UP RESEARCH

4.1. Hollow-massive timber panels

As a direct extension of his work with the Studio, Graham Montgomery, one of the collaborating Engineering students, opted to study long-span alternatives to standard CLT as the subject of his subsequent master's thesis, funded by the USDA (Montgomery 2014). In his report, Montgomery explains that increasing CLT panel thickness beyond five plies may achieve moderately longer spans but not without diminishing returns on investment. Thus, the practical limitation on CLT floor spans is around 7.6m (25ft), a figure that is consistent with the earlier calculations he had provided to the design teams in the Studio.

For a long-span alternative, Montgomery proposes a built-up hollow massive timber (HMT) panel constructed from three-ply CLT flanges and glulam web members at 81.28cm (32in) on-center. An unbalanced orientation of the boards in the flanges was ultimately selected to optimize bending strength and stiffness (e.g. Fig. 9). It was also predicted that this configuration would be most resistant to fire damage due to the increased protection of the critical perpendicular-to-span layers.[5] Grade #2 Southern Pine was used for the parallel-to-span layers of the flanges, while Grade #3 Southern Pine was used for the perpendicular layers.

Figure 9: Long-span hmt panel. source: (montgomery, et al. 2014)

The voids in the HMT cross-section provide three primary benefits and one considerable challenge. First, there is the obvious economization of material and conservation of weight. Second, they provide space for the potential integration of MEP systems. Third, they improve acoustical performance with respect to solid CLT panels. The challenge would come in demonstrating adequate fire performance and redefining the notion of “enclosed spaces” which are prohibited for Type IV construction by the IBC. It is our contention that glulam end blocking would effectively seal the voids and limit oxygen. This, in combination with the slow char rate of all of the constituent components, would make the spread of fire highly improbable.

A combination of analytical modelling and physical shear testing was employed to examine two primary forms of connecting the webs to the flanges: structural adhesives and inclined self-tapping screws. Both forms of connection were shown to deliver adequate design values for shear, bending, and vibration in panels spanning beyond 9m (30ft). Montgomery concludes that an emulsion polymer isocyanate (EPI) glue bond offers the greatest economy and constructability, but that the screw connection could be used in cases where removable flanges are desirable, such as areas for accessing MEP systems. The screw connection would also be required if acoustic membranes are utilized between the web and top flange to dampen impact noise and improve the IIC rating.

Additional physical testing needs to be performed with full-scale HMT panels. Also, detailed acoustic testing will be necessary to quantify the enhanced acoustic performance, which, if substantial, may negate the need for sound-attenuating drop-ceilings and/or raised floors. Finally, more fire testing is needed for assessing an accurate fire rating for HMT panels, including the glue bonds, and for evaluating the effectiveness of sealed and/or insulated void spaces. That being said, Montgomery’s work represents a clear first step in addressing research questions raised through the initial Studio project.

CONCLUSION

In conclusion, the 2013 Comprehensive Studio described in this paper proved to be successful and impactful in at least three significant ways. First, the unique interdisciplinary collaboration between students of architecture and students of engineering was especially effective in combination with the focus on a particular structural material and system. A more recent version of this collaborative arrangement was employed in the spring of 2014, and, while it successfully established a working dialogue between the disciplines, it lacked the clarity and sense of discovery that accompany a singular, well-defined, and shared research topic, such as CLT utilization. Likewise, the fact that the 2013 engineering students were simultaneously engaged in their own independent CLT research proved critical to their optimal, fully-invested consultation in the studio.

Second, the participating students and faculty came away with a much-expanded understanding of CLT, an emerging building material in North America. The repetition in the project program and the appeal of faster construction presented an ideal application of CLT and a platform for studying its capabilities and its constraints. At minimum, each student left prepared to participate in the expanding conversation surrounding CLT, a material whose emergence in North America depends on informed architects and engineers.

Finally, the Studio served as a model project for the University’s Wood Utilization + Design Institute and became a springboard for ongoing funded research related to CLT and massive timber. With further testing, the HMT panels described above may eventually offer an all-wood, long-span floor system that is compatible with the tall timber structures currently being proposed and developed around the world.[6]

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ENDNOTES

1 The primary course instructors were: Dustin Albright, Assistant Professor of Architecture; Ufuk Ersoy, PhD, Assistant Professor of Architecture; and Ulrike Heine, Associate Professor of Architecture.

2 The collaborating instructor was Scott Schiff, PhD, Professor of Civil Engineering.

3 The University Housing advisor was Gary Gaulin, Associate Director of Sustainability.

4 The US CLT Symposium, sponsored by WoodWorks, was held on February 28, 2013 in Seattle, WA.

5 Detailed fire testing is on-going as of the time of writing.

6 The groundswell of interest in sustainable, massive timber construction is being demonstrated in the recent proliferation of tall timber proposals such as the Wood Innovation and Design Centre by Michael Green Architecture in British Columbia, the Timber Tower Research Project by Skidmore Owings and Merrill in Chicago, and the Västerbroplan Residential Tower by C.F. Moller in Stockholm, among others.