Modular Construction and Circularity. A Case Study of a Mass Timber Design Studio

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ABSTRACT
The increased use of wood-based materials such as CLT (Cross Laminated Timber) can reduce the GHG emissions of the construction sector. Likewise, offsite and modular construction methods can lead to more efficient material use, reducing construction-generated solid waste. However, it is worth noting that employing mass timber and modular construction is not automatically beneficial under all circumstances. The transition from the current linear, high-impact, and wasteful construction practices to a circular, regenerative one can offer an alternative solution to the problem. Moreover, high education institutions can play an influential role in this transition. However, there is a knowledge gap regarding education for circularity in architectural design. This paper aims to address this gap. It presents an educational approach integrating circular design principles with mass timber and modular construction in the setting of an architectural design studio. This paper analyses the pedagogical methods employed and the learning outcomes of the design studio. The results showed students successfully integrated architectural design and knowledge of modular mass timber technology with an innovative circular rationale and exceeded the learning outcomes in two cases.

KEYWORDS
Design for Sustainability, Design for Circularity, Education for Circular Economy, Disaster-Relief Project, CLT

INTRODUCTION
The construction sector accounts for the largest individual share of greenhouse gas (GHG) emissions, accounting for 37% of all emissions (U.N. Env. Programme, 2021), due to energy-intensive activities of material extraction, transportation, construction, and energy to operate buildings. The construction of buildings alone represents 10% of all emissions, while the operational impact of residential buildings makes up 17% of it (U.N. Env. Programme, 2021). Hence, the high emissions in the sector worsen the continuing heat up of the planet and contribute to the climate crisis. Moreover, the construction industry is also one of the main generators of waste (Nuñez-Cacho et al., 2018). That means a large share of emission-intensive building materials end up wasted in landfills during extraction, construction, or at the end-of-life (EoL), which refers to the final fate of building materials after their service time ends. The most common EoL fates include landfilling, recycling, or conversion into energy.

However, thanks to the strategic role of the building sector in fighting the climate crisis, numerous studies investigated possibilities to reduce its environmental impacts. In particular, the use of bio-based or circular materials is of great interest. Bio-based materials not only have a smaller carbon footprint but also delay emissions by storing carbon throughout their lifespan, known as biogenic carbon. Among the bio-based materials, the literature consistently favors wood-based building materials, such as CLT (Cross Laminated Timber), as a means to reduce the GHG emissions of the construction sector (Gustavsson & Sathre, 2006) (Robertson et al., 2012). CLT is a structural, large-sized solid wood panel produced with perpendicular layers of saw timber chemically bonded by an adhesive and pressed together. In addition to bio-based materials use, the pursuit of strategies to minimize waste from the construction and demolition of buildings is paramount in fighting climate change, leading to a decreased use of virgin resources, thus reducing impacts associated with the mining and processing of building materials. Offsite and modular construction methods can lead to more efficient material use, thus reducing both the need for excessive material extraction and construction-generated solid waste. Together, the increased use of circular building materials and more resource-efficient construction practices can result in up to a 31% reduction in the emissions associated with the housing industry (Circle Economy, 2022).

However, it is worth noting that employing mass timber and modular construction alone is not automatically beneficial under any circumstances. Studies showed an accurate assessment of wood environmental impact must address a time scale that includes the EoL scenario of wood-based products (Börjesson & Gustavsson, 2000) (Gustavsson & Sathre, 2006). As an example of the impact of EoL, a study demonstrated that the biogenic carbon benefit of wood in construction is uncertain in a landfill scenario (Fouquet et al., 2015). Previous studies by the author of this paper also support the critical role of EoL for mass timber (Passarelli, 2018) and mass timber modular construction (Passarelli, 2019) in assuring or even improving the environmental benefits of using wood. These studies pointed out a direction where the reuse of mass timber and mass timber modules can decrease the GHG emissions of wood construction through its lifespan expansion, thus increasing its environmental potential.

Hence, the transition from the current linear, high-impact, and wasteful practices in construction to a circular, regenerative one can offer an alternative solution to these practices. In this context, the concept of a Circular Economy (CE) is progressively gaining traction among scholars and practitioners, as indicated by its fast-growing number of peer-reviewed articles (Kirchherr et al., 2017). However, a transition to a circular economy requires a drastic shift from the conventional way products and services are designed, produced, and used, including in the construction sector. Previous studies emphasized the essential role of higher education in this transition (Kirchherr & Piscicelli, 2019) (Qu et al., 2020). Higher education institutions can be strategic agents supporting a CE and have a dual impact of promoting behavioral change at the personal level and implementation in professional practice (Bugallo-Rodríguez & Vega-Marcote, 2020). Nevertheless, there is a significant unexplored knowledge gap regarding education for a CE in architectural design.

This paper aims to address this gap. It presents an educational approach integrating circular design principles with mass timber and modular construction in the setting of an architectural design studio. The general goal is to contribute to the discussion of education for a CE and modular construction using mass timber.

MATERIALS AND METHODS

This study introduces a mass timber-focused design studio that engaged with the topics of modular construction and circularity. The author of this paper co-taught the studio in 2020 (spring term). The course was held in a school of architecture in the south of the USA. This paper analyses the pedagogical methods employed and the learning outcomes of the design studio. It aims to contribute to the growing body of knowledge on modular construction and mass timber education from the lens of circularity. Firstly, this study introduces the three assignments developed during the design studio with their respective learning goals. In the sequence, this study describes the final modular mass timber design assignment in-depth and presents representative projects developed by the students. The outcomes are evaluated and compared to the initial learning goals. The study ends with a critical discussion of successes and shortcomings in the course and possibilities for improvement.

RESULTS

The Mass Timber design studio, offered during the spring semester of 2020 in a school of architecture in the south of the USA, had twelve students enrolled and unfolded through three sequential but complementary assignments: 1) Individual Research; 2) Design Translation; 3) Disaster-relief project. The students worked on the first two assignments individually. In the last assignment, students chose to work with a partner or individually. Below is a description of the assignments with a greater focus on the last one.

Assignment 1: Self-directed research

The first assignment proposed a scientific investigation of a broad topic correlated to wood and wooden construction. Research topics dealt with a range of challenges related to wood utilization as a building material and aspects of wood construction technology. The topics included the availability of forest resources in the gulf south, sustainable forest management practices, wood environmental indicators, wood species' mechanical and physical properties, modern wood-based building materials, and modern construction methods.

At the end of the assignment, students produced 34 x 44 inches posters and presented their findings to the whole cohort and a group of reviewers. Posters were pinned up in the studio space throughout the semester, accessible to all the participants at any time. The primary learning goal of Assignment 1 was to familiarize the students with the main characteristics, challenges, and possibilities of wood and wood construction technology.

Assignment 2: Design translation

At the beginning of the assignment, the instructors provided a list of distinguished detached houses designed by renowned architects. All houses were built at some point, employing construction methods other than wood. The house list included constructions from the early 1920s to the 2010s to provide a greater variety of contexts. Another goal was to evaluate different design intents and technological aspects of construction in distinct geographical regions, namely, North America (4), Europe (6), and Asia (2). Each student in the course then chose one project from the list to document, analyze and translate.

The Design Translation assignment had three sequential phases: Case-study Documentation, Literal Translation, and Transformation. The sequence aimed to progressively build knowledge through iteration of design (qualitative) and technological (quantitative) aspects. In Phase 1, students sourced documentation on their chosen project, up to a level allowing them to redraw its plans and sections at the scale of 1:50. In Phase 2, students attempted to “translate” their chosen project into a mass timber construction using Glulam, NLT, DLT, CLT, or MPP. In Phase 3, students proposed a transformation of their chosen project that reflected their interpretation of its spatial character and construction improvements. (Figure 1)

The learning objectives of Phase 1 aimed to promote a deep understanding of the chosen projects. Phase 2 goal was to introduce possibilities and challenges associated with mass timer architectural design and construction. Lastly, Phase 3 was an opportunity to apply the knowledge built up during the semester and propose a design solution addressing qualitative and quantitative constraints.

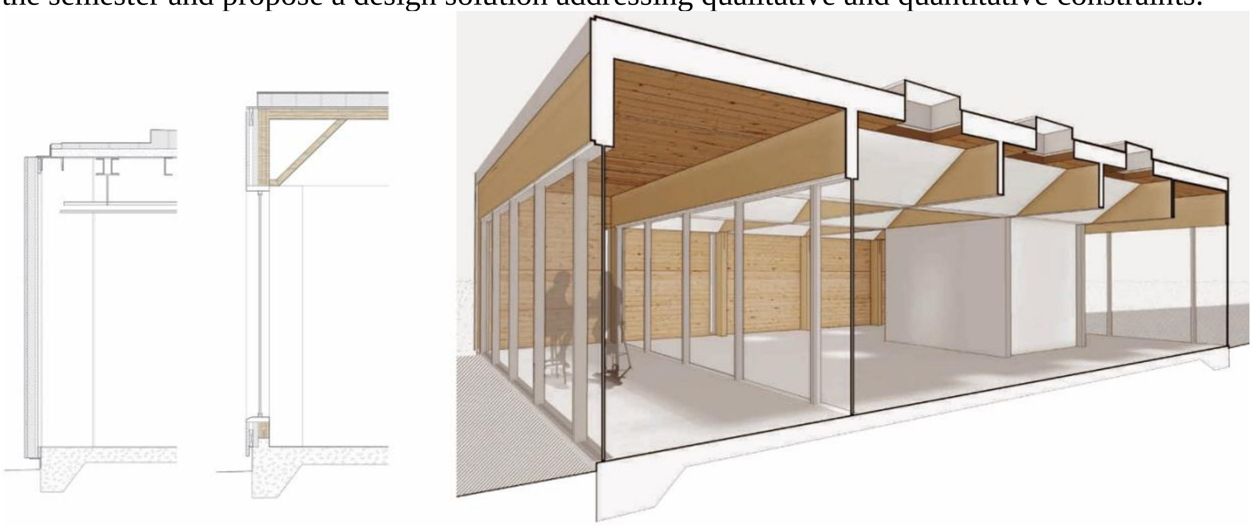

Figure 1. Design translation of Wimbledon House. Original wall section in Phase 1 (left); Literal translation wall section in Phase 2 (middle); Transformation section perspective in Phase 3 (right).

Assignment 3: Modular disaster-relief project

The last assignment in the course explored the design potential of mass timber and modular construction design under principles of circularity. The task was to use mass timber elements and offsite construction to propose an innovative approach for the design of a disaster-relief unit. Besides a high-quality architectural design outcome, students had to demonstrate efficient use of materials, knowledge of mass timber fabrication and construction methods, and transportation strategies. Most importantly, following the circular economy principle of lifecycle extension, a crucial part of the assignment was to design modules for disassembly and reuse. In other words, students had to approach the design task with the perspective of multiple life cycles and envision the mass timber modules used in two consecutive but different scenarios.

Overall, the proposed solutions by the students fit in three different lines of thought and scales of interventions, namely component (2), building (4), and urban scale (2). One representative project from each scale is presented and briefly discussed below.

Component scale: Students working on the assignment from a component perspective decided to develop a kit-of-parts for the disaster-relief project. After examining the transportation limitations for space modules, the students concluded prefabricated panels would be a more efficient way to deal with the anticipated mobility issue after a natural disaster. A student envisioned a trade-off where financial and spatial savings of flat-pack prefabrication are redirected to build slightly larger and better-finished buildings at first (Figure 2). Hence, the student attempted to avoid the conventional idea of a temporary shelter-like disaster-relief project and instead aimed to provide a permanent quality dwelling straight after the disaster.

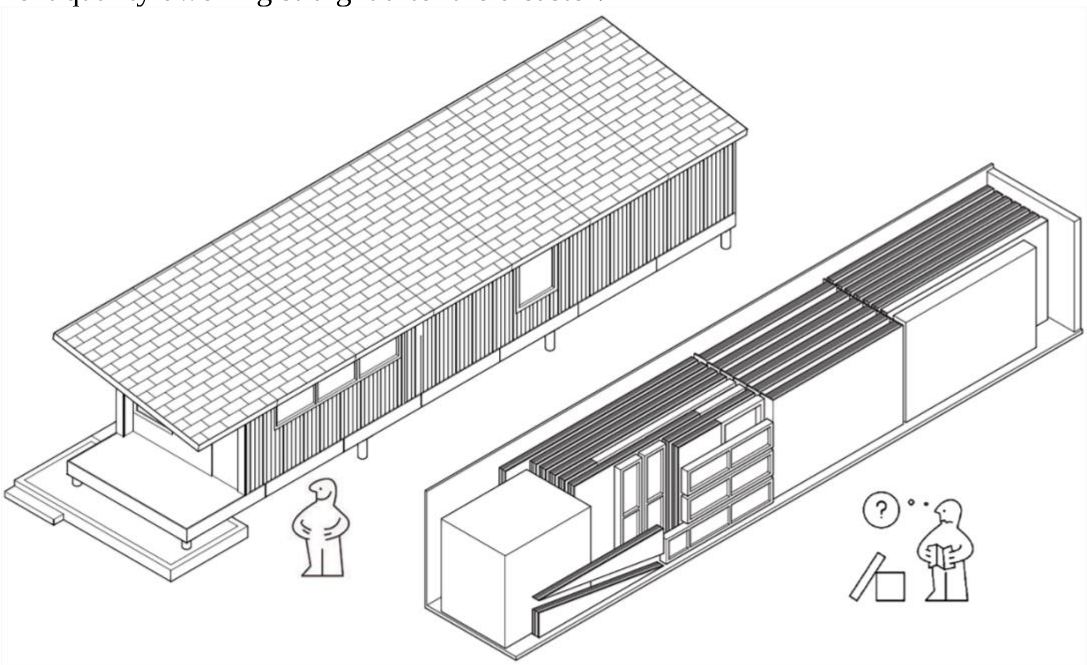

Figure 2. Kit-of-parts that compose a permanent modular unit for post-disaster housing.

Building scale: Conversely, students working on the assignment from the perspective of the building scale chose to use the initial character of impermanence associated with disaster-relief projects as a design driver to plan for two distinct, consecutive, and complementary life cycles for the modules. One pair of students imagined that in the first cycle, given the urgency of a disaster-relief project, finishing materials would be excluded to deploy modules in affected areas as quickly as possible. Hence, for immediate relief, modular dwelling units are wrapped with weatherproofing membranes only (Figure 3, bottom). Then, in a second moment, modules would be moved to a different, permanent location, finalized, and take on new arrangements as multi-family apartments. Through the skillful use of modular construction, students essentially transformed the idea of disaster relief into a holistic concept of disaster recovery by including the time dimension. The proposal intends to contrast itself with the conventional approach by using somewhat disposable FEMA trailers (Figure 3, top).

Urban scale: Students working on the assignment from an urban scale provided a compelling vision to simultaneously tackle the challenges of modular mass timber construction and circularity in cities. The groups proposed attaching the mass timber modules to existing but underutilized infrastructural buildings. One proposal envisioned the modules deployed on a rooftop of a parking building and the other on the stands of a municipal American football stadium. The latter conceived that disaster-relief modular dwellings would first take advantage of the available installations of its host, such as restrooms, dressing rooms, kitchens, etc. Nevertheless, progressively, a more autonomous multi-family complex would emerge and take over the previous stadium infrastructure, thus actively repurposing it (Figure 4). The boldness of this proposal essentially subverted the brief of the design studio by designing a second life not only for the mass timber modules but also for the structure that hosts them.

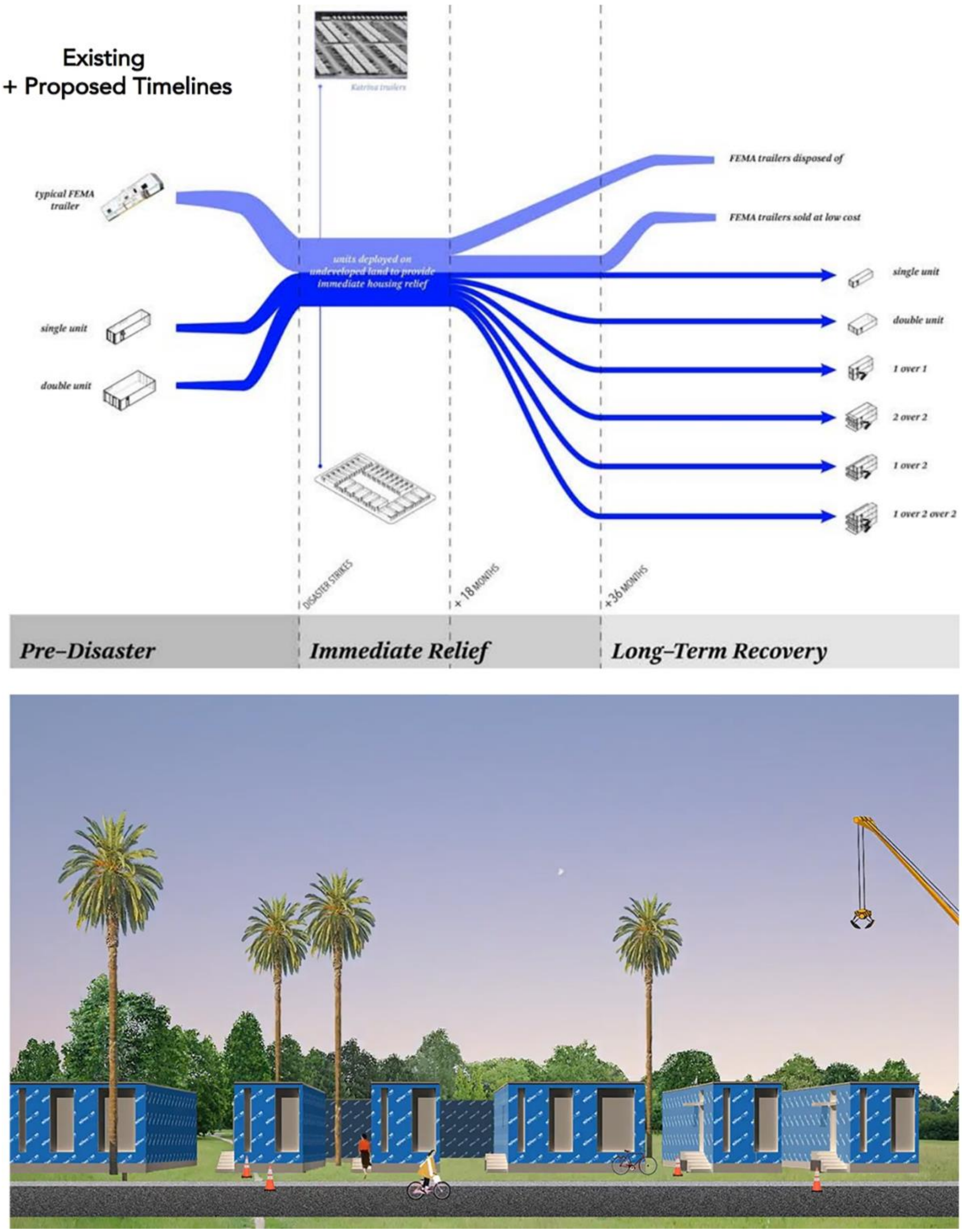

Figure 3. Timeline of modular units from disaster-relief to post-disaster dwellings (top); modules deployed immediately in the after-match of the disaster (bottom).

Figure 4. Section perspective of disaster-relief modular construction hosted on an American football stadium.

CONCLUSION

The mass timber design studio simultaneously introduced three topics to students still unusual in the curriculum of architecture schools in the US, namely, mass timber, modular construction, and design for circularity. Therefore, the instructors expected that students enrolled in the course were unfamiliar or completely strange to the main course subjects. Nevertheless, students acquired enough knowledge to evolve from an unfamiliar state to proficiency in dealing with mass timber modular construction challenges and circularity in only 15 weeks. The structure of three sequential but complementary assignments proved indispensable to building knowledge progressively and accomplishing the proposed learning goals. However, there is room for improvement in the first assignment. Although relevant to introduce the topic, the broad research topics had a limited impact on the following assignments. A second version of the course must seek a balance between general topics and specific knowledge that students can directly apply in the design assignments. On the other hand, the design translation assignment operated as intended. The pedagogical approach helped uncover the synergies between qualitative and quantitative aspects of mass timber and equipped students with critical skills for the next task. The final assignment was the most complex as it required advanced interdisciplinary and lifecycle thinking skills. Students integrated architectural design and modular mass timber technological knowledge with an innovative circular approach. Despite the challenging task, they successfully answered the brief, reaching the expected learning outcomes. From a quantitively point of view, the focus on lifecycle and resource-efficient design already during the concept design phase can significantly lead to waste reduction from CLT cut-offs during manufacturing. Most groups could keep a waste ratio within 5% to 10%. Moreover, in the two urban scale proposals, students went beyond the expectations, proposing a novel way to tackle the problem of modular mass timber and circularity. Hence, this study concludes it is essential to find new forms to integrate education for a CE in the still conservative architectural design curriculum. This way, higher education institutions can live up to their potential as agents of change to help in the transitioning from linear, impactful, and wasteful practices to a circular, regenerative industry.

ACKNOWLEDGMENTS

The author is grateful for all the effort and hard work done by the students in the Mass Timber Design Studio, which provided invaluable contributions to the course.

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