Weaving and Tuning Cast-In-Place Falsework

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ABSTRACT: *This paper examines a novel construction technique the relies on Weaving and Tuning to make the construction of cast-in-place concrete walls assessable to low-skilled labor. In contrast to formwork constructed by highly-skilled craftsmen—by hand or computationally fabricated—the student work product of this semester-long Advanced Architectural Tectonics course demonstrates that a construction system that can be deployed loosely on-site (woven) and later adjusted and fixed into the desired location (tuned), allows for low-skilled labor to execute complex cast-in-palace concrete forms. These conclusions are supported by first establishing the experience level of the student participants, documenting their learning process, and work product.*

KEYWORDS: CIP Concrete, Tensile Formwork, Student Construction.

INTRODUCTION

Although tensile systems have proven structural efficient in the construction of complex forms for decades, their use as temporary structural support (falsework) for casting concrete has seen negligible impact on construction practices (Veenendaal 2011). The Fabric-lined tensile formwork system discussed in this paper is an approach to deploying formwork that minimizes the materials consumed and technological equipment required for its deployment (Palagi, 2020). The research presented in this paper focuses on the skill of the labor needed to construct such novel systems.

Current trends in the scholarship of cast-in-place concrete have been dominated by two distinct realms of digital fabrication: novel tectonics and robotic installations. The breadth of research into novel concrete formwork demonstrates multiple paths with which digital fabrication techniques can achieve a high-level of accuracy in complex falsework (Block 2016; Méndez Echenagucia 2019). Various woven or cable-net systems minimize the amount of concrete consumed in the final cast form by maximizing the structural efficiency of the form through computational modeling and the accuracy of digitally fabrication (Popescu 2020; Veenendaal 2012). The falsework required to resist the tensile forces due to the concrete slump (to maintain the tolerances required for structural integrity of these designs) is achieved through robust, novel scaffolding. In contrast, the use of Robotics for the direct placement of concrete slump highlights the potential speed and consistency of future concrete construction when the formwork and the direct contact of a labors' efforts are removed (Buswell 2018). In each of these approaches, the use of bespoke falsework or the requirement of advanced technological equipment on-site, demand highly trained labor to execute their construction (Popescu 2019). In contrast, this paper examines a novel construction technique the relies on hand Weaving and Tuning to facilitate low-skilled labor in the accurate construction of complex concrete walls. This paper presents the findings from 18 novice builders attempting to learn and execute the fabric-lined tensile formwork for small, yet full-scale, structural concrete walls.

This fabric-lined tensile system formwork system does not attempt to minimize the Concrete consumed in the construction of the walls. This formwork system trades an increase of concrete cast in the final form for the minimization of the material consumed by the falsework and the increase of accessibility for low-skilled labor to construction complex cast-in-place structural walls (Palagi 2020). This system relies on the steel reinforcement required for the completed concrete wall as an internal scaffolding during the casting process. Between the vertical reinforcement, a repeated tensegrity system called tensegrity cushions are initially woven into place loosely and later tuned into the orientation desired (Roland 1970). Once in place, a series of external crossing tension members lock the tensegrity cushions together (in effect, created a vertical spaceframe, while, supporting the fabric liner). With the tensions cushions extending roughly equal distances, and internal tension between opposing surfaces, the static pressure of the slump is normalized, balancing the wall.

METHODOLOGY

To document the impact of weave and tuning techniques, four data sets were collected over a semester long elective course with 18 upper-level architecture students:

- A pre-semester survey documented the construction experience of the student participants.
- Lab notes taken while familiarizing themselves with the system, documented the students' time and effort for deploying each phase of the system's sequence of construction.
- Student work product from the Team Research assignment supplies empirical testing of the student's ability to execute the established system through multiple full-scale casts. Each cast approximately 18" wide, 32" tall, and 4-8" thick.

- The final Independent Investigation assignment, demonstrate the student's mastery of the construction system through their attempts to evolve the construction system.

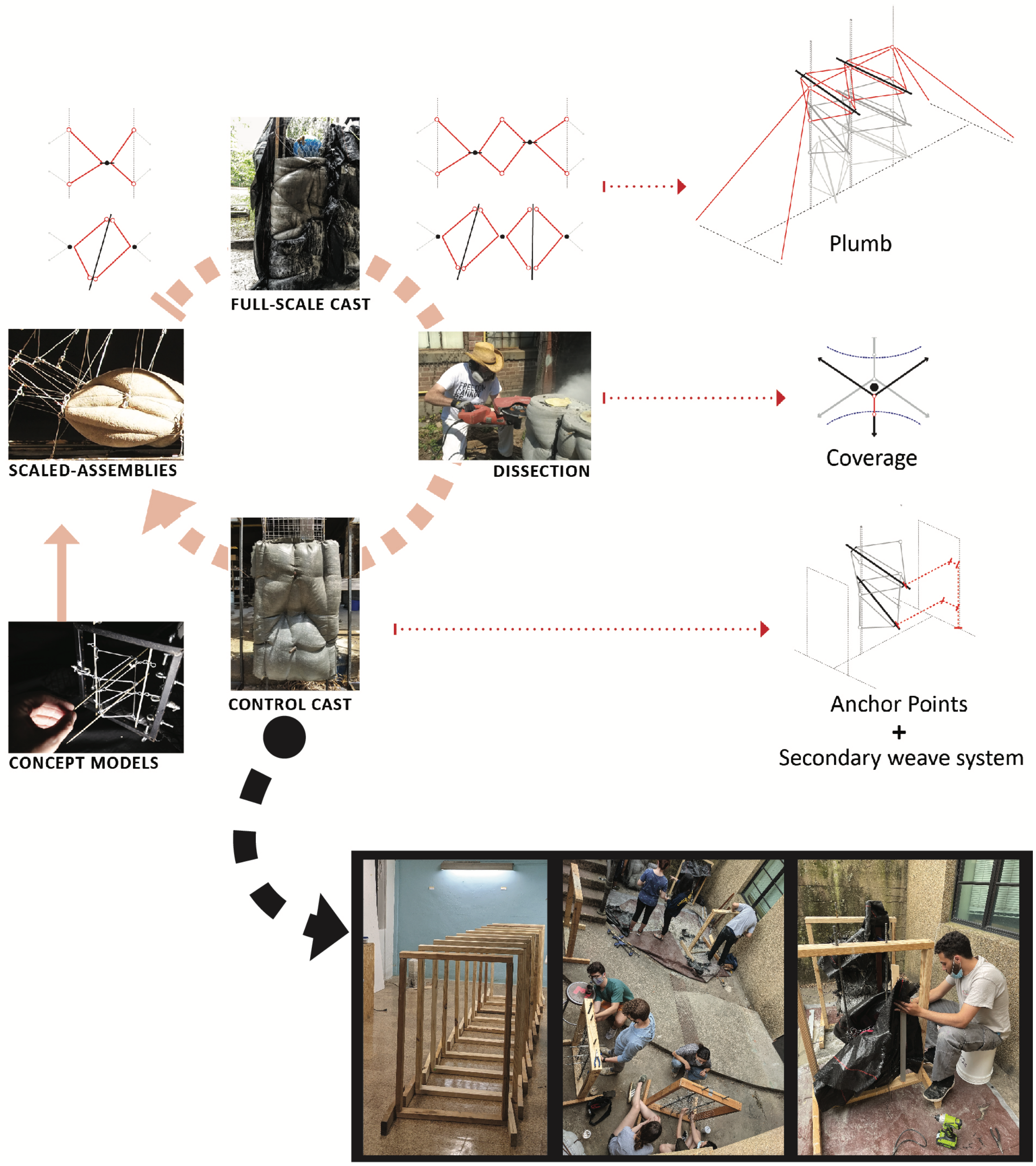


Figure 1: Student investigations furthering initial proof-of-concept (Palagi 2020).

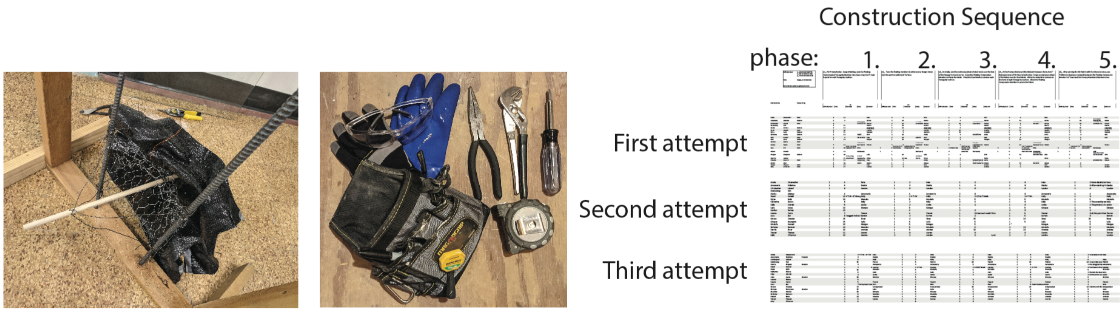
PARSING THE DATA

LABOR_ A clear lack of construction experience was recorded in an 8 question pre-course survey. Of the 18 architecture students enrolled, not one had been employed in any construction field. The class was divided into two cohorts (Blind and Shadow), with a balance of students with equivalent construction experience.

Table 1: Excerpt from Pre-Course Student Survey

Question	-1- Little to None	-2-	-3-	-4- a good deal
Work Experience in any construction field.	14	1	0	3
Personal Experience Casting Concrete.	10	7	1	0

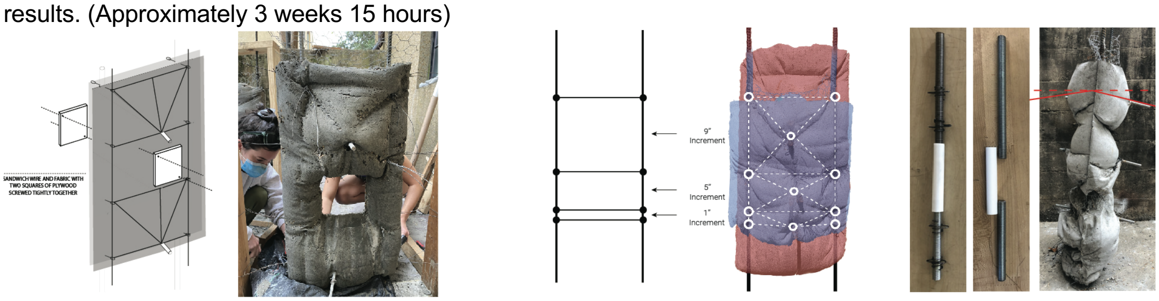
LEARNING CURVE_ The students spent the first two weeks of the semester familiarizing themselves with techniques and sequences of deploying a single structural bay of the construction system, a Tensegrity Cushion. The students identified as the Shadow cohort, watched the instructor deploy a Tensegrity Cushion, while the second cohort, the Blind, were given only written instructions. Through both the verbal and written instructions, five phases were named in the deployment sequence of the system. The students were each tasked with constructing a Tensegrity Cushion a minimum of three times over the two weeks. They document the time each phase of the construction took them, along with recording any specific notes. All data (times and notes) were verified by a witness and compiled in a single, class-wide excel file. Analysis of the data showed the Shadow cohort were initially faster than the Blind along with less struggles noted in their first attempt, but by a third attempt they times and effort balanced. (Approximately 2 weeks or 10 hours)



A. B. C.

Diagram 2: A. Tensegrity Cushion mock-up. B. tools required for course C. Class-wide collection of Lab notes.

EXPERIENCE_ Following a student-led discussion of possible research agendas, teams of 3 to 5 students formed around personal interests. The agendas each looked at the testing of nuanced variables in the existing system. Each group were required to cast two full-scale tests of their research and completed a research document consisting of the initial proposal, test cast A, findings and proposal, second test cast, and final results. (Approximately 3 weeks 15 hours)



A. B. C.

Figure 3: Group: A_ Examining apertures. B_ Challenging novelty of pattern. C_ Incorporating a thermal break.

MASTERY_ Students were then asked to continue independently experimenting with the potential of the system. Unlike in the Team Research assignment, no specific requirements were given to the students for their individual investigations. The final independent student work shows an increase of the students' control when tuning the system, facilitating greater control in the tests. In addition, the independent nature of these investigations demonstrated a cogent understanding by the students of the system at this point in the course. (Approximately 2 weeks or 10 hours)

A. B. C.

Figure 3: Ind. Research: A_ Examining apertures. B_ Challenging novelty of pattern. C_ Incorporating a thermal break.

CONCLUSION

Prior to this research, the construction of the proposed Fabric-lined tension formwork had been executed solely by the author. This paper documented the ability for 18 students, with little construction experience, to learn and execute this idiosyncratic construction system.

Weaving, unlike the additive construction techniques utilizing wood framing, heavy steel, or masonry, does not require accuracy in the placement of the aggregated elements within an assembly; rather, merely an adherence to spatial relationships between elements. For students with little construction experience, the stress of "measure twice, cut (perfectly) once" did not impact their learning of this system's construction. The ability for the initial assembly's weave to remain loose, allowed the novice builders to practice their techniques, reinforcing the conceptualization of the system, without failure due to their low level of craftsmanship. The use of weaving can be attributed to the students' understanding of the construction sequence, rather than the specific instruction method, as both the apprenticeship (Shadow) and remote (Blind) demonstrated equivalent time and effort after merely three attempts.

In addition, the ability to tune the loose deployed system, circumvented the requirement of a skilled hand in executing a high-level of craftsmanship in the final cast form. The work product from the Team research assignment demonstrates the students' ability to execute the construction method after merely practicing a single bay three times.

DISCUSSION

The dire need for labor, specifically in the construction of safe, low-cost residential projects, is felt throughout the globe. Yet a curved-concrete wall's inherent resiliency to severe weather and lateral forces rarely overcomes the high labor costs of its construction (Popescu 2019). The system examined, draws upon the repetitive nature of weaving techniques to facilitate a quick learning curve (broadening the labor pool); while, as the student work exhibits, the ability to tune the exact position of the final falsework, rather than crafting a skilled final cut, opens the door for low-skilled labor to execute a highly accurate level of construction. Moving beyond the mundane act of mimicry, the final independent investigations, in which the students challenged the system with programmatic variations, showed how quickly an unskilled laborer to was able to modify the system to their personal goals. Like the act of weaving tapestries, once the logic of the weave was internalized, expressive variations are easily explored. The weaving and tuning of this system extend design authorship to the hands of those on the ground, opening opportunity for cultural, programmatic, and otherwise site-specific intent.

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