Action Over Form: Combining Off-Loom Weaving and Augmented Reality in a Non-specification Model of Design

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Abstract

This paper presents a three-part investigation in the use of off-loom weaving and augmented reality (AR) in the construction of architectural building components and assemblies. Tim Ingold's model of morphogenesis, a conception of form emerging from the interplay of people, tools, and materials, guides the ambitions of the investigation. The goal is to develop architectural spaces not from pre-determined drawings, but through an emergent process of collaborative exchange. AR is explored as an instrument to facilitate this objective.

The investigation draws on material science studies on cementitious composite technologies, computational design and construction methods of off-loom weaving, and methods of construction using AR headsets. From these it develops an expanded application for cement composites to make free-standing structures, a collaborative building method using off-loom weaving for architecture, and a method using AR headsets to assist off-loom weaving. These methods and applications facilitate the development of form through expert and non-expert exchange, building through gesture, and interacting with materials. Further advancement of the methodology requires applying a technique to fluidly input geometric coordinates of physical form into a virtual environment.

Keywords: Augmented reality, cementitious composites, morphogenesis, off-loom weaving, collaborative building

Introduction

This paper presents a three-part investigation using large scale off loom weaving techniques in conjunction with augmented reality (AR) technologies. It postulates that virtual technologies can change designing and building by facilitating fluid exchange between people, tools, and materials. By using a flexible building material and augmented reality media, this study explores building methods which work in concert with intrinsic material properties and physical movement in contexts of collaborative building. This is guided by Tim Ingold's principle of 'morphogenesis' which describes the emergence of form through the coordination of designers, materials, and context (Ingold 2013).

The work is part of a larger research program conducted with a cultural anthropologist to understand the effect of new materials and technologies on design. The research program includes studying how new materials and technologies impact designers' thoughts, actions, and behaviors through interpreting tacit, non-verbal communications and behavior. This paper addresses the technical scope of this collaborative research. The first study it presents, "Lap, Twist, Knot," is a preliminary exploration of off-loom weaving using cement composites. The second study, "Augmented Weaving," explores the participation of non-experts in design and construction through the coordination of AR technologies with off-loom weaving techniques. The third study, "Augmented Weave: Urban Net," is ongoing research exploring full scale construction coordinating AR technologies and off-loom weaving with cementitious composites.

Literature Review

Tim Ingold's non-specification model of design and building - developing designs in concert with tools people and near environments, without adhering to strict predetermined drawings and specifications (Ingold 2013, 2011, 1999) – provides basic organizing principles for the research. These principles include knowing by doing, working with intrinsic material properties, and attention to embodied practices. These principles provide a lens through which to interpret technical research in the fields of materials science, and computational design and building. The technical literature the research builds on are: material science studies on cementitious composite technologies (Annesley 2019; Babaeidarabad, Arboleda, Loreto, & Nanni 2014; Mercedes, Gil, & Bernat-Maso 2018), computational design and building methods of large scale braiding (Lüling & Richter 2016; Sabin 2013; Zwierzycki, Vestartas, Heinrich, Ayres 2017); and methods of construction using augmented reality applications (Jahn, Newnham, Beanland, 2018). The research additionally references examples of building construction as performance, and methods of collaborative building (Nicholas, Stasiuk, Schork 2014; Halprin 1969).

Methods

The work of Ingold guides the research ambition to develop ways of building which evolve through material engagement, interpersonal exchange, and representations which direct action, rather than prescribe form. The first investigation, "Lap, Twist, Knot" (Figure 1) uses methods of building drawn from movement choreography. The research team developed coordinated movement to construct a large scale building component from a cement composite. This was initially developed through scale models and captured in scores: diagrams and text directing the sequential positioning of each fiber strand. The final building component – a nine foot tall column - emerged from a rehearsed performance of the cementitious fiber under the influence of gravity and manipulated by four design participants.

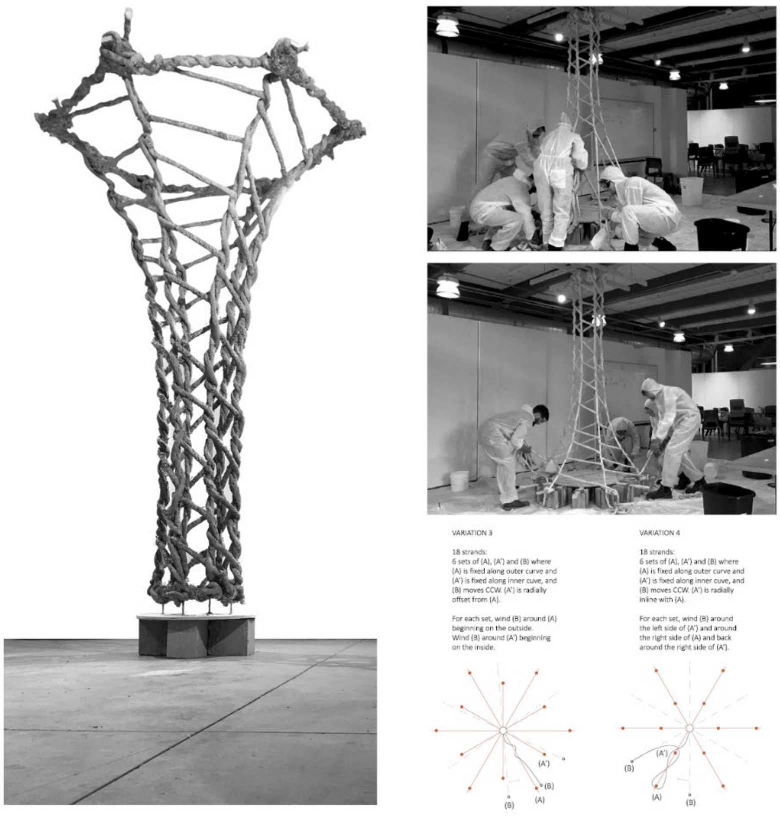

Figure 1. "Lap, Twist, Knot." Full scale investigation of woven cementitious composite using choreographic movement and graphic and written scores.

"Augmented Weaving" (Figure 2) introduced technologies of augmented reality and non-expert participation to the choreographic practice. The investigation used Fologram, a graphical algorithm editor application which coordinates parametric computer modeling with augmented-reality headsets and phones. The research team adapted the prior method of choreographed weaving to a new method using a parametric computational model coordinated with an adjustable physical armature via Fologram. Two research participants, one trained designer and one non-designer, conducted this investigation. The parametric computer model was linked via ArUco tag markers to a flat plate in the armature which could be manipulated by hand. One participant moved the plate and trained their AR headset on its ArUco marker. The headset communicated this new plate position to the parametric computer model, updating the virtual position of the plate in the computer model. The updated virtual plate position generated a new form in the computer model. The computer model, in turn, updated the AR headset projection. A choreographer wearing a second headset could then see the updated virtual form in physical space, make design evaluations, and request new positions for the plate. Once the final form was determined, the computer model provided virtually projected positions for "knots" as anchor points and "twists" as nodal crossings to direct construction of the physical weave. The projected positions for knots and twists were an elaboration on the graphical scores from "Lap, Twist, Knot". Due to the simple construction detailing of laps, twists, and knots designers and non-designers in "Augmented Weaving," wearing AR headsets were then able to collaboratively execute the final form.

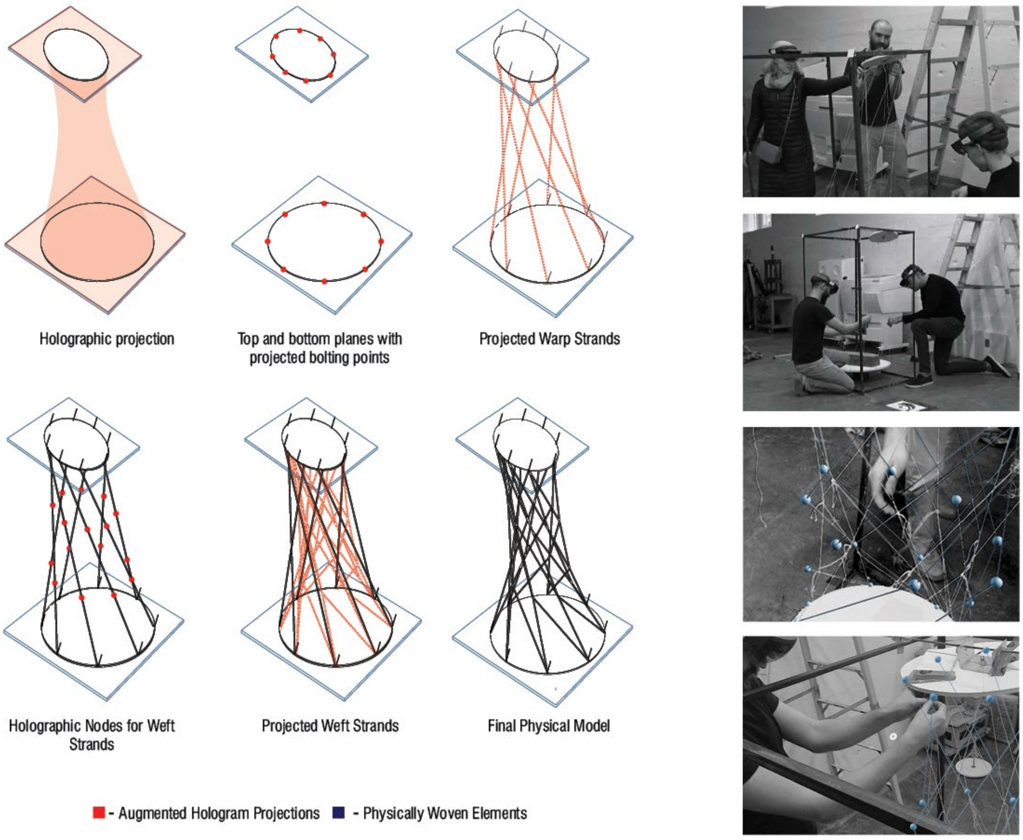

Figure 2. "Augmented Weaving." Expert and non-expert encounter in off-loom weaving using augmented reality and interactive, dynamic weaving armature.

The third investigation, "Augmented Weave: Urban Net" draws on this three-dimensional scoring to explore potentials of the technology for building at full-scale with a cementitious composite. The study overlays physics engine modeling simulation to predictively evaluate the effects of gravity and guide the positioning of cementitious strands (Figure 3). Components were constructed in an inverted configuration, then turned upright so the resulting structures work in compression, belying the thinness of their construction.

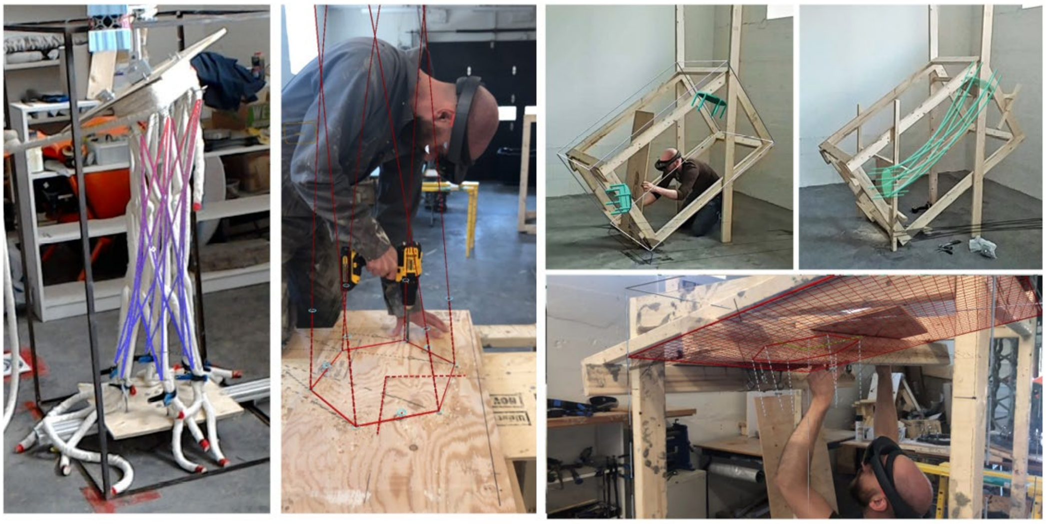

Figure 3. "Augmented Weave: Urban Net." Holographic projections locating drill holes and mounting plates, directing shape-relaxed forms in a cementitious composite, and providing structural simulation data.

The target geometries were derived from a building assembly, generated as a three-dimensional minimal-bending diagram through a computational simulation of gravitational forces (Figure 4). This three-dimensional diagram was rationalized into discrete architectural components which were prefabricated in a wooden three-dimensional frame (Figure 3). Mounting plates were positioned in the frame according to holographic projections. Drill hole angles and locations for the plates were also guided by holograms. Once the plates were mounted, holograms guided warp strand placement and the location of weft strand hitch-knots along the warp strands. Through interactive buttons, the holographic guide for each strand was individually isolated to direct the strand's placement and identify it by length.

Figure 4. "Augmented Weave: Urban Net." Overall target geometry and in-progress assembly of woven cementitious composite building components.

To further advance the computational potential of the process, the investigation also developed a method of characterizing the cementitious composite textile by calculating structural performance values for entry into structural simulation software, Karamba3D. The goal of this characterization was to visualize structural performance of the building components and initiate real-time structural feedback in the AR interface. The material characterization was done through filming a three-point bending test from which values for ultimate strength, shear modulus, and young's modulus were calculated. This method of material characterization was verified against a slender steel bar. Although this method treated the composite as a homogenous material, it was an accessible approximation of material properties.

Findings

In line with Ingold's model the findings and discussion are organized into three categories: people, tools, and materials.

People. In "Augmented Weaving" the technology facilitated non-expert participation. Non-designer participants were able to direct designers in the shaping of a component as well as join them in its making. Clear instructions, and a simplified range of options contributed to this success. This included a robust parametric computer definition.

The co-location of new tools and materials also led to new roles in the design and building practice. As the technologies were explored expertise was developed around certain tasks, and new tasks were developed. During periods of construction, different participants assumed particular roles: mixer, weaver, director. The director would point to positions for the strands and the weaver would continually check in to ensure proper location, while the mixer provided the material. This also highlighted the role of gestures in coordinated positioning and guiding of elements into place.

Tools. The use of sequential visual guides - breaking tasks into visually descriptive steps - proved to be an effective method for building complex form three-dimensionally. The guides projected in three-dimensional space allowed fabrication and assembly to be accomplished without a single traditional construction drawing. The interactivity of the holographic interface allowed people to manipulate these visual guides, and access explicit building information model data such as strand lengths. This facilitated a facile, yet precise mode of working with the material that would not be otherwise possible without considerable effort and elaborate documentation.

Materials. Using this shape relaxed construction method researchers made building components which could support 150 pounds from a material which tested in isolated bending only held 10 pounds of weight. The physics engine modeler viewed through the AR interface combined well with the shape-relaxed method of malleable composite construction. Preliminary visualizations with Karamba3D facilitated conversations with engineering professionals. These visualizations have yet to be worked interactively into the design process.

Discussion and Conclusion

The research has added to off-loom weaving a collaborative building method which can be incorporated with processes of large scale textile construction. The investigation has added to research in cementitious composites normally used in building repair an expanded application building stand-alone structures. And it has added to research in construction using augmented reality, methods for working with woven, composite materials and gravitational forces. Finally, it has added to social science research in technology, observations on how AR headsets might structure interactions between *people* (across disciplines and levels of expertise), *tools* and *materials*. These outcomes are discussed in more detail below.

People. The current investigation, "Augmented Weave: Urban Net", will culminate in a full scale construction. This full scale construction will test user reactions to the structure, and use AR headsets to provide additional content about the structure. This may include visualizing structural data, alternate configurations, instructional demonstrations, and information about the building process. Further expansion of the public component of the research will work with choreography professionals to score and rehearse movement in the process of building with AR headsets.

Additionally, a two week workshop with student participants will engage novice designers in methods of design and building piloted here. The workshop includes querying participants about their reactions to and experiences with this design and construction method.

Tools. In addition to projecting graphic notation, the use of AR headsets opens the possibility to project heads-up displays of instructional videos. Instructional videos have been used in prior investigations as a type of convention, like a construction document, to transfer knowledge across participants and disciplines (Forren & Nicholas 2019).

Materials. The research continues to develop interactive methods working with AR and the Karamba3D definition for use in form-finding. The goal is to view structural implications of strand positions in real time, and adjust them interactively. One objective is to develop a model of building where participants can create a physical form and then manipulate it in response to holographic information about the structural performance of the physical form. To accomplish this will require feeding the physical form into the virtual environment through a scanning protocol, photogrammetry, or tracking system. A version of tracking was tested preliminarily in "Augmented Weaving" by placing ArUco markers at the nodal points of the assembly.

These developments facilitated by AR technologies – expert and non-expert exchange, building through gesture, and interacting with materials - contribute to an ecological concept of design that takes into consideration a range of influences in architectural visualization and building. To design and build with computers in context shifts understandings of computational design and construction from one that is an insular, expert driven activity preceding building to one that is collaborative, public and concurrent with building. This adheres to concepts like Ingold's of design and building as more than just a rote production of form, but rather the emergent result of exchanges between people, tools, and materials.

Project Credits

Primary funding: Social Science and Humanities Research Council (SSHRC) – Canada; the Canadian Precast / Prestressed Concrete Institute (CPCI)

Project Assistants: Lap, Twist, Knot (Aziza Asatkhojaeva, Liam Guitard, Ryan Vandervliet); Augmented Weaving (Sebastien Sarrazin, Daniel Wesser, Jacinte Armstrong); Augmented Weave: Urban Net (Sebastien Sarrazin, Makenzie Ramadan, Aswin Ak, Felipe Guimarães Lima)

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