Design Computation and Restoring Craftsmanship

The Bailey-Derek Grammar in Wire-Bending

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Abstract. Craft knowledge, practices, and communities are vanishing due to globalization, automation, and techno-centric developments. This paper evaluates a computational design tool - the Bailey-Derek Grammar - for restoration of craftsmanship in the practice of wire-bending. By conducting workshops, interviews and surveys, document and artifact analyses, I examine the role of the Grammar in repairing the craft. The results shed light on how a computational description of tacit knowledge in the form of a shape grammar aids in restoring technical knowledge and skill in a craft. Results also indicate that the computational design tool promotes democratization of the craft by creating new forms of practice, and new roles for participation and engagement.

Keywords: Craft, Repair, Restoration, Shape grammar, Wire-bending

1 Introduction

The purpose of this study is to investigate how the Bailey-Derek Grammar might restore craftsmanship – technical knowledge (*theoria*) and technical manual skill (*praxis*) – in the dying practice of wire-bending. Wire-bending is a making practice which started in the 1930s in Trinidad. In the craft, wire and other linear rod materials are bent with hand tools to create two-dimensional (2D) and three-dimensional (3D) artifacts and structures (Noel 2015). Material connections are made using wire bends and secure wrappings with adhesive tapes. Currently, much of the knowledge in this craft is tacit. Tacit knowledge is described as a set of rules that reside within someone, and that are many times difficult to explain, verbalize, or formalize into a system of symbols with which humans are familiar (Polanyi 1974; Collins 2010). The Bailey-Derek Grammar is a series of shape rules and computations (step-by-step drawings) that describe the materials, steps, and techniques in wire-bending coming out of Trinidad & Tobago, for analysis and synthesis. It is a set of abstractions describing knowledge in the craft so that it can be used in design education and practice. The Grammar begins to externalize and formalize tacit rules (knowledge) embedded in wire-benders so that these rules are less tied to the originators, which is particularly important when craftspersons are dying and/ or retiring from practice (Noel 2015; Muslimin 2017b). In this paper, through a series of workshops conducted in the USA, and Trinidad and Tobago, I evaluate the role and effects of the Bailey-Derek Grammar in restoring craftsmanship in wire-bending.

1.1 Craft and Repair

According to Risatti, technique in craft (a sum of technical knowledge, set of procedures or rules) and technical skill (motor skill) requires two kinds of learning: (1) technical knowledge of the materials and how they are worked to create objects (*theoria*), and (2) technical manual skill to work the material (*praxis*) (Risatti 2007). Craftsmanship, on the other hand he says, fuses theoria and praxis into *poiesis* with both abstract and practical material concerns. In this dialectical, dialogical process and feedback system of craft, thinking and making; visualizing and executing; perception and action; knowledge and manual skill go hand in hand (Risatti 2007, 169). Anthropologist Tim Ingold argues that skill exists within a system of relations between the maker and his or her environment; and is transmitted through practical hands-on experience not abstract descriptions (Ingold 2000, 291). While Risatti writes that craft involves technical knowledge and skill, and Ingold writes that skill is a virtue of relations between the mind, body, and environment, Sennett argues that technical skill involves making and repairing (Sennett 2012). According to him, repairing things comprise restoration, remediation, and reconfiguration. The long-term goal of this study is to develop this concept of "repair" and craftsmanship through the lens of computation.

Sennett describes **restoration** as a "*recovery in which the damage and use of history is undone; the restorer as servant of the past* (Sennett 2012, 213)." **Remediation** he says, "*preserves an existing form while also substituting old parts for new and improved ones* (Sennett 2012, 213)." It requires a knowledge of alternatives that might be available, can improve the original or make the old purpose better, and positions the repairer as a fixer (Sennett 2012, 213–14). **Reconfiguration** he describes as a "*radical kind of repair*" that is more experimental, "*exploring the connections between small repairs and their large consequences* (Sennett 2012, 214)." In this paper, I focus on the Bailey-Derek Grammar as a restorative computational design tool (Noel 2015, 2013).

1.2 Computation, Craft, and Repair

Shape grammars and digital technology in design computation have been used in the description, remediation, and reconfiguration of craft and making knowledge in wire-bending; weaving; passura designs; ceramics; crocheting; ostrich eggshell jewelry; embroidery; basketry; and steam-bending to name a few (Noel 2013, 2015, 2016; Muslimin 2017b, 2017a, 2014, 2010b; Zoran and Buechley 2013; Muslimin 2010a; Jacobs and Zoran 2015; Zoran 2013; Çapunaman, Bingöl, and Gürsoy 2017; Schulte et al. 2014). Shape grammars were used to document and reinterpret tacit knowledge in passura designs and weaving, with the resulting Grammar having the possibility of also serving restorative functions (Muslimin 2017a, 2017b, 2014, 2010b).

Three previously developed approaches to wire-bending include traditional, computational, and digital methods (Noel 2016, 2017a). These novel approaches can be situated within the frame of repair. First, Computational Crafting which combines traditional wire-bending techniques and the Bailey-Derek Grammar, can be framed as a form of restoration since it builds on the practice's history and attempts to undo the damage caused by undocumented knowledge, dying practitioners, and non-existent pedagogy. Second, Crafting Fabrication (and certain aspects of Computational Crafting) can be characterized as remediation since new computational techniques – non-digital and digital – are included to make the old process better. Third, Digital Crafting can be characterized as a form of reconfiguration since it begins to explore the craft's larger consequences and possibilities for practice and pedagogy. In their employment of digital fabrication to explore restoration and remediation, Zoran and Buechley "restore" broken crafted artifacts with 3D printing techniques to transform them into something new (2013). In another example, Schulte et al. reclaim the craft of steam bending through digital design, and form generation (Schulte et al. 2014). I would categorize the two aforementioned works as examples of remediation since they incorporate new approaches to their crafts in order to revive them. While some works have used computation to develop new methods, technologies, and designs for and from the practices, this project seeks to repair craft in wire-bending by not only restoring knowledge in the craft, but also by deploying these new knowledges informed by computation back into the communities from which the work originated (education).

In this study, I evaluate the Bailey-Derek Grammar, and its role in restoring the craft of wire-bending. This includes investigating its performance as: (1) a pedagogical tool to record and transmit wire-bending knowledge and technical skill; and (2) a design tool that can be used in the restoration of wire-bent artifacts. I hypothesize that the Grammar can aid in the transmission of wire-bending knowledge, and help improve technical skill in the design, fabrication, and restoration of wire-bent artifacts. This study is structured around three workshops in December 2017 – one pilot study conducted in the Department of Architecture at the Pennsylvania State University (PSU), and two studies at Bishops Anstey Trinity College East (BATCE) in Trinidad & Tobago. By employing Risatti's definition of craftsmanship, Ingold's concept of skilled practice, and Sennett's description of technical skill as conceptual frameworks, I discuss the workshop and its outcomes. The paper is organized as follows: In *The Bailey-Derek Grammar,* I briefly describe the Grammar and its affordances in more detail; in *Methodology*, I describe the participants and how I performed the studies. *Results* describe what the collected data show. *Analysis and Discussion* explain the findings and limitations of the study. *Conclusion and Future Works* presents the work's implications, contributions, and possible future directions.

1.3 The Bailey-Derek Grammar

The Bailey-Derek Grammar is a computational design tool that allows analysis and synthesis of knowledge in wire-bending coming out of Trinidad & Tobago by describing the materials, steps, and rules in the craft (Noel 2015, 2013). Named after expert wire-benders Albert Bailey and Stephen Derek, the Grammar is an abstraction of the craft that gives insight into its theoretical knowledge as a "*set of [...] rules that can be verbally communicated and then executed*," it tells someone "*WHAT to do*" (Risatti 2007, 99). In it, materials are abstracted and represented with rules and steps to generate designs and describe how technical connections are made in the craft (Fig. 1). As a generative system, it facilitates design by calculating and doing with shapes and rules – as opposed to documenting with photos or video – because it allows visual reasoning (seeing and doing), calculating, and sensory-perceptual experiences in design (Stiny 2006, 311; Noë 2004; Arpak 2016). When it comes to design and restoration, users can de-abstract the set of instructions - moving from shapes and rules to materials and techniques - to bring artifacts into being (Risatti 2007, 172).

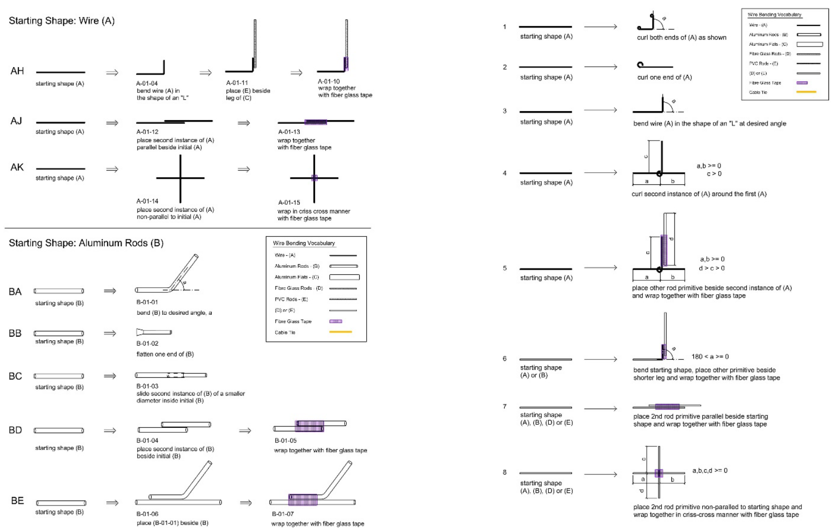

Fig. 1. Bailey-Derek Grammar describing the materials, steps, and techniques. Steps (left), and rules (right).

2 Methodology

This project consists of one pilot study in the US, and two workshops in Trinidad & Tobago (Fig. 2). In the first phase, participants were tasked with designing and making a three-dimensional artifact with hand tools, wire, and at least two other linear rod materials. They were required to document their steps, materials, and procedures so that someone else could follow their instructions and make the same artifact (replication). Teams were kept separate, incommunicado, and were not allowed to see other teams' artifacts. They would then swap instructions and attempt to replicate each other's artifact using only the instructions received (*restoration*). This was done to gain insight into participants' existing knowledge in design and fabrication using linear rod elements (technical knowledge and skill), and to assess what restoration might look like before introducing the Bailey-Derek Grammar.

In the second phase of the workshop, participants received the Bailey-Derek Grammar on handouts. I explained its material representations, material behaviors and techniques, and demonstrated how the Grammar worked (*theoria*). They then engaged in practical hands-on experience in making connections for approximately 20 minutes (*praxis*). Engaging in repeated hands-on making aids in skill improvement since the more skilled the maker, the better the quality of workmanship, judgement and dexterity (Ingold 2000). After introducing the Grammar, participants carried out the exercise again, this time using the Grammar as a technical guide for craftsmanship (*poiesis*) and communication.

Fig. 2. Tools and materials in Workshop #1 (left), Tools and materials in Workshop #2 (middle), and the Bailey-Derek Grammar being used in-situ (right).

Data collected for this study included survey information; individual and group interviews before, during, and after each exercise; audio recordings; document and artifact analyses; observations; and photographs (Hammersley and Atkinson 2007). Open surveys asked participants to describe their experiences in the workshop, and their use of the Bailey-Derek Grammar. Interviews, conversations, and discussions were audio recorded, transcribed, and coded. Triangulation of quantitative and qualitative data and analysis would identify patterns and themes emerging from their experiences.

For this study – restoration, and evaluating the grammar in-situ – some desired goals included improving novice and expert wire-benders' abilities to: (1) design and fabricate artifacts using traditional wire-bending techniques; (2) document and transmit wire-bending processes; (3) analyze and hypothesize on the creation of wire-bent artifacts; (4) gain confidence in understanding, and development of wire-bending skills and techniques; (5) gain interest in wire-bending; and (6) have a positive making experience.

2.1 Pilot Workshop

The pilot workshop was conducted in the School of Architecture at The Pennsylvania State University with three participants - one male, and two females. Two were both architects and graduate students; the other a Post-Doc in design and digital media. Team 1 consisted of one individual (male architect), and Team 2 of two individuals (female architect and female Post-Doc). The workshop lasted a total of ten-hours, running over two-days. According to self-reported pre-workshop survey data to gain insight into their levels of skill, participants' design experience ranged from 5-15 years, with no one having any wire-bending experience. While participants in the pilot study had moderate to high levels of design experience, they did not have contextual knowledge of wire-bending. Ten (10) linear rod materials were available to participants: 1/16" and 3/16" galvanized steel; 1/8" and 3/16" fiber-glass rods; 1/16" carbon fiber steel; 3/16" hollow section carbon fiber steel; 1/8" PETG rods; 1/8" clear polycarbonate rods; 1/4" HDPE rods, and 3/16" balsa sticks; fiber glass and masking tape for wrapping connections. Some hand tools included pliers, hack-saws, and scissors. All eight artifacts created were analyzed.

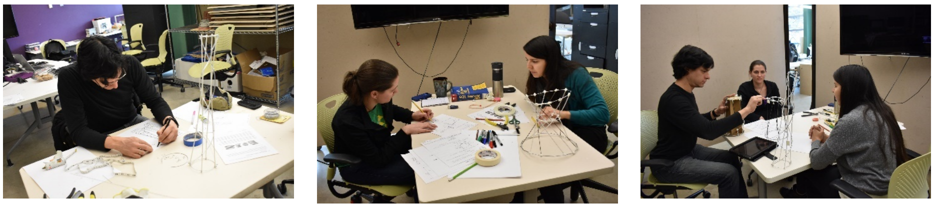

Fig. 3. Team 1 (left), Team 2 (middle). Teams come together for group interviews and discussions (right).

2.2 Bailey-Derek Wire-Bending Workshops

The wire-bending workshops conducted at Bishops Anstey Trinity College East (BATCE) in Trinidad & Tobago had a total of 31 participants: 68% females and 32% males. 81% of the participants were art students ranging in ages from 14 – 22 years old, with the remaining 19% educators ranging from 31 – 50 years old. In Workshop #1, there were six teams each consisting 2-3 participants, while in Workshop #2 there were four teams each consisting 4-5 participants. Teams were formed for even spread of gender with a maximum of one educator per team. Self-reported pre-surveys indicated that 65% of participants had little to no experience in wire-bending, with the remaining 35% reporting moderate experience. No one reported a high nor very high degree of experience in wire-bending, but 77% reported moderate to high levels of interest in wire-bending. 28% self-reported little to no experience in drawing by hand, and 36% little to no experience in making by hand. Participants were given a handout with one 2D drawing of a 3D shape (cube, cylinder, pyramid, etc.) to be used as a prompt since only 16% of the participants were trained designers and educators. While the majority of participants had little design experience, they all had contextual knowledge of wire-bending. Five (5) linear rod materials were available to participants: 1/16" galvanized steel; 1/16" and 3/16" fiber-glass rods; 1/16" balsa sticks, and 3/16" curtain wire window cord cable. All 44 artifacts created were analyzed.

Fig. 4. Workshop participants examining available materials (left). Teams engaging in study (middle and right).

3 Results

Each team designed and fabricated 3D artifacts, documented their steps, and made artifacts from the instructions received. All artifacts were analyzed for their correctness in connection details and replication (restoration). Documents were examined to gain insight into how and what information participants recorded.

3.1 Pilot Study Results (BEFORE Grammar)

In their role as craftsperson in this first stage of Phase 1 (designer and maker = poiesis), the artifact produced by Team 1 (one person) was sturdy, while the artifact from Team 2 was less stable. None of the connections made adhered to traditional wire-bending techniques, and both teams reported receiving missing information in their instructions. Instructions from Team 2 comprised of four pages of text and sketches describing dimensions, materials, and steps, while instructions from Team 1 consisted of one page of drawings with descriptive text, and symbols indicating materials, dimension, steps, and a drawing of the final object. For the second stage of Phase 1 in their role as replicator, Team 2 felt that the one-page instructions they received were simple, and the replication process (restoration) easy. For Team 1, textual and drawing instructions received were confusing and difficult to understand. In general, participants had problems comprehending all the instructions recorded, therefore, connections varied and some guessing took place. The replicated artifacts matched their original in form, but most times missed the mark in connections, materials, and design details. Figures 5, 6, and 7 show artifacts, craftsmanship, and details before participants learned the Bailey-Derek Grammar.

Fig. 5. Artifacts made without the Bailey-Derek Grammar: Artifact A made by Team #1 on left-hand side and replication by Team #2 on right-hand side (left). Original artifact B made by Team #2 on the left and replication made by Team #1 on right (right).

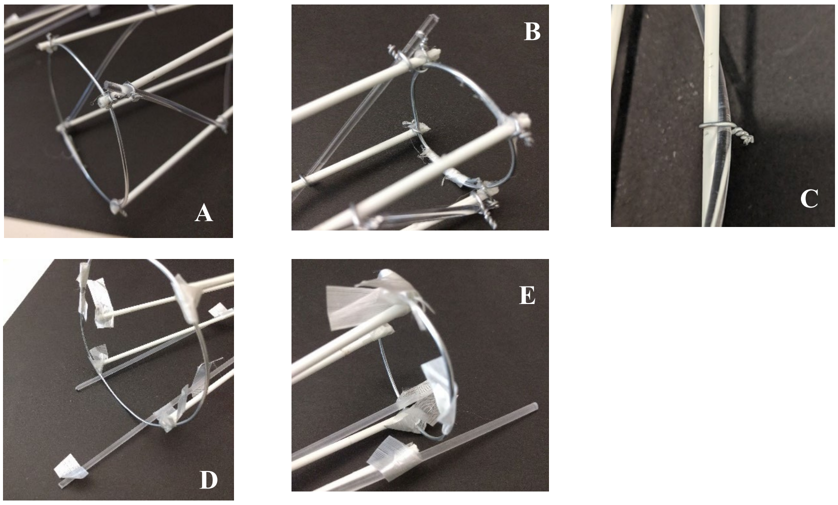

Fig. 6. Technical connection details before Grammar: Original artifact A (Figs. 6A, B, and C), and corresponding details of replication below (Figs. 6D, and E).

Although the connection details in artifact A (Figs. 6A, 6B, 6C) were different from those in traditional wire-bending, they held the linear rod materials together securely. Tape wrapping techniques in artifacts were not secure, and did not match their originals (Figs. 6D, 6E, 7). These issues resulted from the absence of a common language for communication, and participants' lack of wire-bending knowledge.

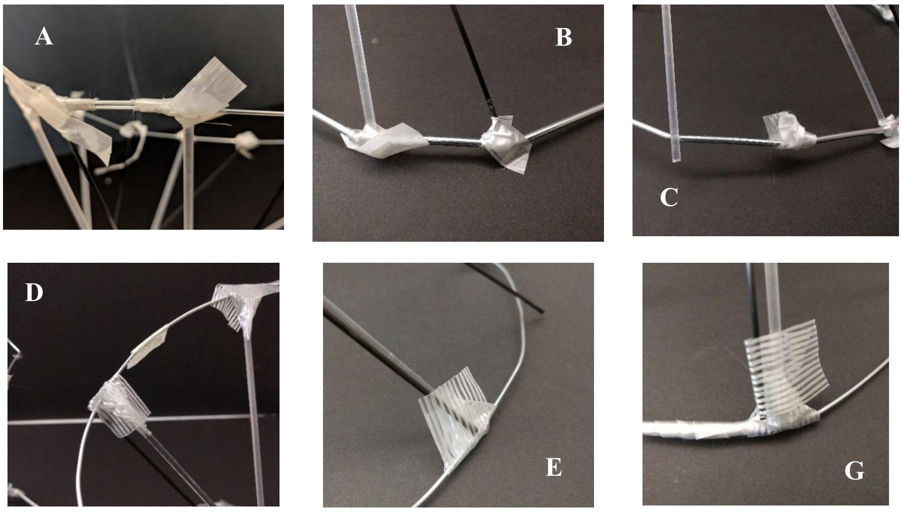

Fig. 7. Technical connection details before Grammar: Original artifact B (Figs. 7A, B, and C), and corresponding details of replication below (Figs. 7D, E, and G).

Participants had difficulty connecting linear rods, and understanding conflicting or missing instructions. They did however enjoy the act of making with linear rods, and the paired team enjoyed cooperating and collaborating with each other.

3.2 Pilot Study Results (AFTER Grammar)

Examination of artifacts and documents after participants were introduced to and practiced the Bailey-Derek Grammar showed that all connections created adhered to the Grammar's techniques. Craftsmanship (poiesis) improved in both teams. They reported feeling increased confidence in their design and fabrication decisions (technical skills) as less time was spent making connections by trial and error. Team #2 developed their design by selecting connection details they wanted to explore. Artifacts after the Grammar were more stable than those before. Teams reported that the instructions they created and received communicated more clearly their intent and actions. This was evident in document analyses where participants wrote and drew the rules used in their designs and instructions. When it came to replication (restoration), artifacts were much closer to the original in form, dimensions, materials, and connection details. Both teams reported feeling "*more freedom*" during the design process.

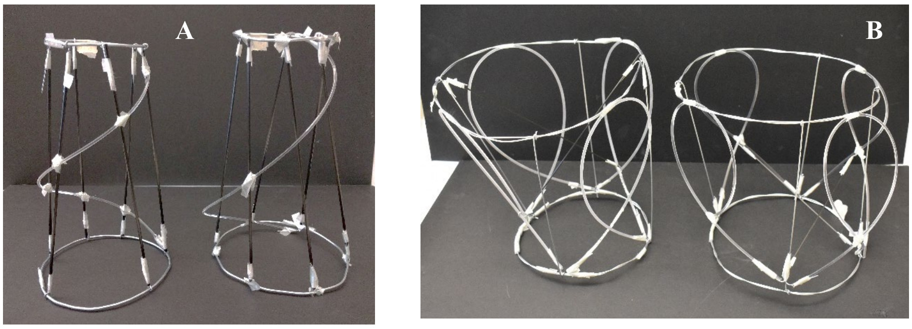

Fig. 8. Artifacts made AFTER Bailey-Derek Grammar: Artifact C made by Team #1 on left-hand side and replication by Team #2 on right-hand side (Fig. 8A). Original artifact D made by Team #2 on the left and replication made by Team #1 on right (Fig. 8B).

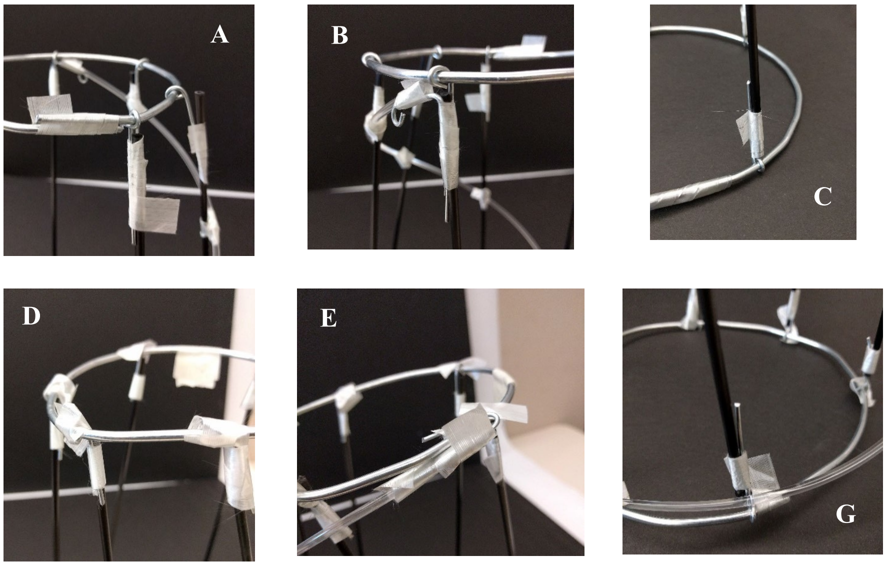

Fig. 9. Technical connection details AFTER Grammar: Original artifact C (Figs. 9A, B, and C), and corresponding connection details of replication below (Figs. 9D, E, and G).

After learning wire-bending techniques through theory and practice, connection details in artifacts matched rules 1, 2, 4, 5, and 8 of the Grammar; tape wrapping techniques were more secure; artifacts were more stable; and the materials, dimensions, and details of the replicated artifacts better matched their originals.

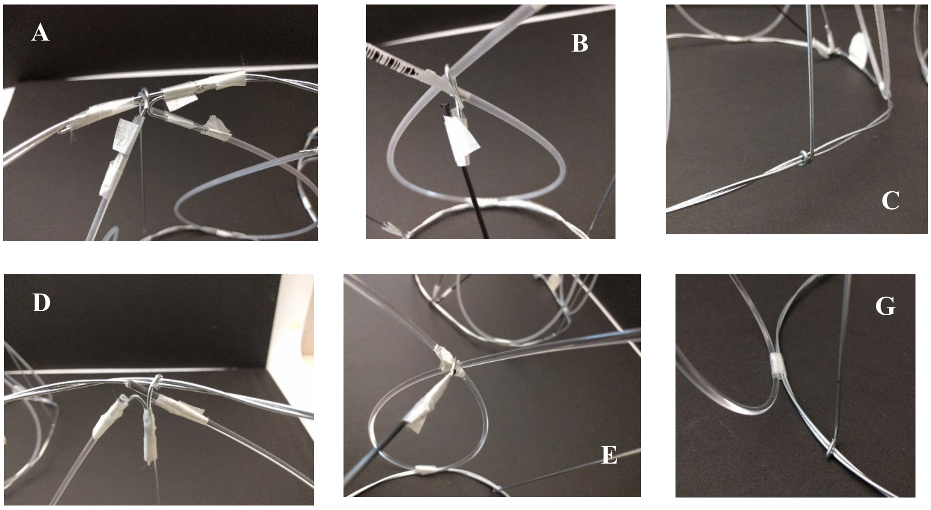

Fig. 10. Technical connection details AFTER Grammar: Original artifact D (Figs. 10A, B, and C), and corresponding connection details of replication below (Figs. 10D, E, and G).

Participants reported feeling more confident in their ability to make an artifact by connecting linear rods; more freedom in design; more confidence in their design; and they saw the Grammar as an enabler rather than a restriction.

3.3 Wire-Bending Workshops Results (BEFORE Grammar)

Some challenges experienced by participants in the workshops in Trinidad and Tobago included: figuring out how to connect different linear rod materials; incomplete or inaccurate instructions; vague or inconsistent terms used in instructions; and documentation of instructions while their design was evolving. 68% of participants reported having difficulties documenting their processes and instructions. For the 32% who reported having no difficulties documenting their instructions, 80% of them were on the same team. Also, although stating that they had no difficulties documenting their instructions, 96% of those who received their instructions reported having difficulties following them. 77% of all participants reported having difficulties following the instructions they received. When asked what the most enjoyable part of the exercise was, 61% of the responses mentioned the creative process. This included the act of making; experimenting with their ideas; seeing the designs created by other teams; problem-solving and improvising where information for replication was missing. 33% enjoyed the social aspects of making (cooperating and bonding with teammates) the most. Some teams selected one member to document their steps during the fabrication process, while others made their artifact, then came together to recall the steps with one person documenting them. Many saw the need to have drawings with supporting text. One participant commented that the use of drawings - instead of copious amounts of text - allowed flexibility while designs were evolving. Fig. 11 shows artifacts before teams learned the Bailey-Derek Grammar, and Fig. 12 shows the connections and craftsmanship resulting from a lack of wire-bending knowledge; conflicting instructions and standards; and missing information. Table 1 summarizes some of the challenges faced by participants.

Fig. 11. Artifacts made without Bailey-Derek Grammar. Original artifacts are on left with replications on right.

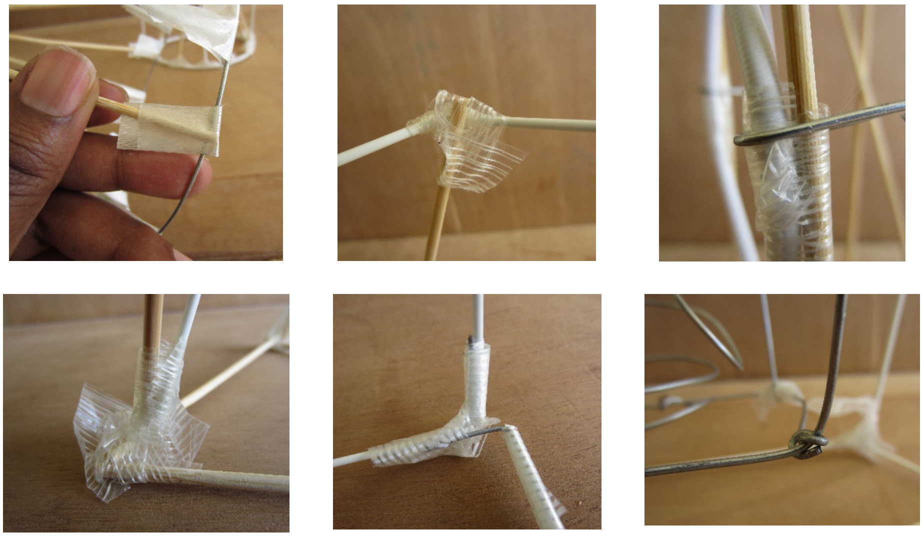

Fig. 12. Technical connection details BEFORE Grammar. Wire-bent connections and tape wrapping techniques were inconsistent, and in most cases insecure.

Table 1. Summary of participant feedback on challenges experienced BEFORE the Grammar.

Challenges:
1. Lack of knowledge on how to connect linear rod elements.
2. Conflicting standards, terms, and instructions.
3. Missing information.
4. Lack of confidence in making and communication.
5. Documenting instructions during the creative process.
6. Poor craftsmanship.

3.4 Wire-Bending Workshop Results (AFTER Grammar)

After participants were taught and practiced the Bailey-Derek Grammar, the form and technical details of their artifacts improved, so did the quality and quantity of steps, materials and dimensions in their instructions. They felt that their artifacts were neater, better designed and fabricated; they were interested in making more artifacts, and teaching others how to practice wire-bending. Figs. 13 and 14 show some of the artifacts and connections created. Craftsmanship (*theoria* and *praxis*) and replication (restoration) improved after the Bailey-Derek Grammar.

Fig. 13. Artifacts made AFTER Bailey-Derek Grammar. Original artifacts are on left, replications are on right. Originals and replications better matched each other in material specification, form, dimensions, and construction details.

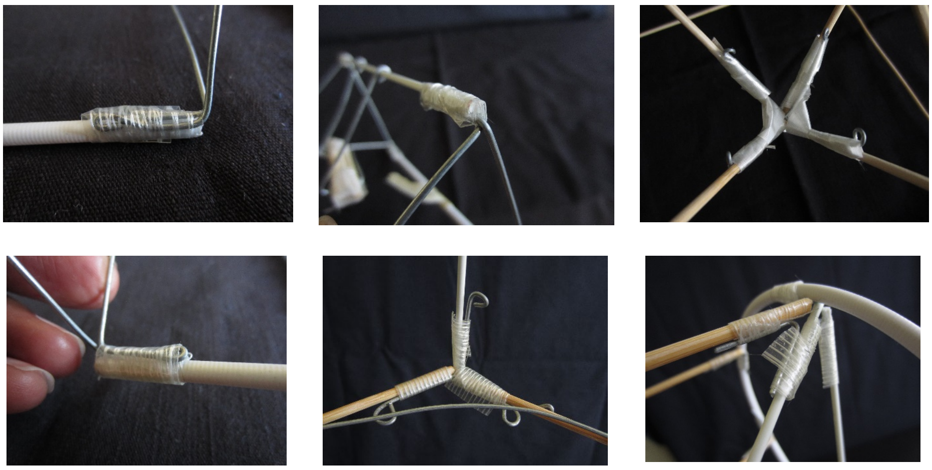

Fig. 14. Technical connection details AFTER Grammar. Wire-bent connections and tape wrapping techniques followed traditional techniques in the Grammar; were consistent, and secure.

Participants' ability to describe the potential pedagogical uses for the Grammar demonstrated their comprehension of its purpose. When asked what they learned, participants said:

- *[I learned] how to carefully map out instructions using symbols, words, diagrams, etc. to work in a more systematic way (student).*

- *[I learned] how to make instructions clearer using symbol notations. It [grammar] is a transferrable skill as long as I provide a key anyone can follow. I could see the application in a number of different [places]. Maybe replacing wire-bending terms with other symbols that have nothing to do with wire-bending, but just using that kind of methodology, very interesting the whole shape grammar thing (educator).*

- *One of the things that I really like about this process is, it was metacognitive. It caused me to think about how I design, and how by doing that I could then put things down, I had to think a lot more, thinking about thinking (educator).*

The aforementioned comments demonstrate that participants understand the computational principles of the grammar as an abstraction of wire-bending knowledge that gives insight into, and is able to communicate technical knowledge in the craft. The workshops facilitated pedagogy on wire-bending principles (*theoria*) and techniques (*praxis*), an introduction to computational thinking, and design communication through restoration and the Bailey-Derek Grammar. Table 2 summarizes some of the benefits and affordances of the Grammar.

Table 2. Participants' observations, feedback, and affordances on the Grammar.

Benefits of the Grammar	Affordances of the Grammar
1. Improved instructions/ communication. 2. Improved cooperation. 3. Reduced misinformation. 4. Increased confidence. 5. Increased risk, creativity, and design freedom. 6. Increased desire to make and learn more. 7. Increased desire to teach others. 8. Improved craftsmanship. 9. Facilitated thinking about thinking.	1. Wire-bending as a collective/ group practice – speeds up rate of transfer and possibility of innovation. 2. Universal/ agreed standard for communication. 3. Allows knowledge transmission (pedagogy). 4. Facilitates replication of artifacts. 5. Produces well-crafted artifacts. 6. Facilitates documentation/ hypothesizing of the creation process. 7. Teaches how to connect linear rod elements. 8. Facilitates participation by individuals and groups of different ages and genders. 9. Improves craftsmanship. 10. Creates a space for those who want to re-create and replicate artifacts.

When participants were asked to explain what the Grammar does, some commented:

- *[It] codes the materials using symbols to allow you to use a "language".*
- *[It] shows wire-bending vocabulary and different rules or ways to bend wire.*
- *[It] provides a common language for wire-bending techniques that can be referenced in instructions to be clearer and more secure.*
- *It's like design or[a] natural process of shorthand.*

4 Analysis and Discussion

4.1 Findings

In this study to evaluate the Bailey-Derek Grammar and its role in restoring craftsmanship in wire-bending, I investigated: (1) whether users were able to understand the purpose and principles of the Grammar; and (2) whether the Grammar might be used as: (a) a pedagogical tool for recording and transmitting wire-bending knowledge and skill; and (b) a design tool for restoring wire-bent artifacts. Based on my analysis of artifacts, documents, surveys, and feedback from interviews it was found that: (i) participants were able to understand the purpose and principles of the Grammar; (ii) the Grammar aids in the recording and transmission of wire-bending knowledge; (iii) when used in conjunction with hands-on practice technical skill improves; and (iv) it can be used as a restorative tool to analyze, document, replicate, and hypothesize on the creation of wire-bent artifacts. Additional findings are that: (v) a collaborative approach to wire-bending is possible and appeals to participants; and (vi) the Grammar appeared to increase participants' willingness to explore design options. I discuss these in more detail in the following paragraphs.

The first finding that participants understood the purpose and principles of the Grammar is supported by my examination of artifacts and documents which indicated that technical details matched the Grammar, and instructions and craftsmanship improved. Users described the Grammar as a common language of symbols codifying the craft; suggested uses for the Grammar by artists, craftsmen, students, and teachers; reflected on their thinking; and replicated artifacts thereby demonstrating their comprehension of its purpose and principles. The second and third findings that the Grammar aids in transmitting wire-bending knowledge and skill is based on observations that before participants were given the Grammar, instructions contained incomplete or missing information; lacked a common language system for comprehension and communication; and displayed little to no knowledge of wire-bending principles. However, after introducing the Grammar, not only was there a closer match between original artifacts and their replications, a reduction of missing information, and an established common language for communication of wire-bending knowledge, but, the level of craftsmanship in the artifacts also improved significantly (Figs. 8-10, and 13-14).

The fourth finding that the Grammar can be used as a restorative tool for analyzing, documenting, and replicating wire-bent artifacts is supported by the following observations: after its introduction, artifact construction adhered to wire-bending principles; instructions adhered to the Grammar's rules and steps; and the materials, dimensions, and connection details of replicated artifacts better matched their originals (Figs. 8-10, and 13-14). Traditionally, there is one wire-bender to one wire-bent artifact, meaning, only one wire-bender works on the same artifact at the same time. The fifth finding was that a collaborative approach to wire-bending appeals to participants, and is possible with the Bailey-Derek Grammar. Even before the Grammar was introduced, 33% of the responses listed working together as the activity they enjoyed most. This increase in enjoyment after the Grammar was facilitated by: (1) the Grammar's shared language; (2) the creative act of making; (3) problem-solving; and (4) participants' ability to engage in wire-bending through various roles - as a designer, an analyst, a recorder, and/ or a fabricator to name a few. The final finding that the Grammar appears to increase participants' interest is evidenced by their taking varying approaches - exploring materials, connections, and/ or forms – to designing artifacts. They reported feeling increased confidence, a greater degree of design freedom, and saw the rules as an enabler in the process.

4.2 Limitations

While insight into the Grammar's potential pedagogical and practical contributions emerged from these workshops, I also found some limitations. They included: (1) difficulty fabricating intricate wire bends by hand; (2) difficulty understanding drawings and mathematical symbols in the Grammar; and (3) the Grammar's lack of material behavior information. I discuss these in more detail in the following paragraphs.

Making intricate bends with hand tools
13% of participants expressed having difficulty making wire connections that had tight bends. Although this is not specific to the Grammar but instead to the current way of engaging in wire-bending, it does motivate the introduction of new tools, machines, technologies, and processes to aid those who may have physical limitations or find the practice labor-intensive. This creates a space for those who may be interested in design computation and historic preservation, and democratize the practice (Noel 2016, 2017a, 2017b).

Understanding Grammar
9% of participants expressed having difficulties understanding the drawings and symbols in the Bailey-Derek Grammar. This might indicate that spending more time explaining and demonstrating the Grammar, and engaging in hands-on practice with participants would be helpful. Although this small number of participants had some

difficulty, they were still able to contribute to the creation of artifacts with the help of their teammates. This highlights the ability of the Grammar to serve as a medium through which those who understand it can help those who do not, and create additional spaces for participation. One participant suggested showing, "*3D views of some joints*". While including photographs and 3D views might be helpful to some as a guide, the computational power of the Grammar resides in its existence as an abstract set of signs and symbols to be interpreted and calculated.

Material Behavior
One participant observed that the Grammar, *"doesn't tell you how the material behaves."* This is an interesting point that opens up questions about how material behaviors and properties might or should be described. This material knowledge I argue should be revealed though sensory participation. Disembedding material behaviors from personal involvement might devalue the experience and short-circuit the maker's consciousness such that material qualities are not considered during design (Ingold 2000). This approach gives a "*heightened sensitivity to the fleshy realities of the human body*" and expands discussions in the practice (Noel 2018; Merle 2010).

5 Conclusion and Future Work

In summary, the Bailey-Derek Grammar can contribute to repairing craftsmanship in wire-bending by facilitating the documentation of processes, the restoration of artifacts, and the creation a new space for group design and making. There now exists a design tool for use in education and practice to: (1) increase the rate of transmission of knowledge for the development of skilled wire-benders; (2) increase interest and participation in the craft through design, restoration, and group making; and (3) increase the rate at which artifacts are fabricated, thereby slowing down the impending disappearance of the craft. In addition to being a restorative computational design tool, the grammar can also be considered remediative since it enables documentation and transmission of knowledge – which does not currently exist – and presents computational ways of engaging in the craft.

Future work will continue to test and explore the theoretical, practical, and pedagogical outcomes and contributions of employing computational approaches to repair in craft practices. In the specific case of wire-bending, I will test and explore: (1) the role the Bailey-Derek Grammar plays in remediation; (2) the effects of using other modes of documentation and transmission of knowledge - photos or videos - in the practice; (3) the role of demonstration for observation, imitation, and enskilment by participants for fine-tuning of perception and action (Ingold 2000, 37); and (4) the role of other developed computational approaches to repair. It is important to acknowledge that the cost of testing and deploying this restorative tool was "affordable" for the researcher and participants. This is in contrast to high-tech computational approaches that require larger amounts of infrastructure which are usually costly.

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