A pilot study with the Shaper Origin to determine the learning curve of augmented fabrication

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Abstract
Augmented fabrication is an upcoming technology which combines digital design with physical manufacturing. Since there is a lack of experimental data on the benefits and experiences of augmented fabrication, a pilot study was done with the Shape Origin, a spatially aware manual CNC cutter. The experiment consisted of engraving a set of boards with circular 2mm groove. As a pilot test, the co-authors participated in the experiment and engraved five boards each.

We concluded that the quality and elapsed time improved significantly after repetition. As participants, we ended up with more confidence in operating the machine and growing more knowledgeable about the wood as a material during the engraving, resulting in cleaner cutting results with a flat learning curve.

Author keywords
Augmented fabrication; craftmanship; Human-computer interaction; carpentry

Introduction
Today, evolving technology allows us to design and manufacture automatically (Weigert et al., 2019). Yet because of this, the creative input of the designer and the experience gained during the process vanishes more and more (Zoran & Paradiso, 2013). The experience a designer feels during the process of making the product, will provide insights about the material and applicable fabrication methods. Once it is completely digitally done by machines, the designer is not able to adjust during the process (Loh, Burry, & Wagenfeld, 2016).

With the use of augmented fabrication tools and digital manufacturing, it is possible for people to do the fabrication process themselves, assisted through digital fabrication means (Verlinden & Bekker, 2017;Mahapatra, Jensen, McQuaid, & Ashbrook, 2019; Yung, Li, & Ashbrook, 2018). In this way, the designer of the product can make small adjustments during this process. Also, most augmented fabrication-tools are very mobile (Yung et al., 2018). Due to this high level of mobility, the person can easily transport the fabrication tool from one location to another. This makes switching between workplaces or different contexts possible. A couple examples of such mobile augmented tools are the FreeD, a handheld digital milling device that is monitored by a computer but still preserves the makers gestural freedom (Zoran & Paradiso, 2013), the augmented airbrush an airbrush that allows novices to experience the art of spray painting (Shilkrot, Maes, Paradiso, & Zoran, 2015), and the D-Coil: a 3D modelling approach that uses wax coiling to bring tangibility to the design of digital models (Peng, Zoran, & Guimbretiere, 2015). Each of these devices assist the user in developing a skill that would otherwise be very difficult and would take a long time to learn.

The concept of augmented fabrication is still new in product development and manufacturing, a structured approach to investigate its benefits requires design inclusive research (Verlinden & Horvath, 2009). Most of such systems are still in development while no experimental data is found on its influence on design. This study represents a pilot study of using the Shaper Origin, a commercially available augmented milling machine (Shaper Tools Inc, 2023). The focus is on the learning curve and quality of the resulting workpieces.

Method
In this pilot study, the Shaper Origin will be our practical testing tool (Shaper tools inc., 2023). The research question was formulated as *to what extend (time) does working with the Origin Shaper tool as an augmented fabrication machine improve custom board cutting?* Furthermore, by fabricating a design several times we want to see if the fabrication process is getting faster and easier (i.e., learning effect).

To verify if a learning curve can be flattened by using augmented fabrication tools, practical research is the best option. As Nielsen stated, an estimation of usability requires only 5 participants (Nielsen, 2000), while a subjective verification of the use of such tools is still lacking.

Workpiece design
In this experiment a set of wooden plates were engraved with a circle contour (figure 1).

Since this was a simple design, the engraving design was made on the machine - it comes with a basic toolset in which we could model the contour. This made the start of the process quicker and easier. Figure 2 left shows how the milling path is being mapped in the centre (concentric).

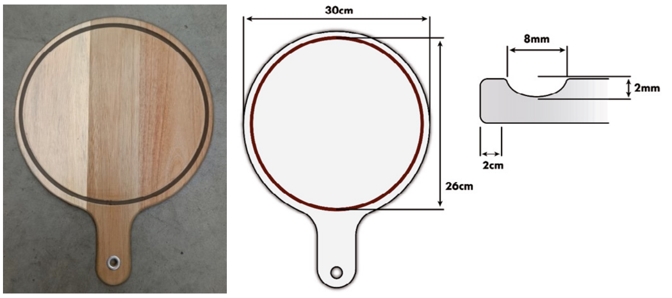

Figure 1. Workpiece and its dimensions.

Figure 2. Left: Shaper Origin display with engraving design, right: finished workpieces.

Each of the participants was tasked to engrave five wooden plates. From a functional perspective, a circular groove/split with a diameter of 26 cm was determined to prevent juices from draining of the plate when dinner is served onto it, as indicated in red in figure 1. Apart from measuring the time to complete the workpieces, the quality of each contour was rated.

Pre-test with Shaper Origin

The shaper origin is a commercially available handheld milling machine that is spatially aware using a specific tracker tape on the work surface, which is observed through a camera by the internal computing unit. The interface guides you by showing a path you need to follow. When you deviate from the milling path, the tool adjusts itself in time to prevent any minor mistakes.

To check if our experiment setup was appropriate, we did a pre-test with a test plate. This way we could make sure the machine was set up correctly, specifically the engraving pattern and depth.

The engraving was designed to be 2 mm deep, this required two milling phases: the first time one millimetre and the second time two millimetres with a ball-end mill (Ø8 millimetre). Thus, the full milling path is 163 cm.

We immediately noticed that the elevated surroundings were not wide and high enough to support the Shaper. We needed to add more of support surface to prevent the Shaper from getting out of balance when moving around the wooden plate.

Furthermore, the tracking stickers required careful planning. Since the elevated surface(s) of the jig had a small surface, these were not usable for placing the stickers. As seen Figure 2 on the right, we ended up using a lower surface as no inaccuracies were noticed by this hight difference.

During our setup and pre-test, we experienced several unexpected challenges, for example the need for more tracking

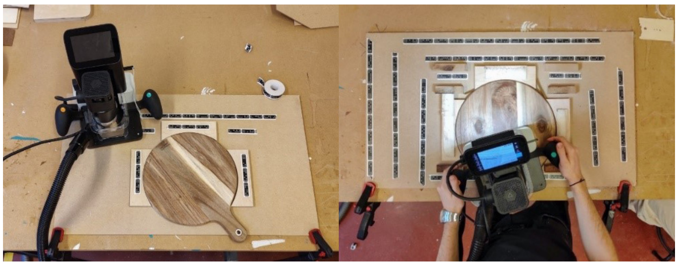

Figure 3. Placement of tracking tape - left: initial, right: final.

stickers on the board. This caused the Shaper to lose track of its position. Secondly, due to a height difference between the working surface and the support blocks, The Shaper often lost balance. The pre-test findings can be found in the Appendix.

Determining engraving quality and flaws

In Table 1, a visual categorisation of flaws is provided. When moving the miller too slow, black spots/burn marks appeared on the edges. This was due to the heat caused by the rpm or because the mill was due for replacement (flaw 1). Another flaw that appeared when going too fast, was these frayed edges (tear-out). These were very visible, so we did our best to avoid them (flaw 2). Not deep enough only shows white marking (flaw 3). Some of the boards had an uneven surface, causing uneven groove depths (flaw 4). This was a flaw we did initially not take into consideration when calculating the quality scores, yet it influenced the overall look of the engraving. Where the starting point and the endpoint met, the lines not always connect perfectly. This was due to starting and ending the milling process abruptly.

The occurrence of flaws determined the quality score for each workpiece. No flaws are represented as a 10 out of 10. Each flaw is subtracted, ranging between -3 (very visible) and -1 (minimal).

Table 1. Categorisation of milling flaws.

Flaw 1 – burns

Flaw 2 - frayed edges

Flaw 3 - insufficient depth

Flaw 4 - uneven surfaces

Results

The participants all are 4th year product development students at the University of Antwerp, ranging between 21-24 years old with no formal training on manual milling/wood-working. Before the experiment, the participants gave a confidence value they felt about working with the Shaper tool. Afterwards they were asked to rate their confidence working with the Shaper tool again.

For each participant, the time to finish one workpiece was captured. The five measurements were be put on a timeline, shown in Figure 4.

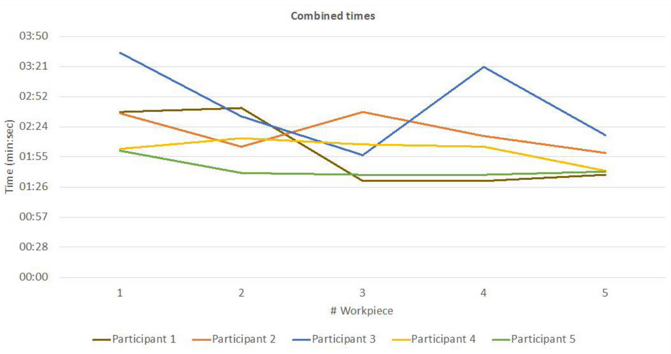

Figure 4. Times per participant.

In most cases, the initial workpiece took most time and there is a gradual decrease of approx. 30-45 seconds to complete each workpiece between first and last plate per participant. Time drops over time occurred for multiple participants, suggesting an increase in efficiency. Secondly, several mentioned the feeling that handling the machine. However, in some cases exceptions happened (like participant 3 in workpiece #4 where tracking was lost) while overall times stayed below 3 minutes – which translates to a minimum speed of 0,9 cm/s and a typical speed of 1,4 cm/s.

Figure 5, the quality plot, reveals increasing scores of each consecutive workpiece in comparison to the initial board. This is due to the fact that the participants found a comfortable tempo of following the contour and operating the machine. The roughness differences between some of the plates were negligible.

In subjective feedback, the nature of guidance and correction felt natural to the participants. Lastly, with more practice, not only the time, but also the quality of the engraving was improving. This became noticeable through the understanding of which groove shape was desired, but also getting used to the manner of operation with the Shaper Origin had an influence across the participants, which resulted in overall better results. There were deviations in the workpiece thickness

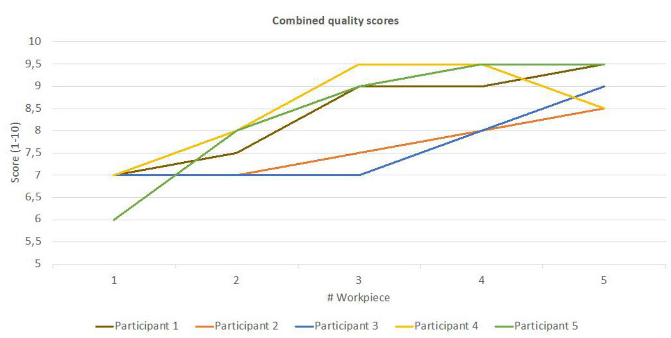

Figure 5. Quality scores per participant.

which on close inspection influenced the performance (flaw #4). The tracking tape should be put on the same level as the milling surface.

Figure 6 shows that the more plates an individual participant cuts, the higher their overall efficiency scored. Even with the difficulties through the middle ground of the plates (2nd plate 2 to 4th plate), the comparison from the 1st plate to the 5th plate all participants scored higher.

Figure 6. Efficiency per participant.

Conclusion

Augmented fabrication tools can potentially greatly reduce the amount of skill that is needed to operate certain machines, this way the steep learning curve might suddenly become much flatter.

This study involved engraving a set of plates, performed by participants that had little experience with carpentry. As the collection of 25 workpieces could be manufactured and objectively tested on quality, this pilot study is a first of a series on the performance of digital craftmanship.

Both by time measurements and subjective evaluation, we can conclude that the augmented fabrication with the Shaper Origin does add sufficient guidance to engrave a continuous curved contour in relatively little time (less than 3 minutes per workpiece). Repeated operation decreases the manufacturing time, while the quality of the engraving was the same during the experiments, while some improvements were certainly visible. Furthermore, the subjective feedback and the confidence score of the participants grew along the executing of the experiment. This all establishes to a small learning curve to operate and design engraving with augmented fabrication – both in performance (time and quality) as well as confidence.

Of course, improvements in small series manufacturing do not necessarily influence the ideation/prototyping process, and specifically with carpentry, more consideration of the material (macro structure, grain, warping) is required to improve quality and creative expression.

Acknowledgement

The authors would like to thank Danny Stoop for the technical support and expertise on carpentry.

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Appendix Pre-test timings and challenges

1st setup	7:17	scanning
Preperation	1:47	Programming circle and dept
Milling 2mm	3:26	Milled to deep, not complete, Too few stickers
2st setup	4:43	Extra stickers, new scan
Preperaton	2:48	Programming circle and dept
Milling depth 1mm	8:26	Lost orientation, no clean groove
Milling depth 2mm	4:02	Lost orientation again, new scan
Milling new supportive blocks, adding extra sticker		
setup 3	2:58	Adding extra stickers and adding support for the shaper
Preparation	1:00	Programming circle and dept
Milling depth 1mm	1:39	No problems, everyhting went good
Milling depth 2mm	1:27	
final test		
Milling depth 1mm	1:23	
Milling depth 2mm	1:15	