Designing and Evaluating Embodied Sculpting: a Touching Experience

Mario Romero
KTH
Lindstedtsvägen 5
114 28 Stockholm
marior@kth.se

Christopher Peters
KTH
Lindstedtsvägen 5
114 28 Stockholm
chpeters@kth.se

Jonas Andrée
KTH
Lindstedtsvägen 5
114 28 Stockholm
jonandre@kth.se

Björn Thuresson
KTH
Lindstedtsvägen 5
114 28 Stockholm
thure@csc.kth.se

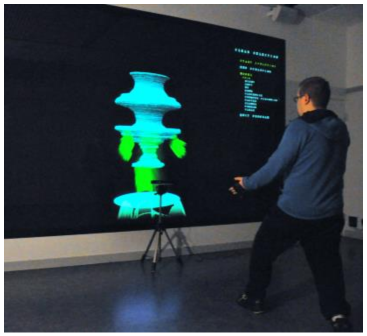
Abstract
We discuss the design and evaluation of embodied sculpting, the mediated experience of creating a virtual object with volume which users can see, hear, and touch as they mold the material with their body. Users' digitized bodies share the virtual space of the digital model through a depth-sensor camera. They can use their hands, bodies, or any object to shape the sculpture. As they mold the model, they see a real-time rendering of it and receive sound and haptic feedback of the interaction. We discuss the opportunities and challenges of both designing for haptic embodiment and evaluating it through haptic experimentation.

CHI 2014, April 26 to May 1, 2014, Toronto, Canada.
ACM xxx-x-xxxx-xxxx-x/xx/xx.

Author Keywords
Embodied Sculpting, User Experience Evaluation, Haptic Feedback, Multimodal Feedback, Depth-Sensor-Based Interaction, Volume Rendering, Digital Crafting.

ACM Classification Keywords
H.5.2. User Interfaces: Auditory (non-speech) feedback. Haptic I/O. Input devices and strategies. Interaction styles.

Milo: Introducing Embodied Sculpting
We introduce Milo, an embodied sculpting experience that combines in-air full-body interaction with real-time volume modification and rendering (see Figure 1). Users see, hear, and *feel* the sculpture they create directly with their hands. Through the depth-sensor of a Microsoft Kinect, we bring the physical body of the performer into the digital space of the sculpture. The sculptor's depth image removes material from the volume by set difference – the intersection between the depth image and the model disappears from the model. When this occurs, the user hears a scraping sound and feels haptic feedback on the palm of their hands. We designed a wireless haptic band for transmitting feedback to the user. We chose a band to ease the process of putting it on and removing it (see Figure 2). In the following sections, we summarize the design process and contextualize it within related work and we reflect on the evaluation experience of embodied sculpting.



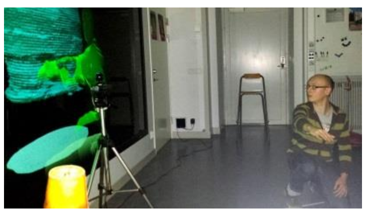


Figure 1: Milo: an embodied sculpting experience where the performer's digitized body shares screen space with a 3D volume. The sculptor removes material from the model by intersecting the depth image with the volume and receives sound and haptic feedback of the action. Two users full-body interacting with Milo.

Related Work

Previous work on digital sculpting programs typically utilize two types of representations for the model. Mesh-based-models are the most common but there is also a few using voxel-based and daxel-based geometries. Hua and Qin created a tool that uses volumetric implicit functions for haptic sculpting using voxels and different sized virtual tools [5]. Moritz et al. created clay modelling tools using 643 voxels [6]. Galyean et al. had real time voxel editing at 103 voxels based geometry in 1991 [2]. Zhu et al. demonstrated real-time editing using daxel-based geometry with one point editing tool [9]. Huff et al. published data on two-handed input combining of 2D and 3D mouse input with sculpting tools and a voxel-based geometry [3].

While virtual sculpting is the process of creating a digital model where the interface is a set of virtual tools that the user controls through 3D tracking devices, such as the Sensible Technologies Phantom®. The experience of virtual sculpting is closer to embodiment when compared to desktop modelling using traditional interfaces, such as keyboard and mouse. Nevertheless, we argue that it is still distant from a fully-embodied experience, where the only necessary tool for sculpting is the body and the necessary output includes visual and haptic feedback, primarily, and possibly augmented with sound feedback.

Dourish introduces a compelling case for embodied interaction in "Where the Action is" [1]. Nesheim presents a current survey paper of general computing embodiment in the age of the Kinect [3].

Evaluating Embodied Sculpting

We began with the research question: What is the impact of augmenting visual-only feedback with sound, haptic, and sound and haptic feedback on the experience of embodied sculpting?

We ran a controlled, within-subject, task-centric user study. The control condition was visual-only feedback. The three experimental conditions were: 1) visual-plus-sound feedback; 2) visual-plus-haptic feedback; and 3) visual-plus-sound-plus-haptic feedback. We randomized the presentation order of the three experimental conditions to mitigate bias and learning effects.

We recruited twelve sighted and hearing adults, who moved with typical gait and used both hands with typical dexterity. Our aim was to target a general, fully-abled population.

In order to elicit the necessary engagement for purposeful interaction, we tasked the participants to copy real-world objects and non-animated 3D models. We gave the participants a set of eight tasks, two per condition. The tasks lasted between five and ten minutes each. We did not strictly enforce a time limit as we wanted participants to be explorative. We ran a think aloud protocol during the study and an exit survey containing six Likert-scale questions comparing the participants' perceived experience between experimental conditions. The questions had open-ended fields to expand on the answer and there was a final open question providing an opportunity to constructively criticize Milo.

We discovered that sound feedback clearly improved the visual experience of embodied sculpting. Yet, once

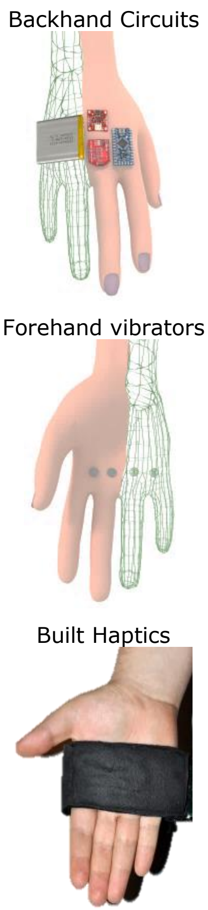


Figure 2: Design of a wireless haptic hand band. An Arduino microcontroller board controls four electric vibration motors on the palm of the hand. The Arduino board, the WiFly, the battery, the charger go on the back side of the hand.

haptic feedback is active, sound feedback has little effect. Haptic feedback accounts for all the improvement and it is much larger than that of sound feedback alone. Figure 3 visualizes the results from the survey. The clearest evidence that haptics matter statistically significantly more than sound is the difference between questions 4 and 5. The Likert scale ranges from "*1-I don't agree at all*" to "*5-I agree completely*." Q4 asks: "Having *Sound-and-Haptic-and-Visual* feedback improved your experience of Embodied sculpting compared to *Haptic-and-Visual* feedback" (Q4: AVG=3.00, STD=1.21). Q5 asks: "Having *Sound-and-Haptic-and-Visual* feedback improved your experience of Embodied sculpting compared to *Sound-and-Visual* feedback" (Q5: AVG = 4.75, STD=0.62). We measured this difference through a pair-wise t-test (t_{11} = -4.47, $p < 0.0005$).

Discussion on Haptic Evaluation

The results from the study into embodied sculpting raise important challenges. They demonstrate the importance of touch and highlight a potential paradox in using tactile interaction for both feedback and UX evaluation concurrently. Embodied interaction, in general, and embodied crafting and sculpting, in particular, serve as fertile discussion points to raise these challenges, due both to the nature of the application and the findings of the evaluation.

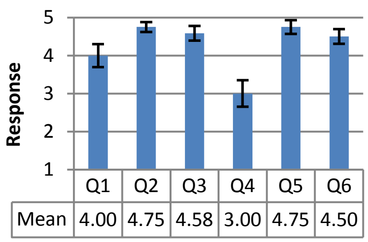
Embodied Expressivity

We see interesting interactions between tactile feedback based on the material of the object, how users control their arm/hand motions, and the resultant creations.

Ultimately, Milo users create multidimensional objects. They span a virtual space and historical time and are colored by the expressive state of the sculptor. In certain moods, the sculptor may use large, secure strokes. In other states of mind or creation, the artist may use delicate caresses to sculpt. In fact, we have observed deep personality traits emerge from sculpting modes. These aspects of the user experience are captured, embedded, and reflected in the quality of the objects. For example, in painting, different colors and stroke types reflect different emotional states. We see embodied sculpting analogues for these states that relate more to this particular experience and material. Can some of these experiences be decoded from the final object or the crafting process? We have started this exploration by logging the sequence of depth buffers that produce the object. It will be interesting to combine these buffers, which can activate the haptic feedback in playback mode, to let the sculptor view, hear, and *feel* the recording and reflect on it.

Invasiveness

Evaluating embodied sculpting through its own haptic interaction may be potentially less invasive and more subtle than the explicit and foreign-to-the-experience tactile modality specially reserved only for UX evaluation, for example, the probes in [2]. Through the development of subtle experience sampling methods for embodied sculpting, we aim to find a sweet spot limiting the Heisenberg effect of UX. Of interest to the workshop is the challenge of naturally augmenting haptic feedback to user experiences for which it is not an intrinsic element. There are likely advantages and disadvantages for both cases, and it is a lush question to raise.



Q1	**S**+V	>	V
Q2	**H**+V	>	V
Q3	**H**+**S**+V	>	V
Q4	H+**S**+V	>	H+V
Q5	**H**+S+V	>	S+V
Q6	**H**+V	>	S+V

Figure 3: Likert scale exit survey of user experience. The survey presents the scale: "1-I don't agree at all" to "5-I agree completely." There were six Likert scale questions. In the table below the figure, we summarize the questions. The terminology "A>B" means "A is rated higher than B." The abbreviations mean: V-visual feedback; S-sound feedback; H-haptic feedback. The plus (+) sign means adding the modalities together in the output. Thus, for example, the text we presented for Q1 reads: "Having Sound-and-Visual feedback improved your experience of Embodied sculpting compared to Visual-Only feedback." In the table, the tested experimental condition is in bold characters.

Participant-born ideas

That haptic feedback is more important for embodiment of sculpting is expected. That it is so dominant is surprising. Yet, as one participant put it, "it makes sense, you are sculpting with your hands and you feel it in your hands".

Yet, several participants pointed out numerous opportunities for improving the design, which, so it happens, also open further evaluation possibilities.

First, we provided binary feedback across all four vibrators on a single palm. While we could have created a more complex interaction model, we needed to explore the basic difference between having and not having haptic feedback. We propose rigorously exploring graded-response feedback equally distributed across all vibrators and also differentially distributed to activate the appropriate parts of the parts of the depth image of the body interacting with the volume. Through Kinect skeletal tracking and volume intersection, we can appropriately map where and how much haptic feedback the user receives.

Second, while creating a one-on-one mapping between the sculpting and the haptic feedback provides a clear immersive embodiment of the experience, there exist other intriguing alternatives. For instance, we can produce a persistence of memory in the haptics. They need not simply turn on and off as the user interacts with the model. They could remain on for a while and, extremely interesting, start tingling before the user's depth image actually intersects the model, as a mode of anticipation similar to the raising of the hairs in the back of the hand before touching the old cathode-ray tube televisions.

It gets particularly interesting if we give the user control over the level of haptics: where, when, how much, for how long. Our conjecture and final contribution to the central discussion of the workshop is that by giving haptic control to users, we will learn both about the experience of embodiment and about use of haptics as an evaluation tool.

References

[1] Dourish, P. (2004). *Where the action is: the foundations of embodied interaction.* The MIT Press.

[2] Galyean, T. A., & Hughes, J. F. (1991). Sculpting: An interactive volumetric modeling technique. In ACM SIGGRAPH Computer Graphics (Vol. 25, No. 4, pp. 267-274). ACM

[3] Hua, J., & Qin, H. (2001). Haptic sculpting of volumetric implicit functions. In Computer Graphics and Applications, 2001. Proceedings. Ninth Pacific Conference on (pp. 254-264). IEEE.

[4] Isbister, K., Höök, K., Sharp, M., & Laaksolahti, J. (2006). The sensual evaluation instrument. *CHI* (p. 1163). New York, New York, USA: ACM.

[5] Moritz, E., Kuester, F., Hamann, B., Joy, K. I., & Hagen, H. (2000). Toward immersive clay modeling: interactive modeling with octrees. In Electronic Imaging (pp. 414-422). International Society for Optics and Photonics.

[6] Nesheim, E. (2011). *Framing Embodiment in General-Purpose Computing. A study identifying key components in a multimodal general-purpose computational environment.*

[7] Zhu, W., & Lee, Y. S. (2004). Dexel-based force–torque rendering and volume updating for 5-DOF haptic product prototyping and virtual sculpting. Computers in industry, 55(2), 125-145.