An exploration of subtractive 3D art forms in virtual reality

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ABSTRACT
This paper outlines a system for three-dimensional digital modeling in virtual reality which resembles a tangible art form. The program explores the potential of subtractive digital carving, how it can be virtualized, and what feels natural and intuitive to a user. Painting in three dimensions is already a popular idea in virtual reality software. The system designed for this project introduces a different way of interacting with three-dimensional material in virtual reality and compares it with an established tangible art-form outside of VR.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords
Virtual reality; User interfaces; Graphics; Carving; 3D Art; Traditional Art; Modeling; Oculus Rift; User Study; Unity

INTRODUCTION

The technology for virtual reality (VR) has been in the works for centuries and the concept behind it sensationalized for decades. Since the turn of the century, important developments in motion tracking, rendering, and gaming have paved the way for more accessible VR. Popularized tech like the Nintendo Wii, 360° video, and immersive gaming have fostered public interest in virtual reality which, over the years, has led to the funding for more pertinent VR technology, such as the Oculus Rift (see Fig. 1), which began as a KickStarter campaign for a low-cost head mounted display (HMD) in 2012 (Sherman, W. R., & Craig, A. B, 2018). The emergence of the Oculus Rift sparked competitors to release their own takes on the HMD; in the years to follow, Valve announced the HTC Vive and Samsung released their own VR Gear, specialized to run from a smartphone placed inside of a headset. VR HMDs became cheaper, more common, and more profitable. Usability issues like nausea and discomfort are being addressed and solutions are being found to make VR more universal (Mammen et al, 2016). Today, there is a wide range of software developed for use in VR. Many games are designed with VR support in mind and the use of virtual and augmented reality is quickly spreading to the workplace and educational spaces. Because of its ability to comprehensively represent three dimensions, there is a strong interest in VR as a tool for three-dimensional modelling. The software which caters to this often overlaps with that designed with a more traditional art community in mind. The use of computing technology to create art has always been prominent; the fields have been converging for decades (Sengers & Csikszentmihályi, 2003). The idea of painting in three dimensions is increasingly popular in recent VR software such as Google's Tilt Brush (Google, 2017), and using VR to make art is a natural progression from two-dimensional digital drawing and painting which has been common for decades. While inspiration from two-dimensional art forms and mediums is common, and features from modelling programs are often integrated, there is little to speak of in terms of direct comparison from traditional three- dimensional art forms to VR art programs. Most existing virtual reality software for the visual arts are based in additive mediums, applied to three-dimensional space; however, very few of these existing programs emulate the tactile instincts of many traditional subtractive three-dimensional art styles. This is counter-intuitive to the methods that humans have normalized for interacting with tangible material to create three-dimensional art.

Figure 1. Oculus Rift, Touch Controls, and Sensors (Tew, 2017)

As a new approach to three-dimensional art and modeling in virtual reality, we developed a piece of software which works through the subtraction of material, based on the traditional arts of carving and more loosely, sculpting. Exploring underrepresented ways of interacting with three-dimensional materials outside of the constraints of the physical world has allowed us to examine human instinct and comfort with different forms of virtual and physical arts. By comparing user experience with our software to that with a tangible, real-world 3D medium (soap carving), we were able to isolate factors which separate the experiences and determine areas which could be improved within our software and other similar ventures.

LITERATURE SURVEY

There are countless angles at which to approach the intersection of art and computing. With continuing technological advancement, there is also increased interest in the many ways art can be produced with computers and with virtual reality. One source we looked at documented the creation of a spray paint simulation that both accurately recreated the process of spray painting, and added an extra level of technical overlay that could be used to enhance painting. The goal was to allow for training without the cost of materials, and to allow paint developers to test out new variations without having to manufacture them first. Using a heat map of paint density users could see if they were covering enough, or too little, and could see in real time a photoreal virtual representation of what it looked like. They tested it with professional and novice painters and found that the virtual results were similar to what was expected of the same tasks in reality (Konieczny et al, 2008). This is a prime example of how art in virtual reality can supplement and affect its real-world counterpart. Understanding the relationship between virtual art-forms and real-world counterparts was the goal of another study at the University of Hawaii-Hilo. Aguilera et. al. studied various mediums and exercises; they created objects physically and moved them into the virtual world, as well as modeled objects virtually and then 3D printed them. By understanding the special elements of tangible media they hoped to enhance future virtual work, as all of virtual reality is rooted in the physical world on some level (Aguilera et. al, 2017). Part of the appeal of virtual reality is the aspect of full immersion in something free from real-world constraints. This changes the way artists can think about the presentation of their work. Even old art can find itself reinvented by virtual reality. Hürst et. al. have explored the effects of extending traditional art pieces such as Van Gogh's into virtual reality in order to enhance the immersion in the artwork. They used algorithms to project the painting onto nearby surfaces, and to morph unrelated images into the same style. Other 3D elements, such as falling leaves and other effects were also added. After analysis of user comments about 'emotion' and 'style', they found that people were more engaged with the artworks when they were in an interactive, fully immersive environment. The project showed great promise for this type of application of visual art to VR (Hürst et al, 2016).

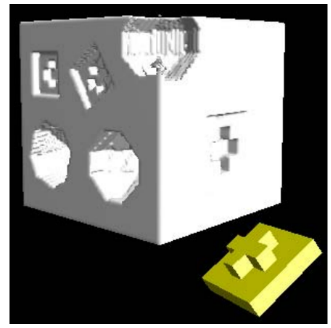

Figure 2. Subtracting voxels with complex forms

Three dimensional subtractive art, though not thoroughly explored as a virtual reality opportunity, has been studied through a couple of different lenses. Starting from a more mathematical perspective, the field of Constructive Solid-Geometry (CSG) involves boolean operations to add and subtract geometric solids to and from each other. This means taking the intersection, union, or difference of two three-dimensional forms (Evan Wallace, 2011). This is a very interesting area of mathematics and has a lot of potential, but would probably require much more optimization in order to function properly in VR for our purposes. A more practical approach we read up on was with a voxel system. One of the earliest works contemplating the topics of voxels and complex polygonal solids (See Fig. 2) was by Prior. His work aimed at surgical applications so that a surgeon could practice various drills or incisions on MRI data. A voxelization method using a series of algorithmic tests on voxels relative to the brush's triangular geometry is detailed. Additionally a few heuristics for optimization are presented to allow for running such a program in real time (Prior, 2006). Early work like this opened for more research on how complex polygonal solids should be formed with voxels and meshed. Because a perfect representation of voxel data is often not desired (and in many cases betrays the intent of the voxel implementation), smoothing is a technique for making the visual representation more true to the intent of the image. Coeurjolly et al presents a method of voxel smoothing using piecewise functions to create quadrangulated surfaces, and shows a few examples of raw voxel data vs their smoothed examples (see Fig. 3). Most impressive is how few voxels are needed to create a smooth believable surface. Implementing an iterative method such as this might allow for higher fidelity with lower voxel counts (Coeurjolly et al, 2018).

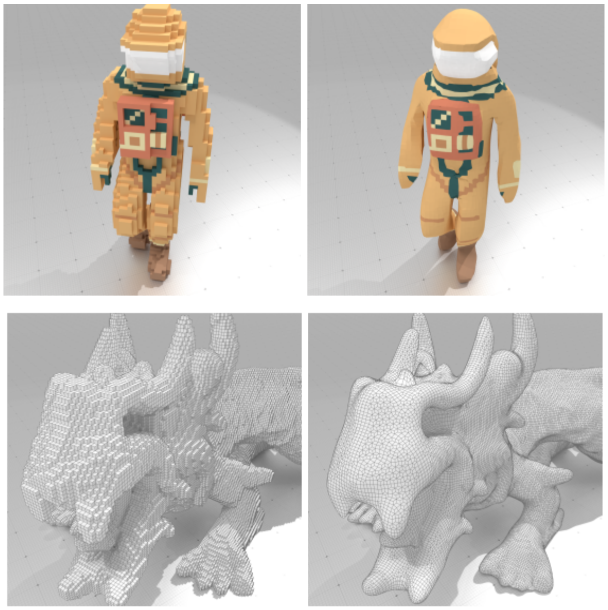

Figure 3. Voxel smoothing

METHODOLOGY

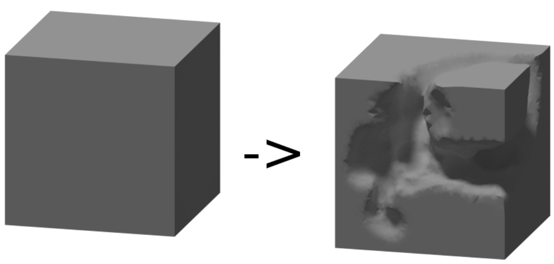

Figure 4. Example of subtractive carving

We have created a piece of software that allows for subtractive carving (See Fig. 4) in VR, and contrasted it with a comparable method of traditional subtractive art: soap carving. The software was developed in Unity due to its easy-to-integrate support for VR. The medium being carved is a block of voxels, or 3D pixels, which are stored in a simple array of boolean values. These values convey whether or not a cubic volume of space (a voxel) is occupied. The voxels are rendered in an optimized process which splits groups of voxels into a system of "chunks" which can be rendered individually and only re-meshed when changes occur within that chunk. This method of rendering the object reduces the amount of necessary remeshing and improves frame rates while carving. The carving itself involves some fairly trivial geometry. We've chosen a simple spherical tool. All of the voxels within the volume of that sphere can be removed by changing all values in the voxel array to false within a certain radius of the sphere's center.

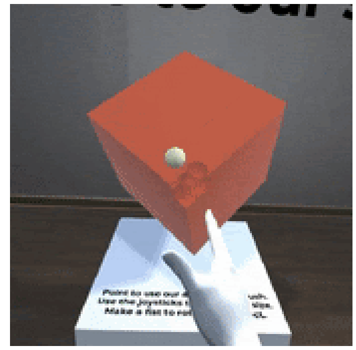

Figure 5. Carving in program.

With this base functionality determined, we were able to design a tool for carving a block of voxels. The tool is a sphere anchored a short distance in front of the user's hand. This sphere, when intersected with the voxel object, removes all voxels contained by it as described above (See Fig. 5). It can be activated on either hand (but only one at a time), and is only active when the user is making a fist and pointing their index finger (See Fig. 6). On an Oculus Touch Control, this means squeezing the lower hand trigger without touching the upper index trigger. When active, the sphere tool can be resized using the joystick on the corresponding control. The user is placed in a studio environment in front of a pedestal and a block of voxels slightly below eye level. In our experiment, we provided room for the user to walk around the pedestal to view and manipulate all sides of the object. However, we also implemented a way for the user to rotate the object by making a fist (See Fig. 7) and turning their hand to apply the relative rotation of that hand's control to the object. Making a fist using a Touch Control here means squeezing both the lower hand trigger and the upper index trigger. For the sake of data collection and further use as a modelling platform, we also implemented an export feature which sends the model to a .OBJ file upon closing the program.

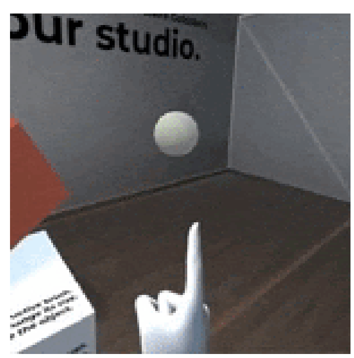

Figure 6. Destructive tool/brush

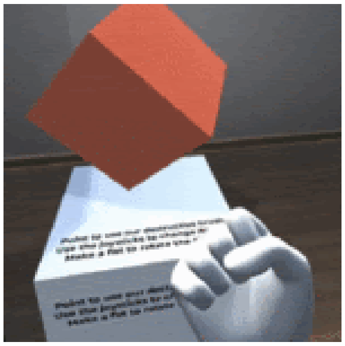

Figure 7. Rotation of voxel medium

We conducted an experiment comparing our version of subtractive 3D art in virtual reality to a tangible real-world subtractive 3D art form. For this real-world art form, we chose soap carving. The desired criteria for the activity we selected included tactile feedback, affordability, and some degree of obscurity. This obscurity relates to our goal of comparing ways of manipulating three-dimensional materials that users are unlikely to have experience with. Such lack of experience is a part of what makes activities like soap carving or art in virtual reality intimidating. The intimidation factor of these activities is one of the key dependent variables we examined in our user study. We collected data from self-evaluation surveys (See Fig. 5, 6) completed by participants before and after both activities. The surveys asked users about their comfort and experience with the activities, as well as the amount (on a likert scale) by which they felt intimidated by the activity. After taking the beginning survey, a user would then be asked to create a fish in either the VR program or by carving a bar of soap in a different room. We chose a fish as the subject because it was a familiar shape to most people which also allowed users to choose for themselves the amount of detail they wished to go into. The order of the activities was randomized across our participants.

Before

1. I have interacted and worked with VR before. (Yes/No)
2. I would feel confident in using VR to make art (1-5 Likert Scale)
3. I have interacted and worked with physical 3D art before. (Yes/No)
4. I would feel confident in using Clay or Soap to make art (1-5 Likert Scale)

5. I feel like I could make something like this with the proper VR tools (1-5 Likert Scale)
6. I feel like I could make something like this with the proper tools (1-5 Likert Scale)
7. I feel like 3D Subtractive art is intimidating (1-5 Likert Scale)
8. I feel like VR art is intimidating (1-5 Likert Scale)
9. Which Seems more intimidating? (Soap/VR)

Figure 8. Before Survey

After

1. VR Time (Value in Minutes)
2. Soap Time (Value in Minutes)
3. I feel like 3D Subtractive art is intimidating (1-5 Likert Scale)
4. I feel like VR art is intimidating (1-5 Likert Scale)
5. Which was harder? (Soap/VR)

Figure 9. After survey

RESULTS

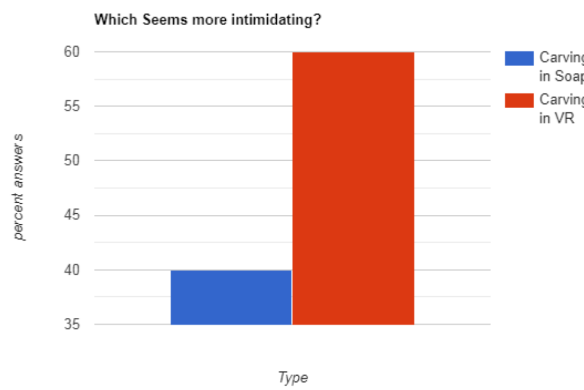

Figure 10. Which art form is more intimidating? (Before)

We conducted two independent samples t-test to evaluate how the ways participants perceived each type of art changed and how those changes compared between the two methods. Means and standard deviations for the two soap carving conditions were: before soap carving ($M = 3.4$, $SD = 0.966$) and after soap carving ($M = 2.7$, $SD = 0.948$). The analysis was not significant, $t(18) = 1.63$, $p = .06$. Means and standard deviations for the two VR conditions were: before VR ($M = 3.5$, $SD = 0.849$) and after VR ($M = 3.0$, $SD = 0.6667$). The analysis was significant, $t(18) = 1.46$, $p = 0.08$. This indicates that, the differences between both of our conditions were not statistically significant. We also conducted an independent samples t-test to evaluate the time difference between subtractive 3D art with soap carving and subtractive 3D art with VR.

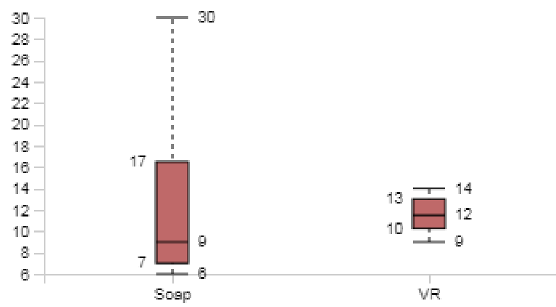

Figure 11. Carving Times

Means and standard deviations for the two conditions were: soap **c**arving time in minutes (M = 13.20, SD = 9.08) and VR time in minutes (M = 11.60, SD = 1.90). The analysis was significant, $t(18) = -0.6$, $p =$ 0.26. This indicates that, the differences between both of our conditions were not statistically significant.

DISCUSSION

For both the VR carving and the soap carving, the users' feelings of intimidation towards the activity decreased after the experience. This was expected. Even though the virtual environment had fewer physical limitations such as gravity, and there was no statistical difference in times, every participant rated it as the harder of the two mediums. This is suggestive of technical limitations in our virtual environment. This is also notable as there were no time limits, and no statistical difference in times. Which means that either the participants couldn't improve their virtual sculpture further, or that they grew frustrated with trying to do so. This could be because of limitations in the detail of the virtual model, forcing users to settle for imperfect final results. The smallest increment of detail was around a centimeter, so this is plausible. Alternatively, because it was subtractive only, and there's no physical push back like with the soap, it could be that users were taking more than they intended too off which lead to a sculpture that could never be completed to their liking. More research would be necessary to say anything conclusive about causation, but it seems highly probable that it's related to some combination of the aforementioned theories.

LIMITATIONS

There may be reasons that our experiment is not statically significant. There could have not been a difference between our two conditions because we either did not have enough participants in our study. We also did not have a representative sample of people that had never done both of the conditions. The people in our study that had more experience could have not been affected by our experiment. Maybe we did not have an adequate training period for both the VR and soap condition. If we would have had multiple sessions where participants would have gotten to learn how to interact with our technology more we might have also seen a difference. The size of the of the medium was also unaccounted for, the bar of soap being non uniform relatively small (< 5" long) while the virtual object measured a foot on all sides. There was also a noticeable difference in detail scale as the smallest change that could be made in the virtual environment was visibly discrete vs the continuas details that could be molded into the soap. This was a necessary technical limitation, but could have changed the user experience, and without further analysis there's clear causation, which in itself could be a flaw. An additional that was not controlled was the time spent on each one of the tasks. Neither had specified times which could have lead to differences in experiences. In future studies it might be good to set a time limit to reign in some of the outlying values timewise.

CONCLUSION AND FUTURE WORK

The results we found point to flaws with natural user interaction, both a designed within our project, and as part of the nature of VR. By discussing with our users and among ourselves, we were able to isolate some of the specific issues that people experienced. One problem we noticed users experiencing was a need for more intuitive control over the object being carved. As is, the rotational control leaves something to be desired in the way of expected and comfortable behavior. Users also had trouble judging depth due to a lack of physical feedback, as well as visual difficulties with lighting the parallel faces of the voxels. Many of the ideas we have for taking this project further address these problems. Moving forward, we would be interested in exploring optimization, scalability, and interactability. With further optimization of the voxel removal process, it could be possible to increase the scale of the entire application by decreasing relative voxel size and increasing the number of voxels , making the shapes of carvings more natural and visually appealing by using higher voxel density (See Fig. 12). We'd also like to look more closely at the current methods of interaction. Features we're interested in implementing include vibrational feedback when carving, different brush shapes to switch between, and a more intuitive way to change the object's orientation.

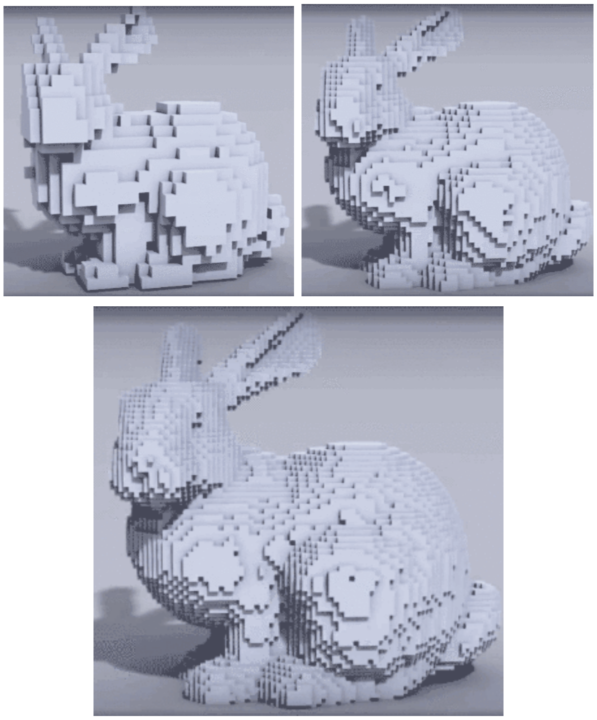

Figure 12. Scaling up voxel density ([Voxel Rabbit])

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