

HAPTIC MODALITY: AN INSCRIBED SYSTEMIC USER “CONSTRUCTION” APPROACH TO SCULPTURE

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ABSTRACT

This paper outlines a haptic “construction” system as means of navigating an interactive design approach to sculpture. A user system applicable to haptic generated form is sought after by way of exploring ‘construction’ as 3-D modality comprised of an interrelated synthesized system. The paper schematically outlines technological and sensory user ‘construction’ modalities as elements towards an expanded ‘synthesis’, ‘construction’ and ‘production’ systemic structure as a way forward for haptic sculpting. ‘Construction’ modalities applied to the case study explore human and machine haptics where the PHANTOM® haptic device and FreeForm® Modeling™ CAD software developed by SensAble Technologies® are used to generate, manipulate and render the touch and feel of a virtual designed sculpture.

Keywords: haptic modality, inscription, construction, sculpture

1. INTRODUCTION

Within each process termed sculpture there is a physiological interaction with material as “substance” involving tactile and supplementary properties. Haptic designed digital sculpture calls for an inclusive understanding of this new medium to enable an exploration of user systems. This paper explores “construction” systems of haptic design as a way of navigating an interactive approach to sculpture. The machine controlled 3-D haptic CAD environment used to generate digital sculpture presents a renewed perspective on the display arena when applying real world modalities of sculpture. Outlined are systemic user elements applicable to human and machine haptics where the PHANTOM® (Personal Haptic iNterface Mechanism) Desktop™ haptic device and FreeForm® Modeling™ (FFM) software developed by SensAble Technologies are used to generate, manipulate and render the touch and feel of a virtual designed sculpture. 3-D ‘construction’ modalities of haptic generated form are comprised of interrelated real world visual semiotic resources such as surface, substance and tools. When systemically categorised haptic sculpting emerges as a synthesised inscription system of technology whereby the human hand is re-introduced via a technological “interface” assembling various renewed effects of the meaning of ‘surface’, ‘substance’ and ‘tools’ in their haptic user interaction.

Although post-modern art practices generally reject such a systemic approach, preferring a separate analysis of object, subject and context, the interactivity of haptic user ‘construction’ lends itself towards applying a

systemic approach as departure point in defining this elusive 3-D medium. In support of such an approach is Simone Gumtau (2006) who claims that identifying semiotic relationships for haptic variables are the most distinctive design parameters and a step towards determining a possible 3-D haptic design palette. This paper therefore presents a schematic outlining potential sensory and technological 'construction' modalities such as spatial orientation, volume, temporality, form manipulation and tool options towards defining a systemic user 'construction' design palette for interactive haptic sculpting (Table A).

Table A. SYSTEMIC USER CONSTRUCTION MODALITIES OF HAPTIC SCULPTURE

MODALITY			CONSTRUCTION	
INSCRIPTION SYSTEMS			TECHNOLOGICAL	SENSORY
SPATIAL ORIENTATION	PLIABILITY		HUMAN SENSORY LOOP (Data: receives/ applies/sends)	
	SPATIAL COORDINATES		KINAESTHETIC/ TACTILE (Bodily: sense/state/position)	
VOLUME			ERGONOMICS	MAPPING X, Y, Z (Anisotropic, Isotropic, Oblique)
			WEIGHTLESSNESS	SOLIDITY PENETRABILITY PLASTICITY
TEMPORALITY (Substance)	TEMPORAL PRESENCE	TACTILE COMMUNICATIVE AGENTS		RECURSIVE SUBSTANCE (Endless/Duration/Repetition)
	REAL-TIME INTERACTIVITY		MECHANICAL AUTOMATISM	RECURSIVE AUTOMATISM (Link: time/medium)
FORM MANIPULATION			HAPTIC-LOOP COLLISION/DETECTION/RESPONSE FILE IMPORT/EXPORT VOXEL SOLIDS	VOLUMETRIC MODELLING HAPTIC TEXTURING
TOOL OPTIONS			SYSTEM ARCHITECTURE	MODELLING CARVING CONSTRUCTION RENDERING

2. HAPTIC MODALITY

Mandayam Srinivasan (2007) outlines that to perform a task using a haptic interface, the human user conveys motor actions by physically manipulating the interface, which in turn, displays tactual sensory information through stimulation of human tactile and kinaesthetic sensory systems. User interactivity results in an immediate engagement with substance and process within the computer as a weightless ubiquitous environment.

The CAD interface shift from keyboard, mouse and joystick operation to the haptic device as 'construction' tool is no longer revolutionary, as its use has become familiar in simulators for medical training as well as film animation design; however it has not yet impacted as a widespread sculpting medium. The Greek term "haptic" meaning "able to lay hold of" encompasses the tactile action on which a haptic feedback system relies which stimulates haptic perception. Haptic force feedback determined by collision detection and response is reliant on kinematic and sensory system architectures. The bidirectional force feedback to the user through the device is termed the haptic loop thus creating a sensation of immediacy during the actual manipulation (Hayward, Astley, Hernandez, Grant and Robles-De-La-Torre, 2004). This sensory haptic loop occurs during both exploration and manipulation of virtual objects classifying the device as a force feedback interface as well as an input apparatus appropriate to the sculptor's tactile needs.

3. INSCRIBED SYSTEMS OF CONSTRUCTION

3.1. Spatial orientation

The "tactile perceptual field" includes the spatial properties of a haptic designed object maintaining contact with hand-arm displacement (Lederman and Klatzky, 1993). This 'tactile perceptual field' primarily activates aspects relating to the overall spatial orientation within a virtual and physiological user design environment. Defining 'construction' modalities encompasses technological device parameters and interactive sensory user factors, dependent on tactile and kinesthetic pliability as well as activated spatial coordinates within the 'tactile perceptual field'.

3.1.1. Pliability

Digital design has both temporal and spatial qualities; the interactive 3-D virtual design environment facilitates meaning to emerge from a sustained human-machine interaction, termed pliability. Conditions for maintaining pliability as an aesthetic experience within an interactive digital design environment are based on prior experiential qualities and procedural knowledge. Digitally designed sculpture that displays a closely connected haptic loop between tactile and kinaesthetic senses can be characterised as having a strong pliable interaction. 'Pliability' within the haptic environment

requires these senses to operate simultaneously to provide the user with means to perceive and act on both technological and sensory interactive modalities of 'construction'.

Tactile and kinesthetic senses

Tactile and kinesthetic senses simultaneously form key operational principals for the duration of the haptic interaction. Kinesthetic senses refer to the bodily sense of state, position and the motion of limbs activated by associated forces; these transmit through sensory receptors in the skin during the interactivity experienced throughout the human-machine haptic 'construction' process. The user is confronted with a relocation of material, texture and substance due to the kinesthetic and tactile interaction.

3.1.2. Spatial coordinates

Ergonomics

The ergonomics surrounding haptic design as an essential technological positioning coordinate determines the users' interaction and work place flexibility with the device as well as the model within the virtual display area. The direct point based PHANTOM® stylus used for interacting with the digital clay operates freely on an articulated armature. Indirect ergonomic options available in the software program facilitate manipulating the virtual clay surface through a range of multi-resolution modelling tools. Directly or indirectly, the correct ergonomics maintain the necessary tactile relationship between user, device and model.

Mapping x, y, z

The sensory nature of this immersive spatial design experience relies on fundamental orientation coordinate mapping (x, y, z) properties of the design arena. Familiarisation with the defined orientation processing of form and spatial user haptic properties, allows the user to engage in an enhanced tactile field. The spatial modality of haptic user 'construction' is therefore reliant on exploratory conditions relating to the various directional planes/stimuli (horizontal, vertical, oblique) which prove crucial to the production or reduction of gravitational forces. In this instance, the user is therefore required to consider the role of gravity and the coding of an orientation in space to ensure an accurate manipulation of the desired form. Simultaneously the user needs to rely on a "working memory" of prior knowledge (Gentaz, Baud-Bovy and Luyat, 2008). This termed a "cognitive stock" resource within each individual on which the haptic user relies to achieve the mental synthesis that is necessary to construct a representational object within the 'tactile perceptual field'.

3.2. Volume

Mass is defined as a system embedded with features such as the object's

centre of gravity, its relation to the horizontal, solidity, impenetrability and the way in which it interplays with surrounding space. The 'construction' of haptic sculpture engaging with the body of the user in relation to various spatial properties of volume becomes characteristic of virtual mass (O'Toole, 1994).

Weightlessness

Merleau-Ponty's (1962, 1968) view on artistic making as a perfect symbiosis of eye, mind, and hand challenges the medium specific sculpture due to a logistical separation between weight and substance. This idea of a split in mental conception and physical substance with virtual haptic sculpting requires reconsideration due to the weightless unrestrained 'construction' environment. As a result, haptic sculpting facilitates Merleau-Ponty's proposed symbiotic sculpting process.

Plasticity/solidity/penetrability

To explore the plasticity of virtual clay as simulated haptic sensory volume element, characteristics pertaining to real clay need consideration. Three main characteristics are prevalent: 1) moist properties of the calculated clay body through water saturation 2) volume preservation during deformation 3) increased surface tension due to saturation prohibiting material disintegration. Guillaume Dewaele and Marie-Paule Cani (2004) performed comparative plasticity tests on interactive global and local deformations for virtual clay. The aim was to simulate virtual clay characteristics via computation models to maintain the substance effects of a real clay body. The proposed model relies on fluid mechanics and mathematical computations to push, pull, twist and bend the virtual objects. Overall findings in the above plasticity case studies reveal that the main characteristics of real clay simulated in real time at a low computational cost provide the user with a realistic interaction with clay as modelling substance.

3.3. Temporality

The term medium within real world sculpture mostly refers to the physical material of the sculpture. Pamela Lee (2004) proposes a more primary understanding of medium that emphasizes its influential value as a communicative agent between two points and in doing so, a dialogue is established between artwork and beholder. Within a haptic user 'construction' interface, temporal presence and real time interactivity encapsulate such a dialogue as communicative agents.

3.3.1. Temporal presence

The overall temporality of 3-D haptic sculpting generates a renewed perspective on how real world-sculpting modalities apply. Michael Fried's (1998) definition of temporality as an endless, duration bound and repetitive recursive experience, and Simon Penny's (1999) reference to digital

technology as substance implicit of meaning entwine as sensory 'construction' modalities inducing a temporal presence within a haptic system of 'inscription'.

3.3.2. Real time interactivity

Due to the mechanical user interface of the PHANToM® haptic device and its association with sculpture it would be suitable to assign Rosiland Krauss's (2000) aligned interpretation of "automatism" as a mode of production of a reality based interactive character wherein a beholder's presence is suspended through mechanical manipulation. In this systemic instance, "real time interactivity" driven by 'automatism' inscribes as an inseparable system consisting of the users' physiological circumstance and the parameters built into the haptic device system architecture. For that reason, 'automatism' with its sensory and technological user interaction (haptic loop) applied as a 'time' based system embedded in temporality suitably equates a haptic 'construction' interface activated during user interaction with the medium.

3.4. Form manipulation

Haptic loop

Technologically, the force feedback of the haptic loop operates as a delayed frequency designed to compute geometric data via a collision detection/response module. In its delayed design structure it receives, applies, and sends data (Bordegoni, Colombo and Formentini, 2006). The efficient functioning of the haptic loop can however be interrupted by system architecture failure as a result of edge of memory (EOM) issues that force modelling to exit resulting in lost data. EOM problems are caused by: 1) high clay resolution, 2) large model file size.

Collision detection and response

During user operation, collision detection and response occur when the PHANToM® stylus touches the virtual surface during contact positioning and/or surface manipulation. At this point, a computational mechanistic model calculating the reaction force during every servo-loop alters the surface of the probe point. The inside/outside property of the function enables a slight collision between the sampling points and surface of the probe. Once a collision point is detected inside the probe surface area, it mathematically responds via modified force vectors, which feed back to the user through the haptic device (Gao and Gibson, 2006).

File import/Export

To facilitate user 'construction' FFM can import a variety of file formats, which allow conversion to virtual clay for further manipulation thereby enhancing program software interoperability. However, in some instances due to the lack

of standardization among various software applications, some geometry does not import as expected, requiring extensive form manipulation prior to 'construction'.

Voxel solids

The mechanical file structure of haptic designed FFM models are comprised of voxels. A voxel is defined as a three-dimensional pixel with a numerical volume unit that is represented by its specific position in x, y, z coordinates; these units of information make up digital clay. Voxels do however limit the surface quality for downstream product development requiring that the model be exported as a compatible file conversion for further program interoperability or the rapid prototyping (RP) thereof.

Volumetric modelling

FFM via haptic device enables a point-based sensory interaction with digital clay for the 'construction' of volumetric objects made up of voxels as defined above. Mandayam Srinivasan and Cagatay Basdogan (1997) explain the computational operation encased in a voxel as haptic interaction properties consisting of bytes of information such as material density, density gradient, colour, stiffness, and viscosity assigned to each voxel that computes at the haptic interface point. Operations within FFM are controlled by force and torque feedback, enhancing realism by stimulating a general tool-object interaction as the users' sculpting tool passes over the implicit surface (Gao and Gibson, 2006). The realism experienced with tool-object user 'construction' facilitates a fluid modelling interaction better suited to the sculptor's tactile needs.

Haptic texturing

Two approaches define haptic texturing. Firstly, an image-based texturing; allowing the user to access a range of pre-loaded synthetic textures. Secondly procedural haptic texturing, which generates synthetic texture fields using mathematical functions for determining the height field of the required texture from which the gradient vector at the contact point is calculated in order to agitate or transform the surface geometry of the object (Srinivasan and Basdogan, 1997).

3.5. Tool options

System architecture

Defining the technological and sensory force variables is dependent on the hardware and software, as well as the interface architecture. The visual haptic process facilitated by adequate system architecture involves sculpting and rendering the model, processing user input, transforming values for haptic and image-based texturing and editing surface properties of the

volumetric representation. The haptic process includes: updating the force feedback displayed by the PHANTOM® collision and response detection feature, finding the contact point, simulate surface properties such as friction and stiffness, and executing the optimal ~1 kHz vibration force computation within the haptic loop.

Modelling/Carving/Construction

Virtual clay deforms according to the user's intended manipulation through simulated pushing and pulling of the virtual surface. For this, there are three main groupings of 'construction' tools: curves, planes, and virtual clay. Editing options in each of these tools assist to generate form; these include control points, direct manipulation, free form deformation and variation modelling. The overall possibilities of editing form and varied tool selections contribute to the users' dependence on a dynamic interaction between model properties and tool options within the haptic 'construction' system.

Rendering

The FFM rendering function applied to 'constructed' virtual clay models, surfaces, and solids is most often used to replicate the envisaged virtual display or explore 3-D material build properties, surface colour, and texture. To enhance overall haptic perception the software application is able to create individual QuickTime virtual renderings of valid views running 360° around the model.

4. CASE STUDY

'Construction' related modalities from conception to fabrication align this artistic medium within the paradigm of sculpture. The sculpture (Figure 1) was modeled using a high-end Windows operating system and graphics card to run FFM and haptic device.



Figure 1: "Helix Rest"

4.1. Generation of form

Profile construction

Starting a haptic virtual clay modelling process begins with the generation of a basic closed curve or import of pre-drawn sketches (figures 2a and 3a). Sketch files are projected onto a clay surface determining the required form from various x, y, z profiles. This process allows for extensive editing options of the profile curve facilitating a more controlled user interaction. Prior to further manipulation the curve can be inflated as clay piece or cut away from a pre-constructed geometric shape (Figure 2b).

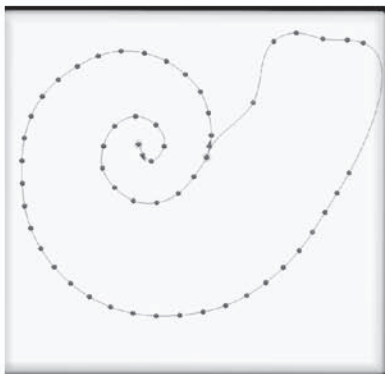


Figure 2a: Closed curve profile

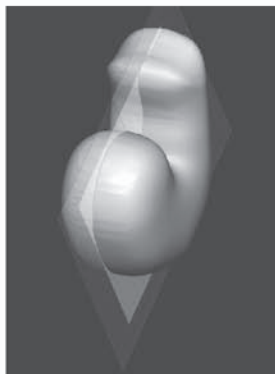


Figure 2b: Inflated curve profile

Haptic feedback and RP strategies align to artistic activities where disruptions to surface finish may be required as opposed to rigid design practice. Edmonds and Soufi (1996) refer to this practice as "emergence" where ambiguous mark making develops through concept sketching. User deviations from curve profiles and initial form 'construction' develop into an expansion of idea. Represented in Figures 3a, 3b and 3c are sequential screen renderings from sketch to interactive sculpting depicting the results of such form deformation.

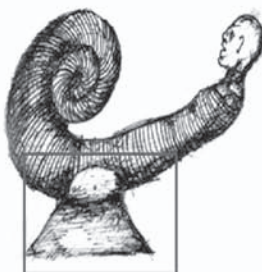


Figure 3a: Initial sketch

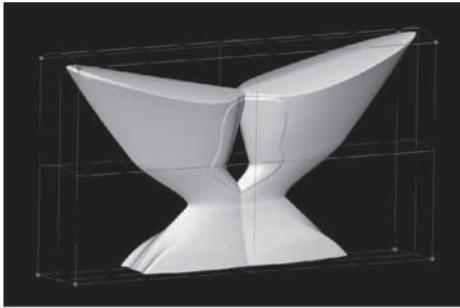


Figure 3b: Initial clay construction deviation



Figure 3c: Further deviation

Approximation of form

Initial form was achieved through a volumetric 'construction' approach. Due to the level of detail required for the RP of the form, the clay coarseness was initially set to a fine resolution thereby increasing the voxel density and file size. As a result, the haptic interaction between sculptor, device, and virtual display at times exceeded its virtual memory limit resulting in data translation delay and loss. The user should approach 'construction' as separate objects, thereby facilitating a speedy data translation of reduced voxel density or file size prior to the merging of objects. Due to the intensity of the facial detail, a separate 'construction' approach was applied to the sculpture with the intention of combining the pieces at the final stage (Figures 4a and 4b). Separate objects are indicated by different clay colours, which also indicate which clay parts are active (yellow) or inactive (grey).



Figure 4a: Separate active/inactive clay objects



Figure 4b: Head detail

The mapping of the global or local x, y, z triad coordinates allows the user to locate the object. The same coordinate translation is required when repositioning two objects to align at an exact collision point. Alternatively, the object can manually be orientated using the "grab" tool option. Applying the coordinate translation is however a fast accurate option when two objects are weightlessly floating in infinity. Spatial orientation of this technical nature presents to the sculptor an adjustment in coordination dynamics that

influences the mechanical automatism experienced as an engaging characteristic of real time interactivity.

Surface deformation

The amount of surface detail is largely reliant on the selection of clay coarseness during 'construction'. The sculptures' smooth surface finish was achieved using interactive size variable smooth, smudge, and carve tools. At times, these operations were carried out using the interactive mirror tool allowing the user to achieve symmetrical form. Once the individual parts of the sculpture were complete, the clay coarseness was uniformly converted to a smooth texture in keeping with the sculptures' organic flowing form. However, the "polyamide" nylon RP build material does not offer the surface detail that a stereo-lithography resin does, therefore the final object conversion back to a coarser clay facilitated easier file translation without compromising detail.

Temporal interaction

Real clay properties linked to defining the workability of surface tension were manipulated via a selection of pre-loaded modelling and carving tools. Exploration revealed that the objects' tactility was dependent on material qualities other than its plasticity, such as size and the nature of the object. Experiential user feed-back during this case study explains that the sensory notion surrounding the haptic user as engaging in a recursive experience of endlessness, duration and repetition during form 'construction' is firmly reliant on the ergonomics of the virtual and technological design environment as well as prior knowledge pertaining to form and principals of sculpture. This embodied approach (Gumtau, 2006) reiterates how interactive haptic sculpting establishes as substance of meaning in its 'temporal presence'.

4.2. Editing and manufacturing issues

Voids occurring between the clay voxels need filling prior to converting the .cly file to a .stl RP build file type. Voids arise due to continual clay manipulation, specifically appearing where surfaces do not align when merging parts. Although the FFM data report claimed that all voids filled, due to user 'construction' voids were still present in the .stl conversion creating pre-build surfacing problems (Figure 5). Translator software "Magics Materialise" repaired the imported .stl file in preparation for the build thereof. Surfacing or filling voids as separate objects prior to the final combining of all clay pieces would have reduced the number of voids present.



Figure 5: Virtual clay voids

When importing .stl files into FFM, data is lost during translation, due to converting surface mesh structures to voxel solids. The user is required to consider this technical issue as it impedes the procedural user 'construction' interface when working with two or more interoperable file exchange systems. The exporting of the .cly file underwent an approximate 96% reduction to the .stl file. Detail was however not lost during the initial 96% .stl mesh reduction for export as the overall mesh reduction merely resulted in fewer triangular formations on less detailed surface areas thereby reducing the overall mesh count and not necessarily compromising detail. Comparatively, Figure 6a shows the appearance of a reduced .stl file structure and Figure 6b displays a more compound mesh structure.

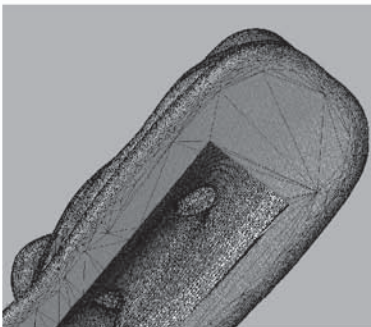


Figure 6a: Reduced mesh structure



Figure 6b: Compound mesh structure

Software tools within this interactive modelling system allowed the artist to emboss name, title of the work and edition specifications on the underside of the form. RP as sculptural medium encompasses manufacturing ethics and copyright issues relating to artistic editions or multiple series productions. This raises concerns surrounding ubiquity, authenticity and authorship, which

have yet to receive extensive critical attention. The sculptor in this case study has limited the edition to five builds with the first of the five regarded as the artist's proof (Figure 7).



Figure 7: Embossing and cavity display

4.3. The realization of form

Build constraints were limited to the additive fabrication Laser Sintering (LS) EOS P385 specifications such as build platform dimensions, tolerances, surface finish and costs. Shelling the build to a wall thickness of 6 mm to reduce material costs created an internal cavity, which raised concerns regarding the strength of the material; this however is a display item only and not a working part (Figure 7). The shelling of the form did not reduce build time, only material cost, as the laser is required to follow the full volume platform path at the same speed irrespective of intricate detail or volume.

5. CONCLUDING DISCUSSION

A systemic approach to interactive haptic sculpting reveals various technological and sensory 'construction' modalities that either challenge or expand real world classifications of sculpture. The spatial orientation surrounding the human-machine interaction with its cyclical receiving, applying, and sending of data, places the user in a pliable state reliant on bodily senses, and position. Although a similar creative embodied interaction occurs during real world sculpting, the continuous haptic loop formed in this instance presents a renewed aesthetic exploration of medium. Outlining temporality proposes a reference to 'substance' as opposed to real-world 'materiality' during haptic interaction as sculptural medium. As a mode of production linked by time and medium, temporal presence and real time interactivity act as tactile communicative agents during mechanical and recursive automatism.

Current limitations

Model complexity is reliant on technical improvements that deliver the stimuli to approximate our real environment. During the case study FFM software's high-end system requirements presented the most challenging limitation due to regular EOM system failure. The overall slow adoption of 3-D haptic modelling and RP as artistic medium can be attributed to high capital outlay and running costs. Due to this, crossing the threshold of commercial viability for the artist has yet to be achieved. At present, these technologies are best located within art-educational establishments where experimentation with new technology is key and not driven by financial capital outlay. The technically dependant concurrent engineering approach to this medium often raises questions as to whether it fits the category of sculpture. In comparison to real world sculpting, the user is equally dependent on technological parameters such as 3-D form, structural elements, material types, properties, and skill. Therefore, in an attempt to categorise haptic sculpting, the medium merely presents a shift in sculptural paradigm, encompassing haptics as an expanded technical and conceptual principal applicable sculpture.

Way Forward

Future sculpting modes point towards voice prompt sculpting, camera captured hand gestures and collaborative sculpting in which asynchronous multi user operation facilitated via network prove to enhance creativity (Gunn, 2006). Irrespective of the interactive haptic sculpting mode, navigating an interactive design approach to sculpture as a 'synthesis', 'construction', and 'production' systemic model lays the foundation from which future divergence of haptic modalities can be theorised.

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