Towards Radical Atoms – Form-giving to Transformable Materials

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Abstract—**Form, as the externalization of an idea has been present in our civilization for several millennia. Humans have used their hands and tools to directly manipulate and alter/deform the shape of physical materials. Concurrently, we have been inventing tools in the digital domains that allow us to freely manipulate digital information. The next step in the evolution of form-giving is toward shape-changing materials, with tight coupling between their shape and an underlying digital model. In this paper we compare approaches for interaction design of these shape-shafting entities that we call Radical Atoms. We use three projects to elaborate on appropriate interaction techniques for both the physical and the virtual domains.**

I. Introduction

The process, which turns intangible ideas into physical representations, is what we call form-giving. With the wake of computing we developed tools to create and shape digital models or digital forms. In this paper our focus is identifying the next steps toward an interaction design framework for shape-changing materials, which we call Radical Atoms [1]. Radical Atoms refers to materials, which keep their physical shape always in synchronization with an underlying digital model. In order to explore form-giving interaction techniques to these dual-citizens of the physical and the virtual domains, we need to assess form-giving interactions from both worlds. In this paper we will outline the most important concepts of Radical Atoms, with an emphasis on key differences compared to objects that create interaction design challenges. Through three projects we will showcase interaction techniques in the virtual and the physical domains. The first project explores purely virtual from-giving: T(ether) is a collaborative virtual reality system that allows users to simultaneously edit virtual data through a spatially-aware [2] tablet device – interaction techniques include gestural and GUI (Graphical User Interface) based interaction techniques with the virtual models. The second project, Recompose, is a shape display that is able to render 2.5D surfaces, using 144 pins. Interaction techniques include free-hand gestures and direct manipulation. The third project, Amphorm, is a kinetic sculpture resembling a vase that is able to change its shape. Interaction techniques include both free-hand gestures and GUI-based interaction on a tablet device. We conclude by identifying the key areas for future research in the topic, using the vision driven design concept of our group.

Figure 1. Interaction techniques in the physical and the virtual domains

II. Radical Atoms

We proposed the concept of Tangible User Interfaces (TUI) [3] that is based on physical embodiment of digital information & computation, in order to go beyond the current dominant paradigm of or Graphical User Interface (GUI). Humans have evolved a heightened ability to sense and manipulate the physical world, yet GUIs based on intangible pixels takes little advantage of this capacity. The TUI builds upon our dexterity by embodying digital information in physical space. TUIs expand the affordances of physical objects, surfaces, and spaces so they can support direct engagement with the virtual world [3, 1].

Through the design of a variety of TUIs, however, we have learned that TUIs are limited by the rigidity of "atoms" in comparison with the fluidity of "bits". TUIs have limited ability to change the form or properties of physical objects in real time. This constraint can make the physical state of TUIs inconsistent with the underlying digital models.

To address this challenge, we presented our new vision, "Radical Atoms" [1]. Radical Atoms takes a leap beyond Tangible Bits by assuming a hypothetical generation of materials that can change form and appearance dynamically, becoming as reconfigurable as pixels on a screen. Radical Atoms is a computationally transformable and reconfigurable material that is bi-directionally coupled with an underlying digital model (bits) so that dynamic changes of physical form can be reflected in digital states in real time, and vice versa.

A. Concept

We envision that Radical Atoms should fulfill the following three requirements: 1) Transform their shape, 2) Conform to constraints, and 3) Inform their ability, in order to utilize dynamic affordance as a medium for representation, while allowing bidirectional input to control the shape and thus the underlying computational model.

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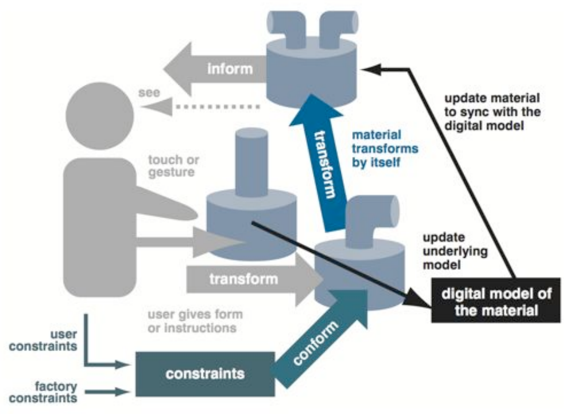

Figure 2. Pillars of Interaction – Transform, Conform, Inform

Transform

Radical Atoms couples the shape with an underlying computational model. The interface has to be able to transform its shape in order to: a) modify the model through the shape of the interface and b) reflect and display changes in the computational model, by changing its shape in synchronicity.

Conform

Material transformation has to conform to the programmed constraints. Since these interfaces can radically change their shapes in human vicinity, they need to conform to a set of constraints. These constraints are imposed by physical laws (e.g. total volume has to be constant, without phase-changes) and by human common sense (e.g. user safety has to be ensured at all times).

Inform

Material has to inform users with its transformational capabilities (affordance). In 1977 Gibson [5] proposed that we perceive the objects in our environment through what action objects have to offer, which property he coined as affordance. For example, through evolution we instinctively know that a cup affords storing volumes of liquid. Industrial design in the past decade has established a wide set of design principles to inform the user of an object's affordance, for example a hammer's handle tells the user where to grip the tool. In the case of dynamic materials these affordances change as the interface's shape alters. In order to interact with the interface, the user has to be continuously informed about the state the interface is in, thus the function it can perform.

B. *Dynamic affordances*

One of the major challenges in field of interaction design for shape shifting interfaces is lack of static affordances. As noted above affordances allow us to easily remember and thus "instinctively" use objects. In the case of shape-shifting materials these affordances exist over time, but not statically. Since static affordances are not able to inform the user of the shape-changing interfaces current function, the challenge of making intuitive interfaces is left to interaction designers.

Following we will list three projects that solve the above mentioned interaction problem through various approaches.

III. T(ETHER)

T(ether) is a tablet based spatially-aware display that allows users to manipulate virtual scenes through gestural interaction. Our system allows concurrent editing of virtual models by multiple users.

The system creates a 1:1 mapping or "tethering" between real and virtual space ("ether"). This provides the user the same spatial reference in both worlds. Users interact with digital volumetric content through a tablet device, which represents a "window" into virtual reality [6, 7]. The device's position and orientation, as well as the user's head position, determine how the scene is rendered, thus the tablet is perceived as a window into virtual reality (spatially-aware display).

The tablet device affords the user with a tangible frame of reference that the system utilizes to create body-aware interaction techniques. In the setup the tablet device splits the interaction space, creating three interaction modalities: behind the screen (object manipulation), above the screen (global controls, e.g. time) and on the screen (object property manipulation) interactions as shown in Fig. 3.

By using a tangible device as reference the user receives physical feedback from modality changes, which leads to a natural role division between modalities. Initial user observations confirmed that our system provides an intuitive interaction to navigate through and directly manipulate volumetric data.

Full-body navigation – The system was designed to encourage exploration of volumetric data scattered in space using the user's body, similar to how people look around in a museum. Every user has a personal window to virtual reality positioned according to the location and orientation of their device and the pose of their head. If compared to the collaborative volumetric data editing setup of Grossman et al [8] the system allows users to work on the same model (close collaboration), while also allowing them to work on different parts (loose collaboration).

Figure 3. Gestural interaction with T(ether)

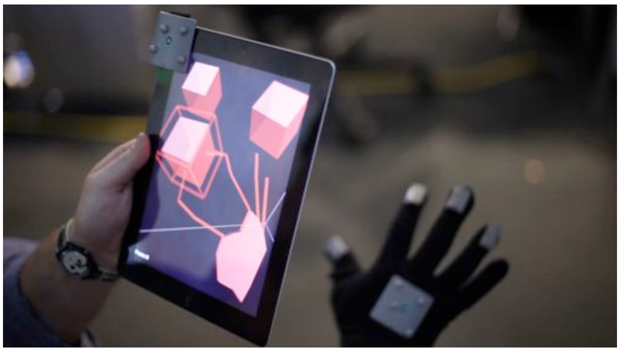

Figure 4. Body-aware Interaction

Hand, as the perfect tool – In order to give the user high bandwidth, natural access to virtual data, the user wears a glove that tracks finger and palm position and orientation. By rendering a model of a hand, when the user moves the glove behind the tablet, the user is afforded a sense of depth perception through the combination of kinesthesia and visual feedback (Fig. 4).

Natural collaboration – According to a concept entitled "Eccescopy" coined by Perlin [9], effective collaboration tools should minimize the use of equipment such as goggles or head mounted displays, which inhibit interpersonal communication. By using only tablet devices, which are not blocking gaze, technology does not invade interpersonal space allowing natural and uninhibited communication.

IV. Recompose

Recompose [10] is a shape display [11] that can render 2.5D physical surfaces dynamically. The project explores how we can interact with an actuated surface through our gestures. The table consists of an array of 120 individually addressable pins, whose height can be actuated and read back simultaneously, thus allowing the user to utilize them as both input and output.

Users can interact with the table using free-hand gestures or through direct manipulation. Direct manipulation allows the user to precisely affect the material world, where the user is guided throughout the interaction by natural haptic feedback. However, direct manipulation is incapable of affecting large areas of a surface due to constraints of the human body. We believe that gestural input solves this problem, through low precision, but expansive interaction.

Figure 5. The Recompose Shape Display

Together, these two input types provide a full range of fidelity from low-to-high precision. We designed the system such that a user can fluidly change context from gestural to direct manipulation without modal state changes. Through these features, we believe to have achieved a seamless expressive interface.

Currently there is no interaction technique that would allow the physical model to be accessed through manipulating the virtual model.

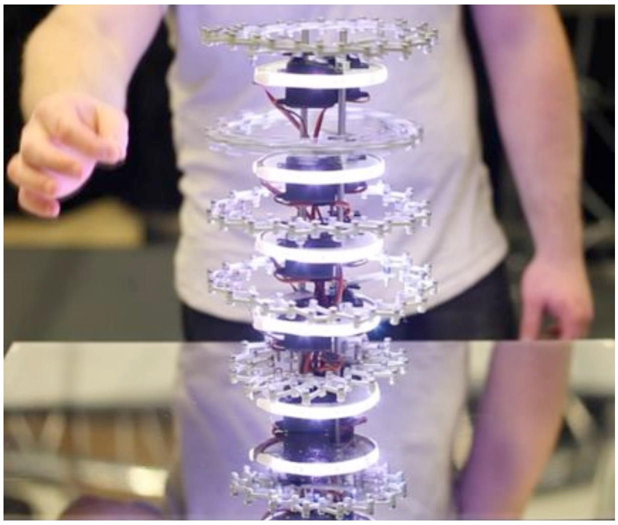

Figure 6. Amphorm – a Kinetic Sculpture resembling a vase

V. Amphorm

Amphorm is kinetic sculpture with shape altering interactions both in the physical and the virtual domains. It resembles a vase that has co-existed with humans for thousands of years. Its shape is defined by 5 elements stacked vertically that can change their radius dynamically.

Amphorm is a constrained shape display, which allows the user to manipulate its shape only with one degree of freedom per joint. By constraining the device appropriate interaction techniques were developed to alter its shape by gestural interactions in the physical space and direct manipulation in the virtual space.

Amphorm is an ambient/calm interface [12, 13], since it lives in the users environment and only responds when the user engages it. Its state is equivalent to its shape, thus all developed interaction modalities manipulate its shape.

The interface allows two modalities of interaction: gestural interaction in the physical domain and a GUI based interaction on a tablet device in the virtual domain.

The gestures for interaction include selection, individual joint manipulation and a contour-defining gesture. The contour-defining gesture allows the user two rapidly configure the entire vase's shape in a single movement.

The gestures allow users to manipulate the shape of Amphorm in the physical world directly. Gestural interaction performs well for crude, rapid and expansive form-giving, but is not favorable for precise alteration of the shape. In order to provide the user with precise alteration tools we also developed a GUI-based interaction panel on a tablet device that allows users to manipulate each joint directly. Although this interaction modality affords the user high precision manipulation, it removes the locus of interaction from the object, by which the interface inhibits the direct connection between the user and the object.

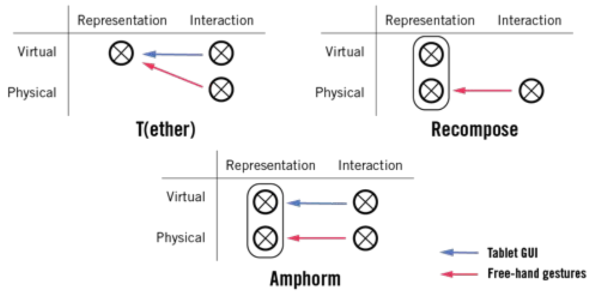

Figure 7. Interaction-Representation relationships

VI. Discussion

The three projects above showcase three different approaches for interacting with transformable materials. For a systematic overview, we categorized the projects, by the representation and the interaction layers they implement (Figure 7).

The representation of the model in the T(ether) project is fully virtual, since the created models do not have any physical representation, however the virtual model can be interacted through gestures from the physical world, and a GUI from the tablet. In both the Recompose and Amphorm projects the model has both a physical and a digital representation, which are tightly coupled to each other. However in the Recompose project there are no interaction techniques that manipulate the digital representation of the object, whereas Amphorm offers interaction techniques in both realms.

The virtual and the physical realm, respectively, afford separate interaction styles. Free-hand gestures and direct manipulation as primary physical interaction techniques allow users to lay down broad brush-strokes for their design.

Physical interaction methods excel at speed, expansiveness and the bandwidth of interaction, but fall short on precision and modularity.

On the contrary digital interaction methods are well suited for precise, final adjustments and can support parametric, as opposed to topological control of shapes.

VII. Conclusion and Future Directions

In this paper we summarized and compared three projects, T(ether), Recompose and Amphorm, which as a reference to assess the path towards our vision-driven research called Radical Atoms. We identified that a major difference between the projects is the domain (virtual/physical) of the representation of the model and the interaction techniques that access the model (Figure 7).

In order to emulate shape-shifting materials, we will continue building perceptually equivalent interfaces to Radical Atoms. These interfaces must have a tightly coupled virtual and physical representation, and interaction techniques directly accessing each of these (Figure 7. – Amphorm).

Although these interfaces will remain only perceptually equivalent to Radical Atoms, a series of them will help us assess the role-division between virtual and physical interaction techniques, without waiting for enabling technologies to be invented.

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