Exploration towards Transformable Tangible User Interfaces

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ABSTRACT

This paper presents the exploration of different design approaches and possible materials to create Transformable Tangible User Interfaces (TTUIs). Human-computer interfaces have evolved from Graphical User Interfaces (GUIs) to Tangible User Interfaces (TUIs) and the evolution continues as researchers envision the future existence of 'radical atoms' and 'hyperforms' to create TTUIs. Exploration of different transformable materials – their properties and possible applications – has begun as a first step towards achieving this vision. Research in this field opens up a possibility of a new era of digitization – a digital world that is completely part of the physical, no divide and boundaries between the two.

Author Keywords

Graphical User Interface, Human-Computer Interaction, Hyperforms, Radical Atoms, Shape Display, Shape Memory Alloy, Soft Mechanics, Tangible User Interface, Transformable User Interface, Ubiquitous Computing.

ACM Classification Keywords

H.5.2. Information interfaces and presentation: User Interfaces.

INTRODUCTION

The divide between the digital and the physical world has led us to continuously make advancements in creating human-computer interfaces. We aim to communicate with the digital world – to be able to manipulate digital information and objects – just as how we interact with the physical world. We desire to weave the digital world into the physical, removing communication barriers and allowing both worlds to co-exist as one. This goal, envisioned by Mark Weiser as Ubiquitous computing (Ubicomp) [2], has been the ultimate goal for many of these technological advancements, particularly in the field of human-computer interaction (HCI).

Creation of GUIs

Improving human-computer interaction has been led by the creation of graphical user interfaces (GUIs). This has been a significant improvement from the earlier command-line interface which requires the user to remember commands and type it in the command line as a way for users to communicate with computers [2]. The "see, point, and click" interaction [2] has been a great improvement as it makes use of the users' ability to see and interpret data through vision. This interface brought the interaction between humans and computers a bit closer to how humans interact in the physical world.

Limitations of GUIs

However, this interaction does not utilize humans' ability for hand-eye coordination and requires too much semantic processing [7]. The movements are constrained to typing and clicking, and it also requires users to understand some unfamiliar icons and task names to be able to do certain tasks which should have been easy to implement in the natural world.

Creation of TUIs

The problems posed by GUIs led to the creation of tangible user interfaces (TUIs).

Tangible user interface (TUI) has been one of the recent advancements in the HCI field. This interface makes the human-computer interaction to be more natural, closely resembling physical interaction. We can move objects or place them in certain positions and expect a certain response from the digital world that is tangible in the physical world.

Limitation of TUIs

But then again, although TUIs closely resemble physical interaction, they still lack some key factors in interaction. Some of these factors were presented in a research study to create a tangible computer music instrument [7]. According to [7], users still prefer to use traditional musical instruments because of the tangible input – muscle tension – required in the interaction. This muscle tension greatly affects human emotions and these are vital in performing certain activities. Also, they receive a tangible output of the state of the activity that they are performing, letting them know the differences between one state from another [7].

In addition to that, tangible objects do not represent change; they become inconsistent in state [2, 4]. One of the most attractive properties of digital objects is their malleability [4] – a change in digital information is readily reflected. However, tangible objects are rigid and static, not transformable once its design has been finalized [5].

Finally, another problem with TUIs is the differences between human and computer input/output modalities [7]. An example would be the difference in turning the "pages" of an electronic book in an iPad versus turning the pages of a real book. These different modes of input and output may result in bigger problems in the future if not currently faced, especially for the future generations who would be greatly exposed to such interfaces.

And so although TUIs enable users to interact with something physical, the interaction still lacks the key factors of a real physical interaction.

Creating TTUIs

Thus, the challenge to keep the digital and physical objects in sync [2] leads us to create a new kind of interface: Transformable Tangible User Interface (TTUI). Creating this interface requires new design approaches and the search for materials that are transformable, self-actuating and self-reshaping.

THE VISION

We now present two of the design approaches that would make TTUIs possible.

Radical Atoms

The concept of 'radical atoms' came into existence with the goal of creating materials that are both physically and computationally transformable [2]. Radical atoms would be the building blocks of these transformable materials which would be called 'digital clay'. According to [2], there are three requirements that should be met by these radical atoms: 1) it should be able to *transform* its state according to the change in the physical and/or digital information; 2) it should *conform* to the physical constraints of both the environment and the user; and 3) it should be able to *inform* the user of its "transformational capabilities" [2].

An example of the interaction with these radical atoms was presented in [2]. A possible substance that could be created from digital clay would be 'shape-memory clay'. This material would be preprogrammed to take on different kinds of shapes, possibly having features similar to that of computer-aided design (CAD) software [2]. They called this material 'Perfect Red' [2]. The interaction between the user and Perfect Red is illustrated in Figure 1.

Radical atoms is envisioned to change the paradigms of human-computer interaction wherein designers would no longer think of how the interface should be designed but rather, the focus would be on the interface itself as the material [2]. Designers would not have to think of the abstraction between the users and the interface, because it is envisioned that users would be able to directly interact with the interface, which is directly coupled with digital information.

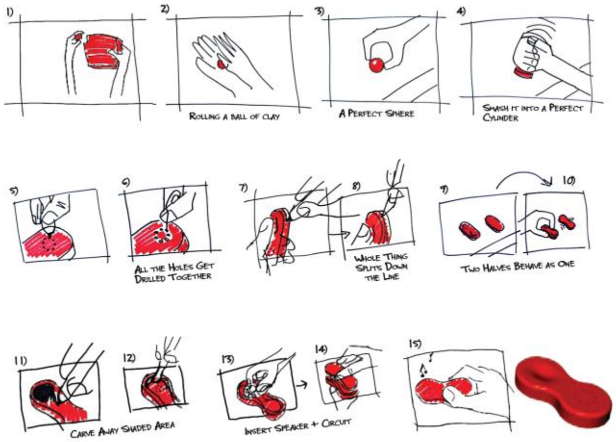


Figure 1: Interacting with Perfect Red, Shape-memory Clay made up of Radical Atoms [2]

Hyperforms

A hyperform is an object composed of robotic modules which are programmed to specify the object's forms and behavior [6]. The modules communicate with their neighbors to respond appropriately to "external stimuli" and arrange themselves in to forms specified by the user and physical constraints [6]. A hyperform is a four-dimensional object which varies in space and time [6]. It is transformable both physically and digitally which could be directly interacted upon by the users.

An example of a hyperform object is presented in Figure 2. This is called a 'social table' hyperform with three distinct components called 'phrases', similar to a musical phrase [6]. It is composed of a table that shrinks or grows depending on the number of people arriving and leaving the table, chairs that track the number of people sitting on the hyperform, and the "serving platform" that is created as needed [6].

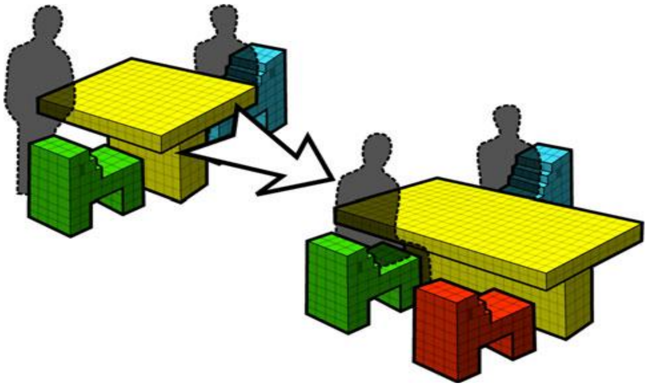


Figure 2: A Social Table Hyperform that changes dynamically as people arrive and leave the table [6]

The different states and transitions that a hyperform could afford would be stated in a ‘hyperform specification’ [6]. ‘Hyperform scripters’ would create the design description of the hyperform and ‘hyperform implementers’ would then create a program to be implemented by the robotic modules [6]. This digital description and program of a hyperform can then be downloaded by the end-users which would be realized given a reservoir of robotic modules [6]. End-users would also be able to customize it according to their own needs and preferences, thus creating new version of the digital description of the hyperform. This customized version can then be shared by posting the digital description online and letting other end-users download it too [6]. When the hyperform is no longer in use, the robotic modules would go back to the reservoir to be used in another type of hyperform [6]. The life-cycle of hyperforms is illustrated in Figure 3.

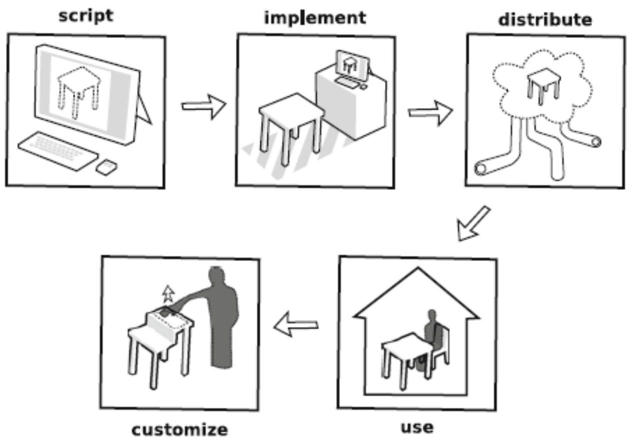


Figure 3: The Hyperform Life-cycle [6]

EXPLORING SHAPE-CHANGING MATERIALS

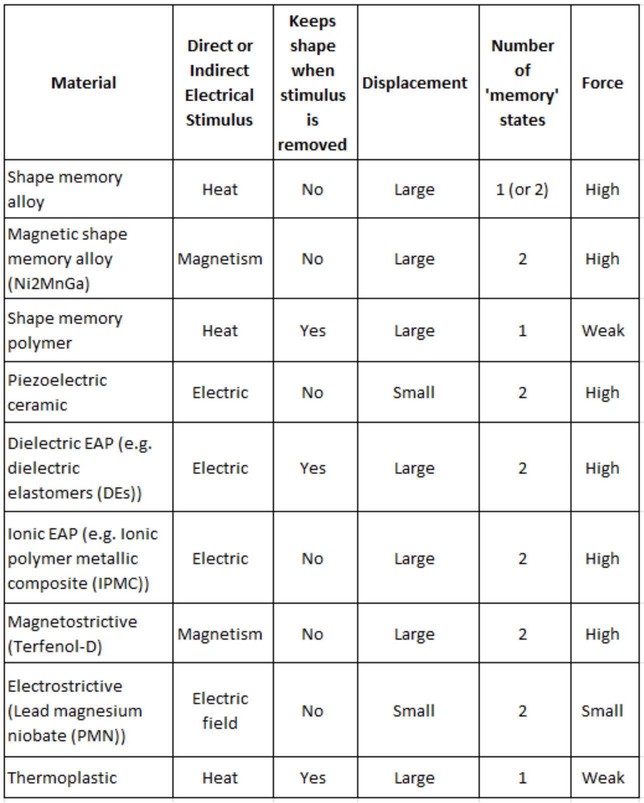
Having this vision for dynamically-changing objects based on varying physical and digital information, we need a specific kind of material that is transformable into different kinds of shapes which could also be somehow connected to the digital world.

As mentioned earlier, digital objects are malleable where as physical objects are static and rigid [4]. Back in the 18th century, Christopher Polhem, a Swedish engineer who invented the mechanical alphabet, described a mechanical design which later on built the simple machines [5]. The design of these machines primarily used materials which are static and rigid as main qualities, such as wood and steel [5]. This design has greatly influenced all the succeeding structures created which are rigid, static and unresponsive to any external stimuli [5].

The vision for TTUIs changes our concept of structural design. This calls for materials that are transformable from one shape into another, something that can respond to external stimuli, and can also be connected or synced with digital information. This type of materials should not be only shape-changing but can also be manufactured in large amounts, cheap and readily available [3, 6].

Exploring Properties of Shape-changing Materials

In exploring different shape-changing materials, it is best to first look at the materials that are currently available and their properties that matches our desire for transformable materials [5]. Below is a table of shape-changing materials with their corresponding properties.



Material	Direct or Indirect Electrical Stimulus	Keeps shape when stimulus is removed	Displacement	Number of 'memory' states	Force
Shape memory alloy	Heat	No	Large	1 (or 2)	High
Magnetic shape memory alloy (Ni2MnGa)	Magnetism	No	Large	2	High
Shape memory polymer	Heat	Yes	Large	1	Weak
Piezoelectric ceramic	Electric	No	Small	2	High
Dielectric EAP (e.g. dielectric elastomers (DEs))	Electric	Yes	Large	2	High
Ionic EAP (e.g. Ionic polymer metallic composite (IPMC))	Electric	No	Large	2	High
Magnetostrictive (Terfenol-D)	Magnetism	No	Large	2	High
Electrostrictive (Lead magnesium niobate (PMN))	Electric field	No	Small	2	Small
Thermoplastic	Heat	Yes	Large	1	Weak

Table 1: Shape-changing materials and their properties [5]

According to [5], the main properties of these materials that designers need to consider are the following: “*deformation strength and power requirement, speed and resolution, number of memory shapes, transition quality, trainability, reversibility, input stimulus, bi-directionality, environment compatibility*, and *consistency*”.

Shape Memory Alloys

Shape memory alloys or SMAs are currently the most flexible among all those shape-changing materials presented. They are also very prominent in the market, have been used for practical objects such as household furniture and clothing, and have “strong shape memory effect” (SME) which enables it to transform into different shapes [5].

SMAs undergo a dual process when transforming from a malleable state to a rigid state [5]. In an ambient temperature, SMAs are in its *martensite phase* where in it is malleable and could easily be transformed into a desired shape [5]. When heated, the phase is shifted into its *austenite phase* where in it becomes rigid and remembers its transformed shape [5]. Figure 4 illustrates the phase shift of SMAs.

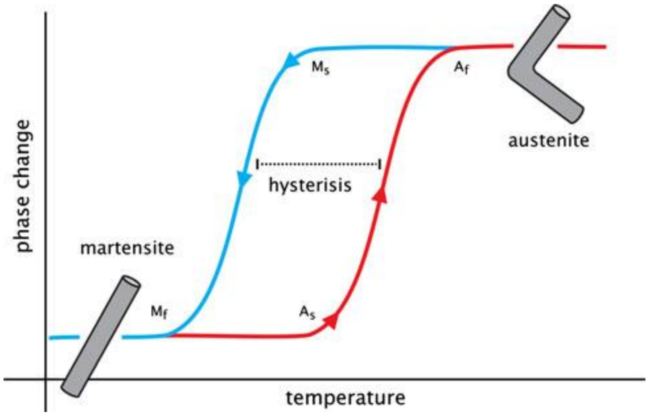


Figure 4: SMA phase shift - from martensite to austenite phase [5]

One research study conducted with SMAs involved an experiment on a shape-changing surface which is "composed of a matrix of single components" [1]. These components are tridimensional, as opposed to the traditional surface composed of two-dimensional pixels on a screen [1]. The third axis states the height and the curvature of the surface which could be either concave or convex [1]. The surface was actuated using muscle wire (SMA) which allows the surface to transform its curvature and be digitally transformed by the computer [1]. An image of the surface is shown in Figure 5.

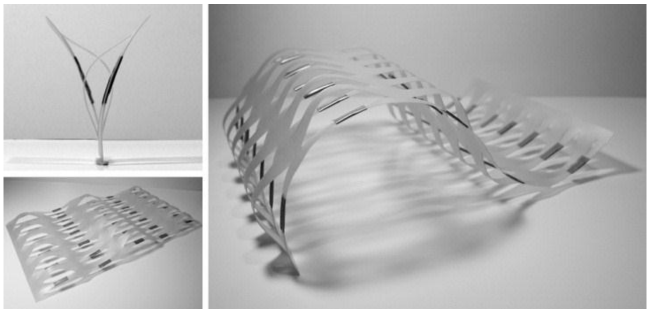


Figure 5: Shape-changing surface actuated by muscle wire (SMA) [1]

Other experiments are still being conducted to create objects using SMAs. By these experiments, the properties and possible applications of SMAs are being further explored.

Shape Displays

Shape displays, on the other hand, are transformable devices which can directly realize tridimensional shapes [4]. An example would be the *Protrude, Flow* by Kodama and Takeno (Figure 6, top) which uses magnetic capabilities to transform the shape of the "ferromagnetic liquid" [4]. Another example would be the *Aegis Hyposurface* (Figure 6, bottom) which can dynamically change shape in response to external stimuli such as human movement [4]. It is made up of metallic plates and is transformed using "pneumatic pistons" [4].

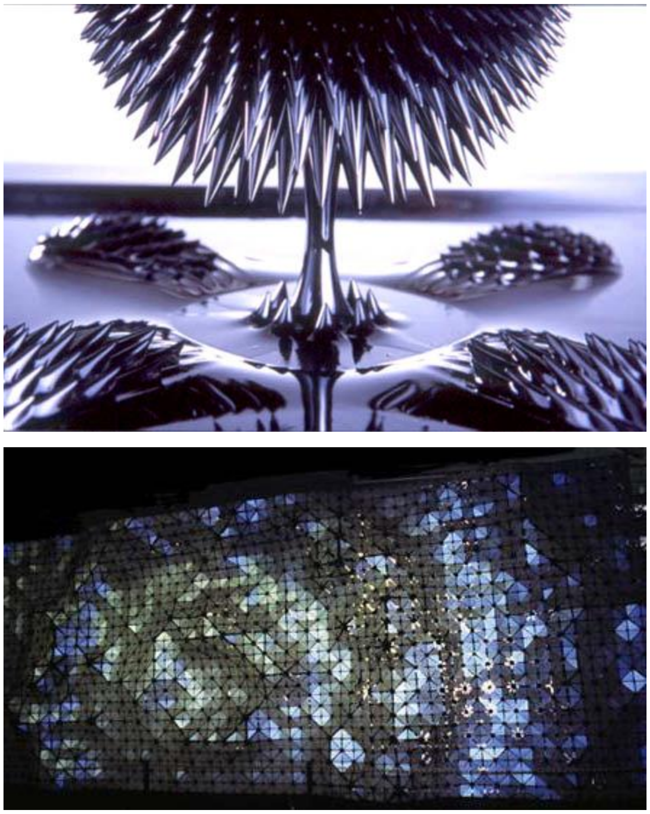


Figure 6: Shape displays - Protrude, Flow (top) and Aegis Hyposurface (bottom) [4]

As shape displays exhibit dynamic tridimensional tangible shapes, it could be generalized that this presents a new design approach called *RGBH graphics* (Figure 7, [4]). As traditional pixels only has three components, R – red, G – green, and B – blue, a new component H – height – would be added to display tridimensional images [4]. This could perhaps be the next step to be explored in pixel evolution [4].

However, the main issue being faced with these shape displays is that, humans can not directly interact with these devices due to its material properties [4]. Further research has to be made to enable these devices for us to directly interact with them.

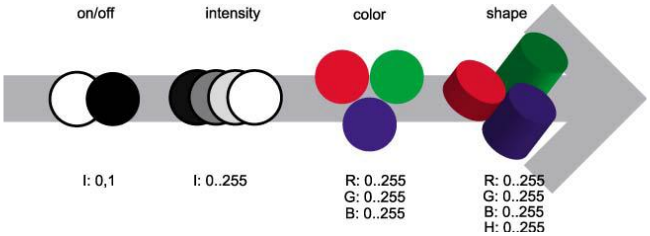


Figure 7: RGBH graphics - pixel evolution [4]

Modular Robots and Automata

One of the materials also being considered to create these transformable materials are modular robots which would have the capabilities to respond to both changes in physical and digital information. This would require ‘hyperform automata’ as the term stated in [6].

Earlier automata – “self-moving machines” [4] – emerged purely from the fascination of humans with this kind of machines. One of the earliest automata created was by French engineer Jacques de Vaucanson during the mid-1730s and was called the *Vaucanson duck* (Figure 8, [4]). This automaton mimics the key behaviors of a real duck: “move, flap its wings, eat, digest,” and could even “excrete food” [4]. This invention did not really serve any purpose, but only for display and the enjoyment of viewers [4].

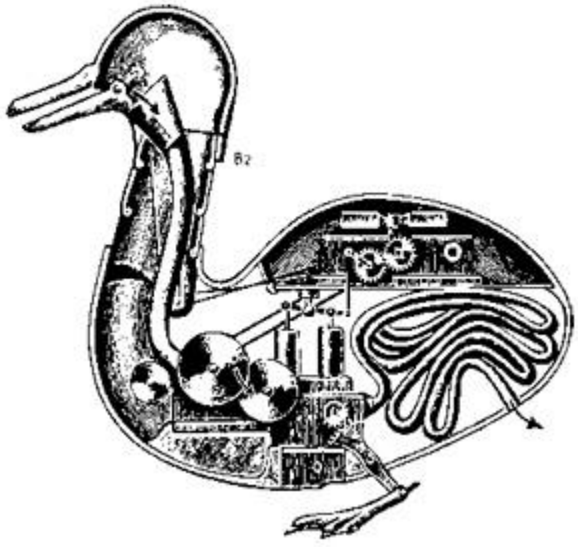


Figure 8: Vaucanson duck - early automata created purely for display and enjoyment [4]

The invention of different automated robots has evolved which greatly affected industries and global systems. Numerous mechanical machines were created which could perform tasks by themselves [4]. However, these robots were not created to interact with humans, but rather, perform tasks without any interaction with humans at all [4].

As the invention of robots continuously evolved, responsive automata has been invented and is still currently being improved [4]. The invention of robots like Aibo, the robotic dog created by Sony, Nao robot, a humanoid robot, and Outerspace (Figure 9), the “curious robot”, were all created not only for display and entertainment but also for human interaction [4].

Figure 9: Outerspace, the curious robot [4]

Connecting this evolving technology to the need for transformable materials, we need to consider this in a microscopic level. Just as matter is composed of atoms, transformable matter, or more specifically “programmable matter” [2], should also be made of programmable atoms – or as stated in [6], robotic modules.

Looking at the current technology, more research should be made to create these robotic modules. The field to look at is nanotechnology which aims to bring technology to the atomic level [2]. Being able to change the microscopic level would bring drastic change in the macroscopic level [2] and that is the aim in the creation of transformable materials.

Different research studies have been made to create robotic modules. One such study was made by Weller et al. [6] where they presented their version of a robotic module called ‘prismatic cubes’ (Figure 10). These cubes could perform ‘low-level transitions’ thus supporting self-reconfiguration with a number of modules [6]. This was done by focusing on the robustness of the structure and by keeping the structure simple [6]. The internal structure is a “close-packed cubic lattice” and the “inter-module bond” is achieved by “electrostatic latch” [6]. When realizing transformation, the modules were designed to move the least possible number of modules to reshape [6]. The modules are able to move up, down, and in a curve which they called “movement primitives” [6].

However, the module’s surface poses a limitation to this robot module prototype [6]. The surface is not desirable for human touch or interaction due to numerous latches and uneven surfaces [6]. It is further being developed to achieve better surface properties suited for human interaction [6].

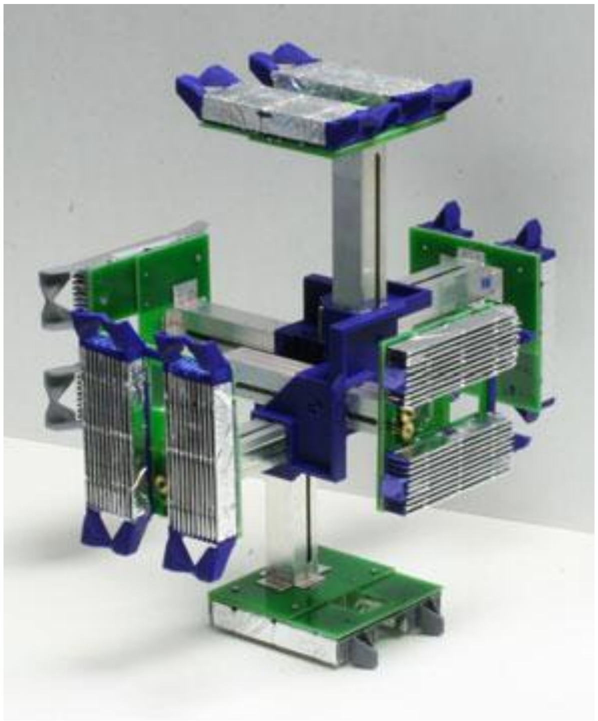


Figure 10: Prismatic Cubes - a robotic module prototype [6]

EXPANDING OPPORTUNITIES

Exploration of shape-changing materials towards the creation of TTUIs presents vast opportunities in different fields – scientific, industrial, and many others. A few of these are presented below:

Soft Mechanics

The field of soft mechanics focuses on mechanical systems which are contrary to the traditional mechanical system introduced by Polhem [5]. This looks at mechanical systems built using shape-changing materials, which can be transformed from one state to another [5]. As these types of materials are being explored, this new design approach could produce powerful and novel structures and objects such as robots that could squeeze into inaccessible places or furniture that could adapt to user customization [5].

Human-material Interaction

As software designers continuously look at different designs for human-computer interaction (HCI), creation of transformable tangible objects which are directly coupled with digital information could transform the design paradigm into human-material interaction (HMI) [2]. This follows the vision that the material would be the interface itself that can be directly interacted upon by users [2].

Global Systems

As the vision and exploration for TTUIs evolves, global systems might be affected as these new design approaches become realized. In the case of hyperforms, if design would be a program that can be downloaded [6], this might change the different design approaches that are currently practiced globally. Also, manufacturing and distribution of goods might be disrupted as designs for physical objects could be downloaded and created in the user's physical location for as long as there is a reservoir of self-reconfiguring material available [6]. Designs for particular objects might also have to change as users would have the capability to customize their hyperforms and share the hyperform specification by posting their downloadable version [6].

Although these situations might seem too distant in the future, it would be good to look at these long-term effects as well as we explore the different applications of these transformable materials.

CONCLUSION

The desire to weave the digital world with the physical world continuously drives us to create human-computer interfaces which enable us to interact with digital objects similar to how we interact with physical objects. This desire led the evolution of interfaces; from command-line interfaces, to GUIs, to TUIs, and now the goal to create TTUIs. To realize TTUIs, different design approaches are being proposed such as 'radical atoms' and 'hyperforms'. This leads us to explore and search for transformable materials which could make the possible design approaches come into reality. Materials such as SMAs and devices such as shape displays give light to the possibilities of realizing these transformable tangible objects that could be directly interacted upon by users which would reflect the state of both the physical and digital information. Further explorations are being conducted and different long-term effects are also being considered as the exploration continues.

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