

PAINTERFACE: AN INTEGRATED RESPONSIVE ARCHITECTURAL INTERFACE

CHIN KOI KHOO¹ and FLORA SALIM²

¹Deakin University, Geelong, Australia
chin.khoo@deakin.edu.au

²RMIT University, Melbourne, Australia
flora.salim@rmit.edu.au

Abstract. Interface design is one of the main research areas in human-computer interaction (HCI). In computer science, many HCI researchers and designers explore novel interface designs with cutting-edge technology, but few investigate alternative interfaces for existing built environments, especially in the area of architecture. In this paper, we investigate alternative interface designs for existing architectural elements—such as walls, floors, and ceilings—that can be created with off-the-shelf materials. Instead of merely serving as discrete sensing and display devices integrated to an existing building’s surface, these liquid and thin materials act as interventions that can be ‘painted’ on a surface, transforming it into an architectural interface. This interface, *Painterface*, is a responsive material intervention that serves as an analogue, wall-type media interface that senses and responds to people’s actions. *Painterface* is equipped with three sensing and responsive capacities: touch, sound, and light. While the interface’s touch capacity performs tactile sensing, its sound-production and illumination capacities emit notes and light respectively. The outcomes of this research suggest the possibility of a simple, inexpensive, replaceable, and even disposable interface that could serve as an architectural intervention applicable to existing building surfaces.

Keywords. Human-computer interaction; integrated interface; sensing and responsive architectural interface.

1. Introduction

Recently, ubiquitous computing has become a focus of computer science research. Computing devices can now be installed anywhere and will eventually be practically invisible. This advance changes the way we interact with

computers, mobile devices, and machines. Although ubiquitous computing is not entirely new to architectural design, there is relatively little research that explores the ways in which integrating ubiquitous computing could change how we interact with existing buildings.

Interface design, especially in the area of human-computer interaction (HCI), is a crucial discipline that supports the implementation of ubiquitous computing. Computer interface types such as the graphical user interface (GUI), tangible user interface (TUI), and organic user interface (OUI) facilitate interaction between digital and physical domains, offering different ways of experiencing HCI (Ishii et al, 2012). These interfaces offer small-scale forms of interaction through keyboard, mouse, speech, handwriting, touch, and gestures, as ways of engaging and interacting with a computer through visible actions (Norman, 2010). Larger-scale interfaces have rarely been explored, especially in the context of architecture and the built environment (Pohl and Urs, 2011). Nevertheless, current design innovations give rise to the idea of large-scale haptic interface design involving DIY electronics and alternative materials (Ng, 2013).

Exploration of architectural interface design concepts suggests the new possibility of augmenting existing architectural elements, such as walls and floors, into parts of a human-computer interface. This interface can be considered a calm technology used for low-tech intervention, as it augments an existing built surface by adding interactivity to an existing wall or floor and allows users to experience a novel form of HCI. Projects such as The Fun Theory's *Piano Stairs* set precedents for this approach by making people curious and inviting them to explore further to discover possibilities for social interaction (The Fun Theory, 2009).

In place of conventional media involving digital graphics and information display through light emitting diodes (LEDs) and organic light emitting diodes (OLEDs), in this paper we introduce an alternative, analogue interface that is 'retrofitted' and 'painted' on an existing brick wall. This interface serves as a 'host' that enables pedestrians to interact with the wall through an analogue medium with capabilities including sensing, illumination, and sound production. This painted interface, *Painterface*, intends to stimulate curiosity among pedestrians and encourage robust social interaction through an alternative analogue medium that extends conventional graphic representational methods through use of sound and light. Using sensor fusion and machine-learning techniques, humans' touch gestures over the interface's conductive materials could be detected and learned to allow for more accurate responses and controlled output.

This research was expected to deliver two outcomes. First, exploration aimed to yield a method for designing sensing interfaces by using conductive

and functional materials. Second, we intended to develop a prototype of an alternative interface for HCI in existing buildings and indoor spaces. This interface, when integrated with an existing wall, anticipates a mode of computer-facilitated interaction with architecture that differs substantially from those involving digital media, such as the media façade.

2. Interactive architectural surfaces

In computer science, the vision of ubiquitous computing turned computers into everyday objects seamlessly integrated into our daily life. The term, coined by Mark Weiser in the late 1980s, anticipated the development of ‘invisible’ devices, in many sizes and shapes, which could bring computing to everyone (Weiser, 1991). One of the main ubiquitous computing devices envisioned by Weiser was the wall-sized interactive surface that would potentially replace the office and classroom whiteboard, magnet-covered refrigerator, or bulletin board (Weiser, 1993). Although this kind of interactive surface is not new in the current context, it is still not fully implemented in domestic and commercial settings due to lack of affordability and ease of use. Furthermore, shortcomings in the flexibility and scalability of these interfaces have hindered growth in their popularity over the past few decades.

Weiser’s vision has inspired many designers and researchers to explore the HCI possibilities of the wall-sized interface, but few have extended this research to the field of interactive architectural surfaces. In general, current designs of such surfaces involve LED or OLED touch screens or, more often now, digital projection augmented with motion-sensing input devices.

One prominent architectural installation adopting the projection approach is *Augmented Structures: Acoustic Formations*, an augmented architectural surface that performs dynamic aesthetic alterations to the original appearance of its existing building façade. This multidisciplinary, large-scale augmented surface is considered a living canvas that presents the viewer with new media experiences, communicated through sound and movement by way of interactive projection (Augmented Structures, 2012). The *Aegis Hyposurface*, designed by dECOi, takes another approach, using analogue kinetic components to create a dynamic surface capable of physical deformation. This surface served as a dynamic and interactive artwork, allowing a theatre to portray on its exterior a response to stimuli captured from its environment (Goulthorpe, 2008). Although both digital and analogue interactive surfaces have successfully served as large-scale responsive architectural interventions for existing buildings, their ‘prosthetic’ approach is not fully assimilated into existing building elements, such as walls and façades, to form an integrated architectural interface.

Current advancements in tangible interface design, explored through smart materials, offer new possibilities in the form of ‘hybrid’ alternatives combining the wall-sized interface and the augmented architectural surface. The concept of “Radical Atoms”, developed by Leonardo Bonanni and Hiroshi Ishii of the MIT Media Lab, is a vision for human interaction with dynamic materials that can sense, change shape, and respond to stimuli. In this vision, the material and the interface are one. This concept of human–material interaction envisions that any physical object (atom) could display, embody, and respond to digital information (bits) through its changing material properties and capacities (Ishii et al, 2012).

In the context of architecture, there is a similar opportunity to design materials that react to the touch of a person’s hand; to external conditions such as pollution and sunlight; and to a building’s ever-changing surroundings (Tibbitts et al, 2014).

Partially inspired by the vision of “Radical Atoms,” which integrates information and material in interaction design, in this paper we investigate a design approach that explores the possibility of sensing and responsive architectural interfaces made through novel use of day-to-day materials. Instead of developing a high-tech material system that is expensive and intricate, we offer the alternative of developing an interactive architectural surface by more fully exploiting the potential of widely available and affordable off-the-shelf materials, augmented with basic physical computing programs. This simple and inexpensive approach allows the architectural interface to be replaced easily and even to be treated as disposable when newer technology and materials are developed.

3. Responsive synthetic material intervention as architectural interface

Two of the main challenges in developing a sensing architectural interface are the limitations of fabrication technology and the high cost of advanced material development. In this paper, we introduce a simple and inexpensive design research process through which to explore the alternative process of designing a responsive material intervention and architectural interface that can be made with off-the-shelf materials. Instead of designing a stand-alone panel-type interface, we investigate a different approach, ‘painting’ the material intervention as an interface on the existing wall. One of the materials used in this investigation is conductive paint, which can be applied to almost any physical surface to serve as a touch sensor. Other easily accessible and inexpensive materials such as piezoelectric film, translucent silicone rubber, phosphorescent pigment powder, and shape memory alloy are used to create the various sensing and responsive capacities of the painted interface.

These materials are the basic ingredients of a responsive architectural interface that seamlessly retrofits with existing building surfaces such as walls and floor. Most of these materials are manufactured in thin, sheet-based or liquid forms for easy application.

The architectural interface has three sensing and responsive capacities that involve touch, sound, and light (Table 1). Touch serves as input for the interface, enabled by the conductive paint. Sound-producing capacity forms one of the outputs of the interface: in reaction to touch, it produces rhythmic sound notes from thin piezoelectric film. Finally, the light-producing capacity illuminates part of the interface when touch is applied to the existing physical surface.

Three preliminary experiments were conducted to investigate these capacities of the interface when applied to a generic clay brick. These are further discussed in the following subsections.

Table 1. Selected off-the-shelf materials produce different sensing and responsive capacities.

Sensing and responsive capacities	Off-the-shelf materials				
	Conductive paint	Polyester film	Transparent silicone rubber	Phosphorescent pigment powder	Shape memory alloy
Touch	•				
Sound		•			
Light			•	•	•

3.1. TOUCH

In general, conventional tactile sensors serve as discrete electronic devices that sense physical stimuli such as the touch of a human hand. These sensors are often employed on flat and rigid surfaces that limit their full capability, obscuring the potential inherent in applying them to flexible or undulating surfaces. In this subsection, we explore an alternative technique that uses conductive paint as a tactile sensor we can apply to an existing physical surface. This kind of paint conducts electricity and can be applied or painted on almost any surface or material. Once it dries, the painted surface becomes electrically conductive and can serve as a tactile sensor (Figure 1).

We conducted the simple experiment of applying this conductive paint to the surface of a generic clay brick measuring 230 mm × 110 mm × 76 mm. Once painted and dried, we connected the surface with a capacitive sensing schema through an Arduino microcontroller. Part of the brick then became a tactile sensor that could read input data when touched by another capacitive object (i.e. a finger) (Figure 2).



Figure 1. Left: The generic clay brick. Middle: Applying conductive paint to the brick's surface. Right: Brick surface covered with dry conductive paint.

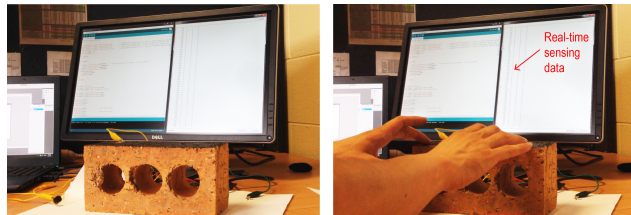


Figure 2. Left: The painted conductive brick. Right: Brick surface sensing touch data from fingers.

3.2. SOUND

In this subsection, we explore giving sound-producing modality through the use of a thin polyester film with conductive ink and a rare earth magnet. While painted with conductive ink, this polyester film enables us to turn an existing building surface, such as a wall, into a paper-like planar speaker (Figure 3). This simple and low cost speaker provides basic audio tone with minimum energy input. Furthermore, being ultra-thin and lightweight, this kind of speaker has the advantage of being able to be seamlessly integrated with the existing brick's surface.

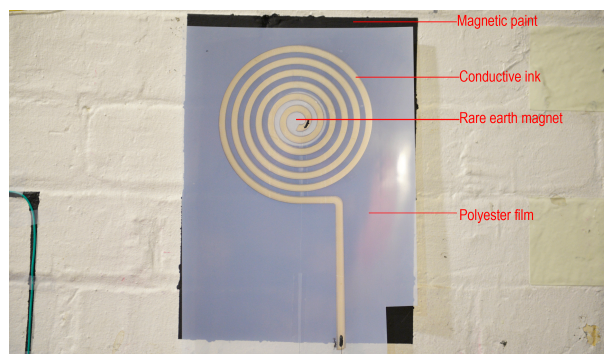


Figure 3. Paper-like planar speaker retrofitted to the existing brick wall.

When connected with the conductive paint touch sensor discussed in the previous subsection, the polyester film will produce a simple binary sound

note. This note can be altered by touching different parts of the painted conductive surface: touching the centre or corner, for instance, produces different sounds. By changing the programming of the capacitive sensing schema, the polyester film can be made to produce tones of differing frequency. In this scenario, these simple tones are basic musical notes that anticipate human interaction.

3.3. LIGHT

Development of the second responsive capacity, light production, focused on creating the possibility of responsive illumination. Instead of retrofitting discrete lighting devices such as LEDs to a surface, we employed a luminous paint applied to the surface of the brick along with a mixture of transparent silicone rubber, phosphorescent glow pigments, and shape memory alloy (SMA) wires. The goal of this experiment was to come up with a flexible and luminous material that is relatively easy to apply to an existing building surface.

While it will glow in the dark passively, this synthetic material lighting will glow extra bright when heated by embedded SMA wires, complementing the passive lighting. The embedded SMA wires not only serve as a heater: their form-changing capacity also enables the synthetic material to change its form and alter the appearance of the existing brick's surface (Figure 4).



Figure 4. Left: Luminous paint with embedded SMA wires on the surface of the brick. Middle: Luminous paint glows in the dark. Right: Extra luminosity around the heated SMA wires creates a visible pattern.

This simple intervention with luminous material is not intended to replace an existing fluorescent or LED lighting system, but rather to create ambient and amorphous light effects to revitalise dark environments. By 'painting' this synthetic luminous material on existing architectural features such as walls or ceilings, these features can be extended beyond their primary function as space dividers to incorporate extra capacities and functions. This approach creates the potential to transform every existing architectural feature into a lighting system.

Application of this luminous material intervention will be further discussed in Section 4.

4. Application of the retrofitted interface

Following on from the positive outcome of experiments involving the sensing and responsive brick interface discussed in the previous section, in this section we focus on implementing the interface.

This interface, which we call *Painterface*, creates a haptic experience for pedestrians through its polymorphous appearance. Physical changes in its surface material properties modify the existing brick wall to offer the possibility of a more intuitive physical interaction than does a conventional digital interface. When ‘painted’ on through application of simple conductive paints and thin films, the existing brick wall becomes a sensing and responsive interface. This augmented interface responds to pedestrian inputs including touch, proximity, and hand gestures. The integrated interface reacts to these inputs by offering feedback in the form of sound and light output.

Where contemporary mobile devices often overwhelm their users and discourage social interaction, this integrated interface, as a responsive architectural intervention, represents a use of computing and architecture that encourages people to communicate and interact with each other in ways physically initiated by alternative analogue media. The approach aims to stimulate curiosity in passers-by to provoke robust social interaction facilitated by analogue representations.

4.1. PAINTERFACE

In its full expression, *Painterface* is ‘painted’ on the existing brick wall of a dark and narrow corridor. The realised project is the design implementation of the retrofitted architectural interface developed through the experiments with synthetic material interventions discussed in the previous section.

The existing brick wall at the implementation site has a stretcher bond pattern that exposes the bricks’ long narrow side. Once *Painterface* is applied, the ordinary and inert brick wall becomes an analogue media interface that people can interact with through touch, sound, and light (Figure 5). By ‘retrofitted’ and ‘painting’ different capacities to individual bricks, these bricks become input and output devices for *Painterface*, changing the ambient environment of the corridor in response to input from pedestrians.

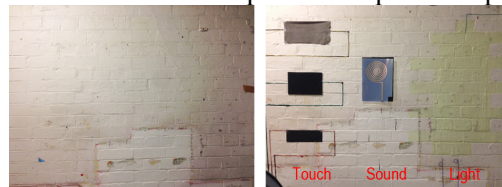


Figure 5. Left: The existing deserted brick wall. Right: The sensing and responsive capacities of *Painterface*: touch, sound and light.

Painterface involves three ‘retrofitted’ zones (Figure 6). Zone 1 is painted with a series of tactile sensors that can sense the touch of a human hand. Zone 2 is the audio area, retrofitted with seamless polyester film speakers that produce sound notes in response to interaction. The ‘painted’ luminous skin layer of the last zone creates animated glow-in-the-dark visualisations that respond to the touch and sound stimuli of the first and second zones (Figure 7). With additional programming, the three zones will output audio and luminous graphics based on the stretcher bond pattern, in response to pedestrian interaction (Figure 8). Although *Painterface* is the first design iteration of this painted interface, serving as an implementation test on an existing building surface, it represents a promising outcome, providing motivation for further development of similar responsive material interventions that can make any building surface interactive.

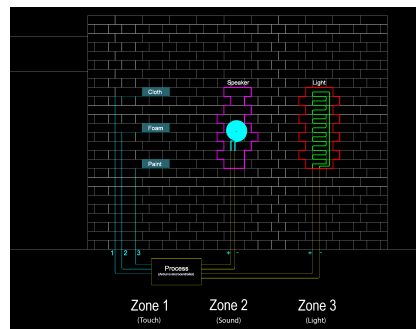


Figure 6. The three different zones (touch, sound, and light) of *Painterface*.

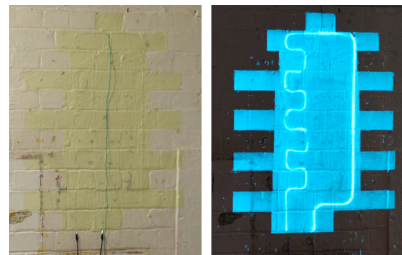


Figure 7. Left: The ‘painted’ luminous skin layer on the brick wall. Right: Zone 3 glows in the dark with heated SMA wires that responded to touch stimuli.

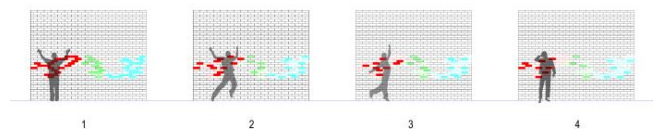


Figure 8. Programming allows *Painterface* to output changing audio and luminous patterns in response to pedestrian interaction.

5. Conclusion and future work

The design investigation undertaken in this research demonstrated the potential for of an integrated and ‘painted’ interface that renders existing architectural surfaces interactive with minimum cost and through a simple process. The preliminary design research acted as the proof of concept for a vision involving ‘painting’ a thin layer of sensing and responsive solid-state devices such as sensors, lamps, speakers, and display systems on almost any existing building surface. Recent advances in energy-harvesting materials such as painted organic solar cells suggest the additional opportunity to turn such a painted interface into a photovoltaic skin, and even an indicator of energy consumption, with minimum maintenance cost.

The design trajectory of interfaces between architecture and people has entered a new era due to recent material advancements and inventions. New materials not only perform functions such as sensing, actuation, illumination and audio output, but also represent the advent of ubiquitous computing in the existing built environment. The rising popularity of contemporary 3D and conductive inkjet printing technology also suggest novel possibilities for DIY application, involving printing these materials with embedded wireless technology on almost any surface of an existing building. This printed computing approach would allow such existing building surfaces to become multifunctional interfaces that respond and adapt to changing environmental stimuli.

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