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Designing Future Ubiquitous Homes with OUI Interiors: Possibilities and Challenges

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Abstract. As our living environments, homes should be expected to house objects with which we are comfortable. This applies equally to the technology we introduce to our domestic environments: it should be blended or embedded within them, or at least intuitive and unobtrusive in the space. In this paper, we survey a number of the latest Organic User Interfaces (OUIs) and discuss how these novel designs can be adopted to help build future domestic smart environments. In this sense, interior spaces, surfaces (walls, floors, tables and ceilings), and interior objects such as furniture and decorative accessories can become computationally-driven interactive artefacts, potentially changing their physical appearances, i.e., shape, colour, pattern or texture. We believe that Human-Building Interaction (HBI) will soon evolve to develop and employ OUIs in domestic environments, dynamically supporting our personal preferences and enhancing our living experiences. We propose some of the potential benefits of 'OUI Interiors' such as employing familiar intuitive interactions, supporting psychological and physiological wellbeing of inhabitants and the opportunity of designing multifaceted aesthetic interiors. Moreover, we highlight some of the challenges to building interactive interior objects, furniture and accessories, such as supporting sustained user engagements over time and designing for daily use within domestic environments with all its social, ethical and behavioural implications.

Keywords: Organic User Interfaces; Ubiquitous computing; Human-Building Interaction; Interactive Architecture; Radical Atoms; interactive furniture; soft electronics; slow technology; Internet of Things (IoT).

1. Introduction

From Weiser's Ubiquity [1] to Ishii's Radical Atoms [2], research has been trying to bridge the gap between user interfaces and our own physical environments. The recent notions of Human-Building Interaction [3] and Interactive Interiors [4] suggest new directions to address this field, such as adaptive architecture, transformable materials and tangible or organic interfaces. Organic User Interfaces (OUI) represent the third generation of interface paradigms and have recently seen increased interest amongst the wider Ubicomp and Human-Computer Interaction (HCI) research communities [5]. OUIs are defined as flexible, tangible interfaces that may include both sensing and actuation capabilities allowing for more intuitive interaction in everyday environments [6, 7]. Within the paradigm of OUIs, everyday objects can be capable of both displaying information and being used as interactive interfaces, which can have flexible shapes and, beyond that, dynamically change their appearance, colour, or physical form. Apart from flexible displays such as OLED and e-ink, OUIs can be designed using soft circuits of connected e-fabrics, capacitive sensing, flexible and soft sensors to detect input interactions, alongside servo-motors and vibrators, with shape-changing and colour-changing materials, typically employed as output modalities. Equipped with such sensing and actuating capabilities, OUIs enable a range of interactive responses to user input that aim to leverage the nuanced and complex ways in which humans already interact with and manipulate regular everyday objects.

The central idea of developing 'OUI Interiors' is to turn everyday objects in people's homes, such as furniture and interior accessories (e.g., mirrors, lamps, objet d'art), into interactive artefacts that can change their appearance dynamically, either passively or actively, responding to interactions with (or between) home occupants. By redesigning these objects to include basic sensing and actuation capabilities (woven into the material of the objects themselves) they will be able to sense and respond to presence, movements, or physical manipulations through alterations of their appearance and/or shape, with the goal of exploring how this might engage, motivate and inspire inhabitants and support new kinds of relationship to both the designed objects and the built environments housing them.

2. OUI Interiors

Arguably, OUIs will play a key role in the next generation of interaction scenarios, specifically with regards to domestic environments, where even now users are increasingly interacting with embedded technologies during their everyday activities [8]. As such OUIs will also play an important role in the age of the Internet of Things (IoT). Examples of existing domestic OUIs range from surface computers [9], [10] [11], interactive furniture and accessories to the multitude of different types of e-paper, e-textiles and other deformable and malleable interactive artefacts [12], [13], [14], [15].

Previous work on interactive furniture include EmotoCouch [16], shape-changing furniture (bench [17] and desk [18]), Long-Living-Chair [19] and Transform[20].

Each of which was designed as an interactive piece of furniture with the aim of studying users' experience of such responsive designs and/or the possibilities and potentials of such adaptive technologies. EmotoCouch [16] was a colour-changing couch that changes the colour of its embedded LEDs to represent different emotional states. Its purpose was to study how furniture might dynamically express emotions and explore how this might affect home occupants by delighting, comforting, and exciting them and encouraging socialized family activity. Shape-changing Bench [17] was a horizontal bench seat that changes its height and angle using embedded linear actuators. The designers explored users' experiences and sense-making around its affordances and transitions and also their interpretations of such a physically dynamic object. The Long Living Chair [19] however, was a rocking chair that detects and stores, in an internal memory, the frequency and pace of its usage over extended periods of time (months and years). Focusing on this single function, and promoting slow interaction, Long Living Chair acts as any normal chair in terms of its affordances, aesthetics and interactions. It encourages users to forget it has a digital component and is 'tracking' usage. This allows it to blend into the background of everyday life, keeping patterns of engagement intuitive and implicit, whilst opening up opportunities to critically examine the utility and role of long-term data about object interactions in the home. On the other hand, Transform[20] is a shape-changing table that does not resemble a traditional table but presents novel deformations that change the ergonomics, functionality and aesthetic dimensions of furniture. Transform moves its physical 'pixels' upwards and downwards to conform to other physical objects, tangibilize digital information and animate physical activities to enhance people's experience, remember their preferences and adapt to their needs.

Examples of haptic decorative accessories include History Tablecloth [21] and Interactive Decoration for Tableware [22]. The well-known History Tablecloth [21], an electronic plastic lace-like tablecloth, was designed to display glowing printed patterns when objects are left on the table, with a halo that grows over time as the object remains in place. History Tablecloth was designed to open up opportunities in the home to reflect on patterns of use of objects, and the routines we have in our homes around these objects and the materials of everyday living. This was intended to foster social engagement around these reflections. Alternatively, Interactive Decoration for Tableware [22] explored designing patterns and motifs that are both visually appealing and digitally meaningful. Hypothesizing that decorative patterns are ubiquitous features of domestic objects, their idea was to use such patterns in everyday objects developed using visual codes to make the objects themselves 'machine-readable' without resorting to otherwise aesthetically limited barcodes and QRcodes. This then opened up a space to make the tableware itself interactive. Interactive Decoration was aimed to investigate how designers might design complex interactive patterns yet stick to the rules at which the digital scanning applications can be able to interpret. This functionality was realized through exploiting the differences of how humans and systems construct patterns from images.

Other examples include embedded interactivity through non-emitting colour-change. For instance, Digital-Lace [23] is an interactive table runner that dynamically changes its fabric colour using thermochromic dyed threads and polymer optical fibre controlled digitally by microcontrollers. Digital-Lace was designed to explore multifaceted aesthetics exploiting responsive materials within the fabrics of an

everyday object such as a table runner. Using novel materials and playing with tonal effects, Digital-Lace interacted with users through colour-change and light/shadow interplay creating novel subtle multifaceted/layered visual effects that reveal, disappear then reveal again.

Fig. 1. Examples of OUI furniture and interior objects: a) History Tablecloth [21], b) EmotoCouch [16], c) Long Living Chair [19], d) Photobox [24], e) Digital Lace [23] and f) Escaping Chair [25]

Alternatively, the Photobox [24] was designed by Mark Selby as a domestic wooden box digitally equipped to allow it to print photos from the owner's Flickr album at random unexpected intervals and was studied in a long-term deployment. Although such a technology might not be categorized as 'actuating' in terms of shape-change, colour-change or flexible display, it still introduced a new form of interaction that potentially enables meaningful experiences, supported and expanded the notion of slow technology [26] and provoked self-reflection, anticipation and re-visitation of

memories and past events in a creative and autonomous yet subtle behavior, in a domestically situated object. This challenged traditional ideas of technology being always on and accessible [24], and envisions domestic technology that is calm, subtle, slow and creates no burden, and further shows how existing objects, designed aesthetically to fit domestic spaces (such as a writing box) can be augmented with new kinds of digital functionality to create new user experiences in domestic spaces. Other examples of domestic interactive objects are the Power-Aware Cord [27], the Impatient Toaster [28], the Escaping Chair [25] and the ADA Lamp [29] that show how everyday objects can be augmented with 'smartness' that interacts implicitly and expresses their own excitement, autonomy and affection.

3. Potentials and Opportunities

Some benefits of interactive and shape-changing interiors have been discussed in related prototype installations [21], [17], [16]. By generalizing the concept of interactive and dynamic interior design, we can move a step closer to realizing the vision of ubiquitous computing [1] and consequently providing building inhabitants with benefits at both the emotional and physical level. The emotional and psychological effect of changing colours, lights, shapes and textures of interiors could have significant impacts on inhabitants, potentially leading to improved quality of life through novel, possibly serendipitous experiences and sensory stimulations.

3.1. Utilizing Emerging Materials

With the availability of the latest generation of miniaturized and inexpensive sensing, computing and actuation facilities (for example, flexible and bendable sensors, open-source electronics, pneumatic actuators [30] and shape-memory alloys (SMAs)) virtually every object in a domestic environment could be transformed into an OUI. Moreover, recent research in material science has been offering more capabilities and tools for HCI through sustainable sensing-actuating organic materials and polymers that have shape-changing [31], colour-changing [32] and even odour-changing properties [33]. However, we must not ignore the fact that a significant number of domestic objects are covered with fabrics, e.g., sofas, cushions, curtains, carpets, linens, etc. Therefore, there is a substantial challenge for OUI interiors in relying greatly on e-textiles and soft circuit technologies that are still somewhat nascent and which will require development to satisfy the domestic OUI designs that will appear over the coming years.

3.2. Employing Intuitive Interactions

Designing for daily use requires designing intuitive interactions that: *i)* are spontaneous and familiar; *ii)* require little or no learning; and *iii)* are easy to execute and recall on a daily basis. OUI user interactions include a multitude of implicit and explicit intuitive actions such as hand manipulations [4, 7] that resemble users'

handling of daily objects, both non-deformable and deformable. Non-deformable hand-manipulations include –but are not limited to- grasping, flipping, bending, tilting, rotating, stacking, clapping, hitting and different types of touch interactions i.e. swipe, tap, knock, etc. Deformable hand-manipulations include shape-changing interactions with objects such as folding, squeezing, pulling, poking, stretching, wrinkling and different types of shape-changing interactions.

On the other hand, output interactions may also employ shape-change as means of user feedback or 'content' display. In this sense, the notion of 'shape-change' includes different ways that the physical appearance of an object might be altered. Ranging from form to colour, texture or pattern of materials used to structure or cover everyday interior objects – all of which can possess transformational capabilities that are intuitive and resemble familiar notations.

3.3. Supporting Psychological and Physiological Wellbeing

OUI Interiors have strong potential benefits to an improved quality of life to home inhabitants at both the emotional and physical levels through manipulating interiors' colours/lights, forms and textures [4]. Likewise, seamless interaction [34] through different psychological and neurophysiological data input (either actively or passively) can enhance and support a better understanding of user behaviour and user experiences within domestic interior spaces that would accordingly have a significant impact on inhabitants. Although this results in ethical, social and behavioural challenges to control and avoid any implications that might impact families with vulnerable members, it still holds quite significant and beneficial potential to those particular groups, aiding self-awareness and self-regulation by visualizing their health conditions [35] on dynamic physical forms of interior elements. This approach opens opportunities for supporting different aspects of human wellbeing, through interior elements that could potentially react to users' daily physiological activities or moods creating aesthetic biofeedback information displays embedded within their interior fabric.

3.4. Designing for Multifaceted Aesthetics

The opportunity to create dynamic spaces using OUIs through coupling of soft sensing and aesthetic actuation -using soft electronics- contributes to both utility and form i.e. both functional and experiential values within the home. Since, domestic objects range from the purely aesthetic to the highly functional, everyday decorative objects can have refreshable appearances that reveal layers of aesthetic novelty over time through slow interactions. This approach suggests our homes might have multifaceted physical appearances that can support unprecedented functionalities beyond purely aesthetic engagement. For example, texture-change of soft objects can be designed to express aggressive visual language through textural transformations that reveal metaphorical personal traits stimulating self-awareness and self-control [36]. Other examples include 'skin-change' of walls that reflect bio-sensing to promote self-regulation [35], light-change to display the history of use and

communicate physical memory, and colour-change to encourage social communication [37] potentially bringing household members closer.

In this sense, OUI Interiors will help technology weave into our homes in more intuitive and implicit ways than ever before. As essentially domestic objects get worn over time and accumulate user-prints of stains by our food, drinks, and muddy shoes, or rather our intimacy, tears and daily practices, interiors can potentially react to those changes and reproduce more complex interactions, promoting self-reflection, positivity and unexpected pleasure [32].

4. Limitations and Challenges

In the sections below we begin to sketch out some of the challenges that will need to be addressed to deliver our vision of domestic environments suffused with OUI Interiors.

4.1. Developing for Domestic Environments

As much as designing and evaluating any system in the wild can be much harder, requiring more care and sensitivity, there are potentially huge benefits to developing OUI Interiors and evaluating them in actual real homes. This, however, has significant implications for ethics, reliability, support and complexity. Family life is messy, dynamic and may include different types of occupants of different needs, i.e., adults, children, disabled, the elderly, etc. If studies of smart homes have told us anything, it is that we need to understand people and how they want to live their lives before we can really understand how technology can best be designed to suit them. Consequently, interfaces should be designed with a different set of values and functionalities in mind when set to be deployed in the domestic setting.

4.2. Sustained User Engagement

Much as recent discussion has argued for slow technology [26], OUI interiors should be designed, developed and evaluated in the context of long lives. As people are keen to lay their hands on the newest technology, they often want their domestic objects to last for at least a lifetime, if not for multiple generations. In this sense, OUI objects (being implicitly present, sensing and actuating within a domestic environment in the form of homeware, interactive furniture or decorative artefacts) have the potential of being more successful, used and embraced into people's homes, as other domestic objects are, for a lifetime. However, when it comes to technology, designing sustaining devices with long lives, is not an easy challenge, due to the exponential rate of growing technologies, materials and designs (and therefore changing standards and components). Nevertheless, designing for slowness has its advantages of supporting experiences of pause, contemplation and reflection -rather than efficiency and productivity- in addition to permitting somehow enhanced user interaction. Possible ways of designing for slow interactions include creating emotional

attachments to technologies, leveraging the aesthetics of everyday objects, developing intuitive interactions and creating ubiquitous technologies that blend into domestic environments surrounding users and yet fading into the background. Such technologies could retain use and interactivity across multiple generations and lifespans. None-the-less, issues of material endurance for electronic hardware and matters of power consumption and system operability and compatibility must also be addressed to achieve these goals.

4.3. Privacy and Data in Shared Spaces

One of the main challenges of Human-Building Interaction in general and OUI Interiors in particular is capturing and responding to, probably implicit, multi-user interactions raising questions of how such interactive objects/systems will handle multiple occupancy spaces. Will they be able to distinguish users, or not (and at what points is this necessary)? Do they need to discretely link to a person or aggregate data from multiple users? Should it always rely on anonymity? Or would personalization potentials require private identifying data? All of which create difficulties –yet interesting challenges- and implications for the design and development of OUI Interiors.

5. Conclusion

OUI Interiors is the concept of embedding interactive interfaces within the fabric of interior spaces and artefacts, extending both the function and aesthetics of everyday interior surfaces and objects. Through OUIs, domestic environments can potentially modify their appearance (i.e., form, colour, texture) as a means of interaction, either actively or passively. Such interaction is suitable for domestic spaces due to its subtle, calm and slow nature. In addition, OUIs can capture both explicit and implicit user input that are already afforded with physical domestic objects (such as furniture, curtains, cushions, carpets, etc.). Therefore, the design of OUI Interiors for domestic environments suggests significant potential and benefit for home occupants, giving everyday objects the ability to be interactive and context-aware. Although this paradigm comes with a number of ethical and social challenges, the potentials are promising us with a future of Human-Building Interaction (HBI) that supports the wellbeing of home occupants through appearance-changing interiors and intuitive sustainable interaction.

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