Interioractive: Smart Materials in the Hands of Designers and Architects for Designing Interactive Interiors

**Sara Nabil[1], David S. Kirk[2], Thomas Plötz[3], Julie Trueman[2],
David Chatting[1], Dmitry Dereshev[2], Patrick Olivier[1]**

[1]Open Lab, Newcastle University
Newcastle upon Tyne, UK
{s.nabil-ahmed2, david.chatting,
patrick.olivier}@ncl.ac.uk

[2]Northumbria University
Newcastle upon Tyne, UK
{david.kirk, julie.trueman,
dmitry.dereshev}@northumbria.ac.uk

[3]School of Interactive Computing
Georgia Institute of Technology
Atlanta, GA, USA
thomas.ploetz@gatech.edu

ABSTRACT

The application of Organic User Interface (OUI) technologies will revolutionize interior design, through the development of interactive and actuated surfaces, furnishings and decorative artefacts. However, to adequately explore these new design landscapes we must support multidisciplinary collaboration between Architects, Interior Designers and Technologists. Herein, we present the results of two workshops, with a total of 45 participants from the disciplines of Architecture and Interior Design, supported by a group of HCI researchers. Our objective was to study how design disciplines can productively engage with smart materials as a design resource using an evolving set of techniques to prototype new interactive interior spaces. Our paper reports on our experiences across the two workshops and contributes an understanding of techniques for supporting multidisciplinary collaboration when designing interactive interior spaces.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous; J.5 Computer Applications: Arts & Humanities – Architecture

Author Keywords

Organic User Interfaces; smart materials; e-textiles; Interactive Architecture; Interior Design.

INTRODUCTION

Over several centuries the architectural movements that have impacted our built environments have adopted varying levels of reference to nature. It is not uncommon to see architectural forms that try to mimic the flowing lines and natural references of the living environment. This was evident (arguably) in the gothic, baroque, rococo and art nouveau periods [36] and then more recently and literally in 'Biophylic Design'. Since the art deco and modernist periods however, buildings

have adopted increasingly abstract and metaphorically static shapes. That is not to say however that buildings are static and non-dynamic. As Brand [3] astutely illustrates buildings change over time. They have a patina, that develops through use and they age ostensibly, through weathering and other effects of time. It is also true to say that interiors, the artefacts and furnishings we have within our buildings, are moved, age and are replaced over time, shaping a dynamic environment within the buildings themselves [9]. However, these dynamic features of buildings often sit outside of the temporal flows that make them readily perceivable to the average occupant. We are aware of change over time, but the time-scales at play often mean we do not actively attend to it (beyond specific demarcated points of transition). Within environmental psychology there has long been a discussion around the restorative benefits of the natural environment, and concern for how this might be installed within the built environment [18]. One area of research Attention Restoration Theory (ART) [19] posits that dynamic, moving and possibly interactive elements of the built environment might support inhabitant well-being along a number of dimensions. From this we believe that our built environment should be designed to have the capacity for dynamic interactive change, at a time scale that is more perceptible to inhabitants. Not only could our homes morph as we grow old in them, and thus be more adaptable to our experiences and comforts over a lifespan, but also be more responsive to our daily needs and moods.

Research already exists in the area of Interactive Architecture [6, 22] but with limited understanding of Interactive interiors that does not really address matters of interior design in many kind of ways. However, deeper study and research for Interactive Interiors will help and support the vision of ubiquitous computing. In various ways researchers are beginning to think about more dynamic and adaptable living and working spaces [28, 14]. Organic User Interfaces (OUIs), including the use of smart materials offer a rich potential to 'retrofit' [22] interactivity in to domestic artefacts and surfaces. OUIs are defined as non-flat multi-touch interfaces that can exist in both rigid or flexible forms, can take any shape, and can -actively or passively- change this shape [35]. This kind of flexible and dynamic sensing and actuation is more feasible and affordable than ever. Smart materials such as shape-changing alloys (SMAs), colour-changing paints (thermochromic pigments), conductive materials (conductive fabrics, conductive

Figure 1. Examples of Interactive Interiors: (Left) Light-Form [Daniele Gualeni Design Studio, 2010] [31], (Right) Engaging Retail Space [Dalziel & Pow, 2015] [7]. Images reproduced with permission.

paints, metal powders) and other flexible sensors all form an interesting medium for embedding both actuation and sensing capabilities into everyday objects and surfaces.

For the practical and aesthetic qualities of these materials to be fully exploited within interior architecture and design however, the materials must be brought to the attention and understanding of those who work most prevalently in the design of the built environment, namely architects and interior designers. To date however, there has been no significant exploration of how such communities can be supported in working with these new kinds of new materials in interior design projects. Evidently, there is a need to understand the processes through which designers can come to understand and work with such smart materials, in collaboration with technologists, if we wish to see visions of smart environments fully realised.

In this paper therefore, we discuss our study of inter-disciplinarity between HCI and Interior Design. We explore the use of embedded smart materials to support new interactions in interior designs. In particular, we critically reflect upon our efforts to scaffold interior designers and architects, as two specific communities, learning to design with smart materials through hands-on exploration.

Below we first introduce some related work, which grounds some of our key understanding of interactive architectures and OUIs. We then unpack two case studies, as two workshops conducted with architects then interior designers respectively, which brought them in to collaboration with an HCI team who scaffolded their prototyping with new interactive materials, whilst designing novel interactive interior spaces. In each case we were utilising techniques for supporting their exploration (with smart materials) of 4D interaction. We conclude the paper with reflections on the process of supporting interior designers and architects to design with new materials and in doing so try to tackle some of the proposed challenges of Interactive Architecture [22], namely Radical Interdisciplinarity, Appropriation and Retrofitting, and Scalability.

RELATED WORK

Interactive Architecture that used shape-change as means of reflection and interactivity with users has been subject to a few HCI studies [6, 22] and prototypes, such as ExoBuilding [32] a physiologically driven Adaptive Architecture prototype, the MuscleTower [24] another prototype of an interactive/ proactive architectural structure and the Kinetic Interactive

Architecture [27] that explores bodily interactions with different dynamic interior surfaces. But when we observe the design of any of these examples, we can't seem to picture them as architecture to live with. The interactivity, adaptivity, and proactivity researchers introduced in these previous examples were basically kinetic. Other research looked into the possibilities of designing entire building facades as digital displays [11, 33].

On the other hand, architects took kinetic and adaptive architecture to another level where scalability essentially triggers new forms of dynamic behaviours, capabilities and challenges. The most basic type would be the Kinetic sun-shade facades that take a variety of shapes and motion axes, from the very early examples such as the Institut du Monde Arabe in Paris (Jean Nouvel, 1987) [23] to the modern recent buildings such as the Kolding Building of SDU in Denmark (Henning Larsen Architects, 2014) [16], Al Bahr Towers in Abu Dhabi (Aedas Architects, 2012) [1], and the Kiefer Technic Showroom (Giselbrecht, 2010) [12]. Other kinetic architecture may transform the entire structure such as the shape-changing Hoberman's Arch (Hoberman, 2004) [17]. Current Interactive Architecture - other than being kinetic - often include colour-changing LED displays such as the Luminous Interactive Public Art Platform in Darling Quarter, Sydney [8].

A primary aspect of interior architecture is lighting and finding creative ways of manipulating lighting with other forms of kinetic actuations to realise user interaction. In interior design practice, interactive design firms are starting to create interactive spaces to engage and react to users or the ambient environment as well, using light and sound. Examples of interactive interior designs are the Engaging Retail Space (Dalziel & Pow, 2015) [7] that responds to touch using capacitive paint on wood wall panels and reacts through audible sounds and projected graphical animations, and the Aegis Hyposurface kinetic wall (Mark Goulthorpe, 2000) [13] that actuates its shape-changing mechanism either autonomously (pre-programmed) or responding to ambient sounds or noise. Other examples that involve LED interactivity are Light-Form (Francesca Rogers, 2010) [31] and the Philips Luminous Patterns [26]. More immersive experiences can be also found in some novelists' work such as Nicolas Schoffer's Spatiodynamic Luminodynamic & Chromodynamic Space [34]. All these examples were designed and built to extend the user experience in the space by pushing the boundaries and adding

a dynamic nature to the interior design instead of being just static as traditional designs (see Figure 1).

OUI materials leverage these possibilities from being mechanical into organic in terms of the nature and effect of the actuation's interaction and materialism. Such smart materials have the physical changeable properties that are reversible and repeatable, responding by changing their shape (morphogenic), skin texture, opacity or colour (chromogenic) or other morphological forms [29] reacting to external stimuli such as heat (thermo-), light (photo-), electricity (electro-), pressure, water/humidity (hydro-/hygro-), magnetism or chemical reactions [30]. Other smart materials may have sensing qualities rather than actuating ones. For example: conductive fabrics, conductive paints and flexible sensors that allow a range of manipulative and tactile sensing (from light touch to pressure) onto other normal materials. Previous research has looked into how OUI materials in Interactive Architecture can be used to create prototypes for both skin-changing OUIs such as Morphing Lumina Architectural Skins [20], Morphogenic Adaptive Building Skins [2], and OUI Interiors such as the LivingSurface [37], LivingWall [4] and the playful home interior Squeeze [25].

Therefore, interactive interiors based on OUI smart materials have great potential to create immersive enriched user experiences within interior spaces in a range of contexts. Some may be designed as a conversation starter, for storytelling or to stand out from the crowd and/or overcome temporal blindness [5]; while others may be driven by the need to use technology in a way that redefines the identity of the space or the service being presented and practiced within. Other motivations for OUI interactive interiors includes visualizing the unseen [37], yielding pleasure [21] and uplifting emotions and feelings of people through adding new dimensions to the spatial context such as discoverability, revealing, playfulness and temporality.

EXPLORING INTERACTIVE INTERIORS
Our review of related work identified two barriers to the transfer of research into practice. First, previous HCI research does not emphasize the 'design' of the prototypes, in large part due to the computing approach that tends to frame the challenge as one of functional problem-solving nature that is primarily concerned with system performance. That is, an emphasis on functionality and operational aspects of their design rather than the visceral and aesthetic qualities and values it creates and imposes. The second issue is that interactive interior practitioners are rarely concerned with deeper and long-term examinations of how people will interact, perceive and live with such designs for lifetime. Consequently, if we want to explore the design space of different interactive spaces and unwrap the potentials of smart materials in designing interactive interiors and objects, HCI researchers need to engage professional interior designers and architects in a multi-disciplinary exploratory process.

In our study we held two workshops with a total of 45 participants from both disciplines: Architecture and Interior Design, together with a group of supporting HCI researchers to develop concepts and designs for interactive interior spaces. Our objective was to get design disciplines to engage with and explore smart materials using an evolving set of techniques.

INTERIORACTION: CASE STUDY 1
The first case study was a hands-on workshop for a group of architects to get them to experience interactive materials and explore together ways of utilizing and embedding them into building fabrics as a means for designing interactive interior spaces, or as we term 'interioractives'.

Method
The first case study was with the School of Architecture, Newcastle University, UK in which we had 9 participants (3 undergraduate students, and 6 postgraduates in different programs: MArch and MSc in Experimental Architecture) out of which there was 1 male and 8 females. The workshop was held over a full week and was located within our research lab, facilitated by three researchers, and participants signed up willingly as a part of a pre-teaching 'Design Week'. The objective was to collaborate together in groups to ideate and design a interactive interior spaces. Participants were first briefed about the concepts of OUI Architecture and interaction design, then introduced to an array of OUI materials (sensing and actuation) and controlling them using Arduino programming. Several group discussions and brainstorming sessions took place in between their learning sessions to allow them (and us) to evaluate, and critically reflect upon concepts of Interactive Interiors. The smart materials used included shape-memory muscle wires, thermochromic paints, conductive materials and flexible pressure and bend sensors. Participants had a goal to design an interactive interior space that could potentially make use of these novel technologies.

Activity 1: Material Exploration
Participants had the opportunity and time to not only examine the smart materials but to use them in the form of well prepared kits by themselves. We introduced the basics of Arduino electronics and programming to facilitate their hands-on prototyping of different interactive OUIs. They wired different capacitive materials (fabric, thread, fibre, paint, ink and metals) and flexible pressure, tilt, squeeze, bend and stretch sensors as input, and SMA (Shape-Memory Alloy) muscle wires and controllable heating pads for colour-changing thermochromic paints as actuations/output.

Activity 2: Ideation
After the exploring and playing with the materials, participants were asked to work in groups discussing different applications of sensing and actuating interior architectural spaces on four different categories: spaces, surfaces (walls, floors, ceilings, windows, etc), furniture, decoration and accessories. Eventually, few ideas were generated for both the 'spaces' (the whole) and 'accessories' (the detailed), but rather participants focused on 'structural surfaces' and 'furniture'. The ideation activity led to 39 different applications ranging from the simple obvious "window regulating indoor ventilation according to weather or pollution" to the creative and immersive "show warmest place in the house using thermochromic paint" or "lighting sculpture that glows more the more the WiFi-connected number of users in the building". We then analyzed
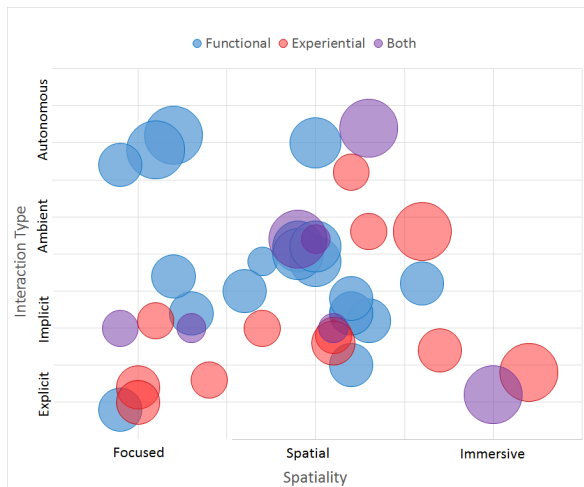
Figure 2. Visualization of data analysis of Case Study 1 Ideation Activity using different dimensions: (a) Spatiality (x-axis), (b) Interaction Type (y-axis), (c) Engagement (diameter), and (d) purpose (colour).

these ideas to unwrap the inherited features and attributes these applications incorporated. Their ideas were (unexpectedly) equally distributed among three types of interaction: (1) Explicit Deliberate Interaction (hand manipulation i.e. touch, press, in-air gestures, speech control); (2) Implicit Motion (motion: proximity/ moving around, posture: sitting down/ laying/ standing, displacement: moving/dropping objects); (3) Ambient and Autonomous: surrounding environment (weather: temperature/ humidity), ambient conditions (sound, light, time, heat) and based on external network feed.

We analyzed these ideas by coding key aspects of each idea/ application according to the type of interaction, spatiality, engagement dimensions, purpose, legibility and re-adaptability. We rated the level of spatiality (over a spectrum from focused to spatial to immersive) and the interaction type (from deliberate explicit control to implicit user actions to ambient conditions recognition and finally autonomous behaviour). We also considered the dimensions of user engagement as: 1D: linear, 2D: planar, 2.5D: planar with an object, 3D: spatial/bodily, 3.5D: building-scale, and 4D: adds the effect of temporality to the 3D engagement. Then we identified the purpose of each application to be either functional, experiential or aiming both function and experience. The result of this analysis is shown in Figure 2 as plotted data points on scales of spatiality and interaction, with the size indicating the dimensions of engagement, for functional (blue), experiential (red) and combined (purple) purposes. Through this approach we only intend to visualize data in a meaningful way that shows the spectrum on a qualitative scale with no emphasis on any particular numerical value so no quantitative rating is considered. As shown in Figure 2, we concluded these findings:

- The average dimension or level of engagement (size of circles) of applications or ideas increases with the increase of the spatiality and/or the interaction getting less intentional i.e. implicit and ambient.

- The average dimension or level of engagement (size of circles) of applications or ideas that has both experiential

and functional purposes (purple) is larger than that of those introducing functions only or experience only.

Activity 3: Design Challenge
The whole group then moved from the lab to the wild, with the aim of designing an interactive interior space, in a gallery room around 6m x 4m. The resulting design concept was: creating a playful experience in the form of an 'enchanted' interior, a cave-like dark room with hidden maze-like qualities, themed as 'Alice in Wonderland', and augmented with interactive installations and clue(s) leading to the location of a treasure (a magical object). Based on the sensing and actuation techniques they had learnt about, they split themselves into smaller groups to design and build six interactive installations to augment their interior walls with interactivity:

1. A tactile wallpaper/poster that used conductive fibre and paint to display audio feedback for users playing with it.

2. A touch-sensitive wood wall-panel using capacitive paint manipulating LED lights that shows an arrow for the right way in the maze.

3. A 2D cardboard light switch based on conductive paint, that activated a far away lighting sign showing users what to do next.

4. A haunted/actuated curtain that moved flipping cut-outs using SMA reacting to proximity sensing.

5. A hidden clue painted with thermochromic paint on a wall that only revealed the invisible treasure code when a connected corresponding pressure-sensitive chair was sat on.

6. A treasure (i.e. actuated object) designed as a mushroom model that activated (bounced cap using SMA wire and lights up LEDs) when a user entered the right code by dipping a finger in capacitive connected tea cups.

All designs were then installed and the room was opened for public visitors as part of a bigger architecture gallery event.

Data Analysis
Our gathered data consisted of 8 hours of audio data, recorded during the workshops, to which we chose to perform selective audio transcription of 2.5 hours that formed the entire length of group discussions and presentations after each group activity. The collected data was also supplemented by participants' sketches, schematic architectural drawings, textual written descriptions of their ideas and designs, and most importantly our observational notes made throughout the sessions.

During this workshop, we not only empowered these designers with brief knowledge on new frontier possibilities of dynamic designs and embedded interactions, but we also had the opportunity to to; (1) investigate how they perceived OUI Architecture; (2) examine their views on appropriation and applicability; (3) unwrap new ideas and potentials of such OUIs; (4) discuss and raise new challenges and considerations; (5) design and implement six different interactive artefacts using OUI smart materials; (6) create an Interactive Interior space with an enchanted theme; (7) capture visitors' user experiences

with the OUI interior developed, and (8) observe user reactions and interaction behaviours of novice users (i.e. exhibit visitors) with OUI artefacts.

Findings

The results of our data analysis can be articulated in three main themes, describing the unwrapped ideas, potentials and challenges of interioractives. For anonymity, we refer to participants as P1 to P9.

Spatio-Autonomy & Context-Awareness

Participants mainly ideated around different context-aware functional uses for interactive interiors, rather than their aesthetics. For example, P4: *"proximity activates lights leading the way to get somewhere"*, P4: *"curtains change opacity whether it was heated up or it was more brighter outside, the curtains' back would become more or less opaque so the space would be more comfortable inside"* and P5: *"if you walk by, chairs pop out so it reacts to you wanting to sit down."* Other functional purposes were also proposed for interioractive objects such as furniture with context-aware ergonomics such as P3: *"more comfortable furniture that shape your body"*, P6: *"reading chair checks and regulates the surrounding ambient lights"* and furniture responding to noise in the space or supporting space comfort: P5: *"chairs would heat up or become more comfortable and soft the colder you are and then also get rather sturdy and colder if you're too hot"*. Throughout the sessions, we observed how designers started thinking of and referring to interior objects as living things that have minds of their own e.g. P6: *"when bins feel full they can tell us they need to be put out at the night before"*, P6: *"plant pot that moves to stay in the sun"*.

Playfulness vs. Calmness

Temporarily Playful: participants expressed how they feel interioraction can be more appropriate for non-permanent installations (e.g. museum seasonal exhibits, shows, tourist sculptures/ attractions, retail stores, temporary entertainment). For instance, P2: *"a lot of this is about the novelty, it's great when you've never seen it before and it's the first time, fantastic, but if that's on your wall forever, it kinda loses its novelty."* and P6: *"it has to be things that are consistently useful rather than being sort of transiently entertaining"*. So for exciting engagement, sequential interaction was discussed. For example: P2: *"you would touch something then it would tell you something to do next and then that does something else, for example it lights up and when you touch it, it tells you to jump around then when you jump around something else happens."* On the other hand, architects suggested residences and permanent spaces should be designed with "calmness" in mind i.e. designing for permanent settings should be carefully considered to avoid boredom and/or frustration through creating hidden and/or calm interaction scenarios. Alternatively, participants pointed out how interior interaction can not only be pleasurable but provoking as means for promoting physiological wellbeing P1: *"what else could get people moving, for example, if you sat too long on a seat it would get really cold or really warm so that it would help you move like a little provocation somehow so not always pleasurable"*. Still, the design challenge showed how participants kept considering

these two paths as an interaction 'double-edged sword' where designing a simple logic is too obvious, unimpressive and therefore not quite playful, while the complicated scenario is unintuitive and often incomprehensible to users. At the end, however, they succeeded in designing their enchanted exhibition in a way where visitors were observably enjoying the playful experience, commenting how it was a *"curious*, *"surprising"* and a *"wow"* experience (see Figure 6). Although, unexpected user interaction behaviour for exhibit visitors was not uncommon, for example, some visitors were observed repeatedly touching everything as if playing a musical beat with interactive sounds and lights.

Design Constraints and Limitations

Scalability issues bring limitations to some designs; P5: *"probably anything that is out in the rain but needs to be controlled by an electric current would become way more difficult to construct it and also would break much easier*. Other aspects such as the expectations of users were also raised; P2: *"you don't want to make people lazy, you still want them to want to interact with things, but if everything is constantly being done for you, if you have sensors that tell you what the weather is like outside"*, P6: *"what if you want it to be brighter, what if you want to sit in the dark"*, P2: *"when you want the design to stop being intuitive and for you to then as the user to take over that"*. Designs were also constrained by the simple but delicate materials that are quite easy to use/prototype but lack the resilience required for a public installation, so careful considerations needed to be taken (e.g. transparent coating, tight fixing, soldering, etc.).

Critical Reflections

Collaborating with architects yielded a productive framework to design interactive spaces. Architect participants successfully: *(1)* understood how to use smart materials in their designs, *(2)* learnt basic programming and electronics essentials to connect/ build their own circuits with sensors and actuators, *(3)* were able to design and create a playful theme of an interactive interior space in a sequential interaction approach, and *(4)* build an interactive space from raw materials of conductive and electronic products we provided. Although not structurally dynamic or adaptive, the space they designed and constructed was context-aware with embedded interactions within the walls, furniture (sensitive seat) and interior objects (enchanted treasure: cups and center piece) using Arduino microcontrollers controlling motion sensors, tactile conductive, shape-changing and colour-changing materials. What slowed down the design process at the beginning was their need to visit and check the physical location, which wasn't ready from Day 1. We have learnt how the site visit is a crucial starting point for interior architects to be able to conceptualize any design. This should be considered by interaction designers wishing to collaborate with architects to create an interactive space i.e. having the physical space ready before hand and scheduling the site visit at the very beginning. Another lesson we have learned from this case study regards the visitors' reaction and behaviour within the exhibit: not all people should be expected to act in the same normal way. For instance, some visitors were overly cautious while gently touching the touch-sensitive walls, while others were too intense and rough

(consumption of wine was involved!). A good interaction design should therefore take such different kinds of users into account.

INTERIORACTION: CASE STUDY 2

Method

The second case study was in the School of Interior Design where 36 students (7 male and 29 female) in their final year of three-year undergraduate program, participated in a full day workshop in their own studio space, together with 3 HCI researchers to facilitate the planned activities. Our research goal was to explore with them the potentials of OUI materials in Interior Design as a means of designing interactive interior spaces in different contexts and using different traditional finishing materials such as Wood, Metal, Paint, Acrylic, Glass, Ceramics, etc. Participants were briefed as part of a module they were attending to develop an interior space for a theatre set for a production of 'Pan's Labyrinth', which we incorporated into our workshop plan to investigate what interesting interaction designs might be employed in such an unusual exciting interior.

Activity 1: Material Exploration

For demonstrating interactive materials to interior design students who are accustomed to material samples from different suppliers, we prepared four sample models that would show tactile and flexible input and colour-change and shape-change output each embedded in standard interior design materials that students may be more familiar with. For example, we designed a tactile palette to demonstrate to designers a variety of possible embedded capacitive-sensing in the form of wood sheet, wood engraving, fabric, leather, fibre, thread, paint, glass, acrylic and ceramic tile, using flexible conductive materials underneath such as capacitive paints, fabrics and metal powders (see Figure 3). These ready made models we prepared helped in rapid learning, exploration of physical interaction and how such materials can be weaved into their normal interior designs.

Activity 2: Ideation

This group activity was designed in a way that is closer to how interior designers work. Their methodology is mainly about how a design concept would be developed based on a series of fixed constraints such as space or building typology, in addition to a set of parameters which allow for creative exploration. As we wanted to explore designing different interactive spaces, we had a set of space contexts (educational, clinical, entertaining, retail, residential and an eatery). We also wanted to explore the possibilities of embedding a variety of the normal interior finishing materials (wood, metal, paint, acrylic, glass and fabrics) with sensing and actuation capabilities. Data sensing may include Explicit hand manipulations or air-gestures, Implicit motion or pressure, Bio-sensing, Environmental conditions, and Ambient sounds or lights, while actuation may include change in physical shape, colour, skin or style, pattern or texture, and activating feedback such as sound, light/shadow or motion. Consequently, we designed six 3 by 3 jigsaw puzzles each containing four pieces (from the set of space contexts, finishing materials, data sensing and

Figure 3. Tactile Palette: a design tool created for Case Study 2 for introducing capacitive-sensing embedded within different interior finishing materials (e.g. wood, fabrics, leather, glass, acrylic, ceramic).
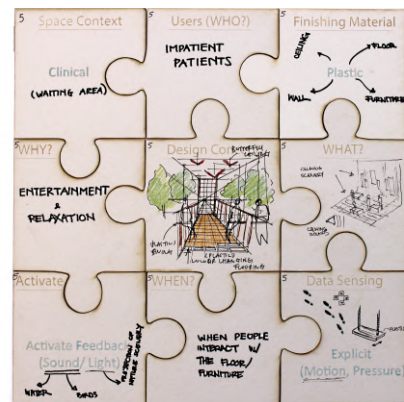

Figure 4. Ideation Jigsaw: a design tool created for Case Study 2 for supporting the development of design concepts to interactive interiors.

actuation effects) that are pre-defined as means of constraining the design with some boundaries, and four other pieces left as variables they can decide (who are the users, what is the interactive surface or object, when will it transform or trigger reaction, and why will it do that). With four constraints and four variables, plus a main middle piece for the design concept, each group would have random nine pieces to help define their interactive interior idea (see Figure 4). This method resulted in a variety of ideas with different combinations of interaction attributes (users, inputs, outputs, context, usability and user experience).

The result was impressive as using this technique proved to be a rapid ideation allowing creativity yet bounded to some constraints. After a few minutes, each of the six groups developed a creative idea of an interactive interior design as following:

1- Shopping in Space: glowing footprints of retail customers would appear on the pressure-sensitive wood floor near key areas (entrance, stairs/lifts, changing rooms) visualizing their flow as they step-in and wander in the shop, could direct them also to area they want, then fading over time. Hangers could

also glow to direct customers to their size reacting to speech, all for creating a memorable experience in shopping.

2- 4D Cinema: hall that changes colours/ patterns of sound-proofing fabric covering walls, floors based on ambient sounds/ light of movie scenes creating immersive story moods for enhancing people's movie experience, or even seats that could have glowing seat numbers for late audience.

3- Campus Navigator: a wayfinding/ outdoors map navigation system embedded across a university campus that stores and shows students and visitors different routes and paths on opacity-changing glass panels that are touch-sensitive to allow users to point to where they want to go and it shows the path on the interactive glass panel in front of the map background board offering information for lost visitors or students on open days directing them to classes, refreshments, toilets, etc.

4- Sensory Assisted Living: texture-changing (uplifting) and colour-changing (associated to emotions) residential object (water cube sculpture/ wall covering/ floor/ toy tunnel) responding to bio-sensing and facial expressions of special needs (impaired/ blind/ child patients) when different moods detected (through heart rate, etc) by kinetic changing patterns and textures to turn their bad days into good ones, motivate, encourage positivity, optimism, inclusion, normality and playfulness.

5- Healthy Smoothies Bar: an eatery for children designed with organic installations (trees) that moves branches, glows LEDs and transforms colour when heated based on busy rate and day and night temperature for educating kids (healthy nutrition awareness, sustainability) and an interesting feature that when moves unleashes a story.

6- Butterfly Clinic: a clinical waiting area designed as a butterfly garden for impatient patients where pressure-sensitive floor panels (hanging bridge), walls or furniture could produce nature sound effects (birds, grass stepping, waterfall) and display calming nature sceneries, responding to user interactions such as moving around and sitting on motion-sensitive swings and passing underneath ceiling butterflies will move their wings, for relaxation and entertainment while waiting for their turn or stressful waiting for their relatives.

Activity 3: Design Challenge
During the design challenge, participants were split into five groups where they worked on theatre set designs that use smart materials and interaction technology to achieve two main goals: 1) immerse the audience within different scenes and 2) create changing scenery through dynamic shape-changing SMA and colour-changing materials. See Figure 5.

Group1: (War Scene) Use conductive fabric integrated in a sand bag to trigger different effects within the scene such as explosions and light effects, creating an integrated way of performing. Using light and photochromic fabric to change atmosphere of the scene from colourful to dark dingy scene or descending mist on stage activating hydrochromic fabric changing colour of the uniforms from crisp clean to military style gear which is important within that scene. Trees in the scene actuated using muscle wire instead of being a static object. Use photochromic foot prints illuminating way-
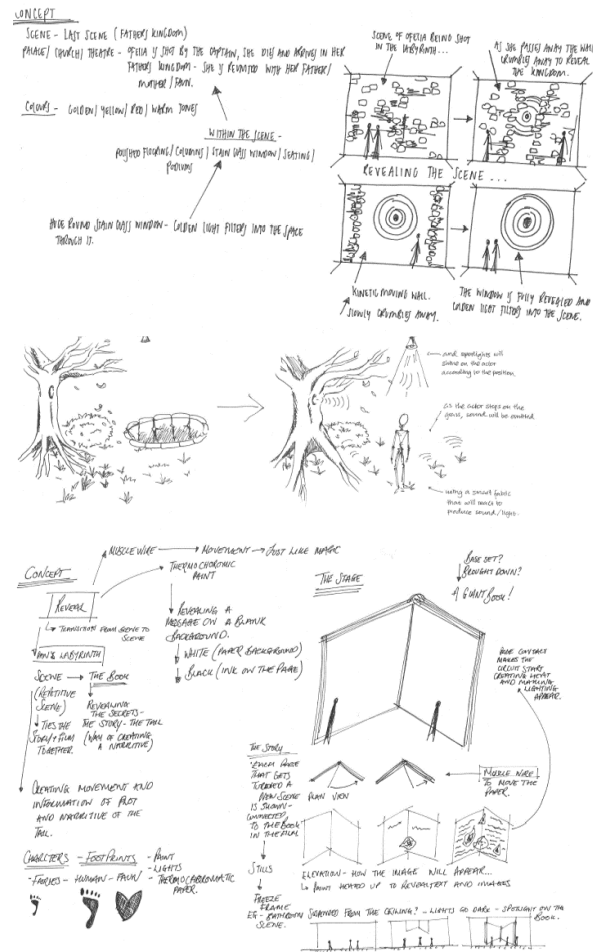

Figure 5. Some sketches from Case Study 2 drawn by participants during the Design Challenge.

finding within the dark theatre. Back-seat panels to produce special effects like smells and gust-air to simulate different senses.Group2: (Last Scene: Death) Use revealing concept to create a scene of stages where the prominent circular back window that lets a lot of light in would react to her death by turning dark once she's shot, colours would be dark, gloomy and dingy. The back wall will use SMA to crumble like rocks break away piece by piece then the wall would reveal another appearance for the next scene, then colours would convert to reveal the golden heaven kingdom. Ink that appears when she opens the book with narrative aspect could be a giant book that reveals the story using thermochromics when pages flip, and footprints of different characters (fairies, etc) would appear to make it magical.

Group3: (Start Scene) When she enters and steps on the grass, it will react to produce sound and spot light to shine on her and follow her as she walks in through the stage, and hidden pressure-sensitive buttons activates the curtain rolling down. The scene where she draws a doorway with a chalk will reveal the perspective view through thermochromics. Similarly, when she reads the book, it reacts by revealing pictures of her future when she touches it.

Group 4: (Labyrinth Pit Scene) when she enters and moves across the stage it will look like she's descending into the pit without actually moving down, using two interlocked circular slanted structures starts off both inline then create focus transition effect between two spaces. SMA hanging from the ceiling creating moving leaves of the forest, and changes the shadows behind it as it moves, as if the sunlight is coming through. Pressure-sensors on stage spark the noise of the forest at night.

Group 5: (Crawling under Tree Scene) getting the audience to make assumptions on what will happen in advance. Create a tree that had dead leaves and flowers that would come to life and open up using SMA to open and close thermochromic fabric flowers and leaves so that when it opens it starts slowly changing colour as well. As she crawls on the sensitive floor will glow beneath her in the dark stage, reflecting the frog scene, creating that sense of mystery. Mapping what is on the stage sets off another response in the cafe or box office, such as glowing footprints of actress, frog, fairies, etc.

Data Analysis

Our gathered data consisted of 6 hours of audio data, recorded during the workshop, to which we chose to perform selective audio transcription of 1.5 hours that form the entire length of group discussions and presenting back after each group activity. The collected data is also supplemented by participants' sketches, schematic architectural drawings and textual written descriptions of their ideas and designs. Again, the notes of our observations of activities constituted a significant part of the gathered data.

This data was then subjected to a process of thematic analysis. Initial codes were generated and refined through iterative analysis to produce coherent themes that were then refined to establish meaningful findings that contribute to the future research of interactive interior architecture and design. Thematic analysis was chosen to reflect the complexity of the research initiative and the desire to retain the generative possibilities of data analysis to support future interactive interior designs. As we had five groups in the Design Challenge activity, we will be referring to them as G1, G2, to G5 from hereafter. The result of thematic analysis process was four main themes described in detail below:

Findings

Special Effects: Light/Shadow, Sounds and Smell
One of the main themes that was clear throughout the data gathered was how designers focused on embedding special effects when asked to design for interactivity. Four out of the five groups used sound and light as means of output feedback/ interaction. Other effects such as smoke and smell (odour) were also used for a more immersive experience. Light was used in the form of both spot-lights and illuminating objects and floors as means of grabbing attention and/ or changing focus from one area or action to another. Personal light was also created to follow the user by G3: *"to shine on her and follow her as she walks"*. Sound effects were often triggered by implicit actions such as walking, stepping and approaching something or somewhere as means of immersive experience

engaging different senses. Controlling both sound and light together was a clear theme across different designs with response to motion and other implicit user input, and were considered a bold mix of actuation effects that instantly captures user attention. Shadow was also manipulated with light to create a sense as per G4: *"as if the sunlight is coming through with a dappled shadow-lighting effect"*. Sound and light were also used separately as inputs to trigger other actions; G2:*"once she's shot, .."*, not just an output interaction. In this sense, one interaction can open the way to another, allowing the interior space to conceal and reveal interactions, unfolding as the user digs up embedded sensation/ interactivity and get exposed to hidden discoverability within the space.

Exploring Materiality through Tactile Sensations
All six groups were clearly enthusiastic about embedding sensation within the fabric of their interior design, using both capacitive materials and pressure sensors. Pressure-sensitive floor tiles seamed popular as four groups designed them in different ways considering them a form of G3: *"hidden buttons"* that can control/ activate some features. Apparently they all wanted their interior to have motion detection as means of implicit input that is either deliberate or not, such as walking, approaching or entering somewhere; G3: *"when she enters and steps on the grass"*, G4: *"when she gets to the center"*, G3: *"As she crawls on the sensitive floor"*. Others embedded pressure-sensing as weaved into the fabrics of soft decorative objects; G1: *"conductive fabric integrated in sand bags can trigger explosions and light effects of the war when stood on creating an integrated way of performing"*. Other designs of embedded sensing included manipulating interior objects such as: G3: *"when she holds it"*, G3: *"when she touches it"*. An interesting code was found as: G2: *"would react to her death by turning dark"* meaning that death can be sensed and can trigger the aesthetic death of the interior space of its owner for a mourning time.

Communicating Through Colour-Change
Realizing their disparate properties, participants used a variety of colour-changing materials in their designs to be triggered at different conditions/inputs. Photochromic footprints (triggered by light in the dark) on the floor was repeatedly thought of as means of immersiveness leaving a glowing mark behind to be faded over time, even that of imaginary or distant characters/users who do not necessarily exist within the same space; G5: *"creating that sense of mystery"*, G2: *"would appear to be magical"*. Hydrochromic dyed fabric was used to respond to mist, and thermochromic paints and dyes were used on walls, fabrics and decorative artefacts. Two main reasons were behind using colour-changing interaction in the six designs: 'revealing' and 'reversing'. 'Revealing' a hidden story, text, picture or view was a noticeable objective behind embedding colour-change in different interior elements and composed an essential part in designing discoverability within the space; G2: *"ink that appears to give a narrative aspect to the hanging book that reveals the story using thermochromics when pages flip"*, G3: *"it will reveal the perspective view through thermochromics"*, G3: *"it reacts by revealing pictures of her future when she touches it"*. On the other hand, 'reversing' was the aim of integrating colour-changing materials

to change the atmosphere, the feeling and appearance of the space between three states normal/default, cheerful/colourful, and dark/gloomy on both the background (walls) and the foreground (objects) accounting on the psychological effects and social-norm interpretations of different hues of colour schemes; G1: *"to change the atmosphere of the scene from colourful to a dark dingy scene"*, G2: *"once she's shot, colours would be dark, gloomy and dingy.. then colours would convert to reveal the golden heaven kingdom"*. Although not designed, but during the discussions, colour-changing materials were considered appropriate to show the unseen such as mapping distant unseen actions or conditions.

Shifting Focus Through Shape-Change
SMA was mainly used to add dynamics to decorative objects that already exist in their designs and was explicitly justified by adding automated vibrance to the interior; G1: *"trees in the scene are actuated using muscle wire instead of being static"*, G2: *"The back wall will use SMA to crumble away like rocks break away piece by piece without anyone moving anything"*. Kinetic actuation in general was also used to allow a focus-shifting effect between two spaces, scenery transition, revealing a hidden appearance. Another usage of kinetic actuation was to create an illusion of spatial movement; G4: *"it would look like descending into the pit without actually moving down"*. SMA muscle wire was not just used for shape-change but to activate ambient subtle motions that could manipulate light shadows underneath; G4: *"as it (SMA) moves it would change the shadows behind it, as if sunlight is coming through with a dappled shadow/lighting effect"*. However, SMA was mostly considered for an organic actuation effect due to its linear lift and bend nature that resembles a subtle breath motion, so most groups embedded SMA within artificial flowers and tree leaves for ambiance. When integrated within thermochromic fabric the combined effect of shape-change with colour-change attributed to creating a living scenery; G5: *"dead leaves and flowers would come to life and open up using SMA to open and close thermochromic flowers and leaves so that when it opens it starts slowly changing colour as well"*. This technique actually utilized the same energy source/ wiring that heats up the SMA to implicitly heat up the thermochromic fabric triggering colour-change as well, so a flower would blossom and brighten at the same time, as if alive.

Critical Reflections
As much as they succeeded in designing with the concept of 'Revealing', other findings included difficulty of designing for 'Reflection, Speculation, Legibility (Indirectness) & Para-Engagement (Extra-involvement)'. For example, G5 mentioned that during their brainstorm: *"we thought getting the audience to make assumptions on what will happen next in advance"*, then they tried to frame it in other ways *"like mapping, so what is on the stage sets off another response in the cafe or box office"* and even *"get the audience to be part of the play, so what they do reflects on the stage or what actors perform can be projected around the audience, reflecting what happens in the scene"*. These 'para-engagement' types of designs create a deeper meaning of involving the users within a public space and takes engagement and interactivity to a level

Figure 6. Capturing visitors response with the interactive wall-paper at Workshop 1 Exhibition: 'Enchanted Architecture'.

that is beyond the traditional direct interaction that is obvious, discoverable and legible. However, they did not actually design much of these insightful preliminary ideas. Perhaps due to their complexity, deepness and unconventional nature.

While designers in Case 1 expressed more elaboration and interest on the 'structural' scale of surfaces (walls, floors, ceilings) and furniture, designers in Case 2 had a perspective of the 'ambient' scale joined both ends of the holistic view of the 'space' and the decorative details/ accessories that essentially contribute to their conceptual design identity and experience. This is mostly the result of the 'theme' at which each particular case study was framed upon. Therefore, we recommend clear and careful consideration of the setting and subject of collaboration with interior architects and designers to yield both 'functional' and 'experiential' applications and domains to enable the emerge of a new level of 'interioractive' designs.

DISCUSSION
From the observations in both workshops and our architects' and interior designers' efforts to understand and work with the smart materials, in addition to the visitors' feedback during the exhibit (see Figure 6), we have developed three considerations for the design of interactive interior elements. We explicate these below, before turning to discuss how our work is contributing to the developing challenges of 'Interioraction'.

Discoverability and Legibility
The discoverability of an interactive interior space ranges from fully discoverable and understandable to being hidden. By discoverability we mean the property or an interface that describes the extent to which a space is designed to express or hide its interactivity. That is; how quickly can people uncover interactive elements within a space and how an interior can unfold as users start interacting with it, either through implicit or explicit interactions. On the other hand, legibility defines how easily users can make a connection between the cause and effect i.e. input and output of interactions. Some spaces can be deliberately designed in a way that appears disconnected to urge users to systematically act within the space in order to reason what is happening. While we may not need or want to be reasoning about the legibility of some spaces, others should be designed in a way to reveal cause and effect relationships in dynamic environments.

	Fully Discoverable	**Undiscoverable** *(Hidden Interaction)*
Fully Legible	Obvious and Consistent	Hidden and Playful
Not Legible *(Hidden Logic)*	Spatio-Temporal and Autonomous	Mysterious and Magical

Table 1. Combinations between ranges of discoverability and legibility of an interactive interior space

In this sense, there is a clear relationship between discoverability (clarity of how to interact) and legibility (clarity of why it reacts). Table 1 shows how combining different ranges of discoverability and legibility can result in different space interactivity features and qualities. For example, a fully discoverable (flat) space that is fully legible (intuitive) with simple logic is understandable, obvious and consistent such as a regular light switch. An undiscoverable (unfolding) space that is also fully legible will be more playful (as it unfolds hidden interactions) depending on its learning curve as it still holds a 1-to-1 legible constant reaction, such as the Engaging Space [7] and the History Tablecloth [10]. On the contrary, a fully discoverable illegible interactive space is one that reacts to complicated logic/ scenarios that often use more variables in the interaction equation such as number of users/tangibles, their position/ roles within the space as well as variable time, distance/proximity or a composition of more variables creating spatio-temporal responses, sequential or accumulative interactions over time. This combination results in an autonomously-perceived space or object with no clear idea of why it is changing or behaving in a certain way, e.g. shape-changing bench [15]. Finally, a space that doesn't immediately show how to interact with it or why it is changing creates a mysterious atmosphere and can in the right circumstances then be perceived as a magical object or an enchanted space.

Revelation and Coherent Dynamics
How the interior space can conceal hidden appearances, and hidden personality of its own and be able to slowly reveal them through user interaction is an interesting aspect of an interactive interior. Although it is not necessarily always the case, a space that entirely transforms its interior elements together playing one symphony creates an immersive experience with its coherent dynamics. For example, colour-change and/or texture-change of an interior's wall paint, curtain, sofa cushion, flower vase, rug and wall art can create an impression of a whole new space or reveal a different feeling or mood. This can be achieved by wirelessly networking each of these soft decorative interfaces and playing with the options of appearance-changing in a coherent theme that can unfold together showing the veiled mystery beneath, designing for both the playfulness and aesthetics of interaction [25].

Spatio-Temporality and Spatio-Autonomy
An actual immersive experience is the one that takes interaction into 4-dimensions (rather than just 3D) by adding temporality as a key player in the user spatial interaction. An interior element can change its appearance as a result of interactions done over a week, capturing all the dynamics of

the space within that period of time rather than instantaneous reactions developed in previous work [20, 37, 4] that relied on a direct and prompt action-reaction approach. Once we design interactive spaces that can change over time or possess some autonomy of their own, our environment can start communicating 'self-expression' through their unfolding interaction.

INTERIORACTION CHALLENGES
Through this exploratory study we aimed at tackling some of the key challenges of Interactive Architecture [22]. Primarily, 'Radical Interdisciplinarity' through engaging relevant design communities i.e. architects and interior designers. Our engagement -as interaction designers- with interior architecture designers has taken a shape that is beyond the traditional researcher-participant relationship. But was rather a co-designer and co-author interrelationship where we all worked together in collaborative ideation, exploration and design group activities and discussions. This yielded a unique and productive experience that should specifically be applied to research around interactive spaces which is inherently multi or interdisciplinary. Other challenges we tried to exploit included 'Appropriation and Retrofitting', where we succeeded in embedding interactivity into standard finishing materials and decorative objects with simple, affordable and available materials that are paintable, printable and programmable. Whilst a delicate and tricky task, the new techniques we have introduced (e.g. the jigsaw, tactile palette, etc), helped simplify the ideas and forms of retrofitting such normal materials and real-world objects in a way that keeps -and extends- the aesthetics of the interior space and does not jeopardize the social and emotional associations people have with daily physical objects and surfaces. However, with regards to 'Scalability', we faced numerous obstacles related to embedding them in room-sized scale, but found iterative design methods and special material considerations to be helpful.

CONCLUSION
Not only did we *i)* engage architects and interior designers in 'interaction design' for creating interactive spaces, but also, through this collaboration, we have *ii)* explored the design space of interioraction, usages and limitations, *iii)* explored the potentials of affordable interactive materials in designing and prototyping interioractives, *iv)* developed new design techniques to do so, *v)* designed six different interactive spaces with a holistic experience, and built an actual interactive interior space (with reactive walls, furniture and decorative objects), *vi)* addressed some of the challenges identified for interactive architecture, and finally *vii)* tested and captured user responses to interactive spaces of novice users (in the wild) who were visiting our 'enchanted' exhibition. As we intend to continue such engaging and inclusive studies, we encourage the community to carry on similar collaborations and investigate new possibilities and potentials of 'Interioraction'.

ACKNOWLEDGMENTS

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