Smart Materials and metaphors to enhance technology adoption among older adults

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Declaration of originality

The research presented in this thesis is the original work of the author except where otherwise specified, or where acknowledgments are made by references. This project was funded by the EU project L.T.M. (NMP.2012.4.0-1) under agreement n° 310311 and was carried out at the College of Engineering, Design and Physical Sciences of Brunel University London, under the supervision of Dr Marco Ajovalasit and Dr Gabriella Spinelli.

The work has not been submitted for another degree or award to any other institution.

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Abstract

Technological innovation is increasingly contributing to the development of smart objects, meant as semi-autonomous devices augmented by sensing, processing and network capabilities that facilitate older adults being independent and in control of a healthy lifestyle. Given the lessened familiarity that the ageing population has with internet-based technologies, a 'digital divide' among generations is often observed. This research is premised on the basis that design interventions can develop intuitive and understandable smart objects minimising age-related differences and promote a greater technology adoption.

The aim of this thesis is to investigate how the understandability of smart objects for the ageing population could be supported through the application, at the product design level, of Smart Materials (SMs), a category of engineered materials whose properties can be designed to both stimulate human sensorial abilities and to develop engaging experiences. In line with such research enquiry, SMs are adopted in this thesis for their ability to embody 'analogies' and 'metaphors' into product designs and systematically stimulate the prior knowledge and memories of older adults to facilitate their understanding of new concepts, following the principle of 'familiarity'. Analogies and metaphors, powerful learning tools for written, verbal and visual communication, have been recently investigated as 'non-linguistic' tools, when physically embedded into product designs, to facilitate the users' understanding how technology works. How non-linguistic metaphors help to cope with age-related differences is still incomplete.

In order to demonstrate that embodied SMs can minimise differences in the understandability of technologies across generations, a qualitative and exploratory study was conducted; empirical evidence was collected through four techniques to accomplish the following objectives:

1. identify critical areas that affect older adults' everyday life and that smart objects should cope with;

2. define a set of embodied Smart Materials to be included into the prototype of a Smart Radio, a novel communicative device specifically design for the ageing population;

3. evaluate the prototype of the Smart Radio, where age-related similarities and differences in the interpretation are made explicit.

62 participants (n=31 under-60-year-old and n=31 over-60-year-old participants) evaluated the developed Smart Radio, the main evaluation study conducted in this thesis, using four different families of SMs. Findings reveal that embodied SMs considerably help mitigate age-related differences in the understanding of smart objects; this in return may increase the chance of technology adoption among ageing users. The embodiment of Smart Materials that enable metaphorical processing shows promising improvements on the older adult's ability to reaffirm their own subjective awareness, hence control, of the world around them along with opportunities for a human-centred technology development.

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Glossary of terms

Analogy

A relational structure applied from one domain to another of knowledge (Gentner 1983).

Designer Model of the Function Representation

A list of 32 output signals of the Smart Radio emerging from the Image Schema elicitation with SMs activity. Each signal is a link of signifiers (the Smart Material) and signified (the hypothetical human activity to be physically represented) in what the researcher considered the best pair and was therefore used as initial benchmark to evaluate the responses of participants of the main study.

Digital Divide

Gap in the adoption rate of current technologies across generations (Government Office for Science 2015)

Embodied Smart Materials (SMs)

Smart Materials embedded into product designs whose dynamic features are designed to recall memories in the user interacting with.

Image schema

"*Image Schemas are abstract representations of recurring dynamic patterns of bodily interactions that structure the way humans understand the world*". (Johnson 2013) in (Hurtienne, Blessing 2007). Gibbs and Colston (1995:349) further expanded the definition saying that "*image schemas can generally be defined as dynamic representations of spatial relations and movements in space*",

Intuitive use

"*The intuitive use is the extent to which a product can be used by subconsciously applying prior knowledge, resulting in an effective and satisfying interaction using a minimum of cognitive resources*" (Hurtienne 2011).

Mapping of knowledge

The act of building a conceptual correspondence between target and source domain of information in a metaphor (Hey L. *et al.* 2008).

Metaphors

Relational comparison between two domains of knowledge with a specific focus on the attributes they match (Gentner 1983)

Product metaphor

"*Association of two distinct entities, a product (target) and a remote entity (source), through physically mapping certain properties of the latter to the former*" (Cila 2013)

Smart Materials (SMs)

"*materials that display smart* behaviours" when a smart behaviour occurs when a material can sense a stimulus from its environment and react to it in a useful, reliable, reproducible and usually reversible manner (Knowledge Transfer Network).

Technology familiarity (TF)

The extent of prior exposure with existing technologies and assessed by the TF questionnaire as developed by Blackler *et al.* (2010)

Chapter 1

Facilitating technology adoption by older adults

1.1 Technology adoption and ageing population

The 49.9% of the world's population is digitally excluded, a total of 3.6 billion people, and within Europe, the figures are 26.5 % or 217 million people (Internet World Stats, 2016). The Office of National Statistics (ONS 2016) reported that in the UK in 2016, only 38.7% of adults aged 75 years and over were recent internet users, in contrast with 99.2% of people aged 16 to 24 years. Extant literature is available on the factors affecting the adoption of technology among older adults such as: lack of skills/capability and confidence (Heart, Kalderon 2013), social support (Hill, Beynon-Davies *et al.* 2008), cost/affordability/income (Lee, Coughlin 2015), excessive learning time compared to younger people (Rogers, Meyer et *al.* 1998), inadequate training and lack of ongoing support (Digital Inclusion Panel, 2004), lack of perceived need/motivation (Melenhorst, Rogers *et al.* 2006, Morris, Goodman *et al.* 2007), cognitive abilities and computer anxiety (Czaja, Charness *et al.* 2006). There has been a growing adoption of digital technologies among older adults recorded (Government Office for Science, 2015), and older adults appear willing to use technological products to support their safety at home and promote their personal wellness and health (Mitzner, Boron *et al.* 2010). Nevertheless, recent data also reveal that older adults find learning how to use and operate current technologies more difficult than younger adults; As a result, there is a gap of adoption rate across generations, named *digital divide* (Government Office for Science, 2015:4). Scholars have identified two major factors responsible for the digital divide:

1. Renaud *et al.* (2008) define *technology adoption* as a process that starts with the user becoming aware of the technology and finishing with the user making use of it. Rogers (2010) proposed a model highlighting five stages of the adoption process: *knowledge phase* to get to know the product; *persuasion phase*, to be persuaded of the need for the product; *decision phase*, leading to purchase; *implementation phase*, when the product starts to be

used, and *confirmation phase*, which seeks confirmation that the right decision has been made. Renaud *et al.* (2008) further developed the concept of use of technology by defining the 'acceptance' as a prerequisite, or attitude, of adoption. They proposed the STAM model (Senior Technology Acceptance and Adoption Model) distinguishing between three phases: *objectification phase* (based on the intention to use a new system); *incorporation phase* (including experimentation and exploration of the new system to understand its usefulness and facilitated by the ease of learning and use the new system); *final acceptance.* In both cases, the 'difficulty of learning' results as a negative factor that impinges the use of novel technologies and limits their adoption. Specifically, studies conducted by Bradley, Barnard and colleagues (Bradley, Barnard *et al.* 2010, Barnard, Bradley *et al.* 2013) theorised the presence of a hump of 'max learning pain' on the curve comparing the task difficulty and learning time. The engagement with technologies is therefore facilitated and encouraged by strategies that consider a minimisation of the perceived learning difficulties.

2. Alongside 'learnability' of new technologies, the perceived benefits deriving from the adoption of products leads older adults to purchase and fully use them (Jensen 2008). The study conducted by Mitzner *et al.* (2010) with 113 community-dwelling older adults and data collected by Melenhorst, Rogers *et al.* (2006) are consistent in emphasising that perceived benefits are decisive choices of older adults for the purchase of a new product.

Although technology adoption is influenced by multiple factors, it is assumed that smart objects' perceived benefit must be significantly bigger than the learning resources spent by the user to interact with them. Moreover, it is advocated that the design of technology for older adults must consider the evolutionary aspects of the user, their cognition skills and diversity in conditions, taste, attitude to technologies and aspirations (Spinelli *et al.* 2016).

1.1.1 Age-related differences in cognitive abilities

Fisk *et al.* (2009) identified age-related decrements in the awareness of external stimuli and in the interpretation of information that results from sensation (defined respectively, 'sensation' and 'perception'); furthermore, a diminishment of coordination of muscle for control of motion and alteration of processes involving the elaboration of sensory information to be stored, recalled and used are also accounted. The latter, defined as 'cognition', regards the ability of thinking, problem-solving, reasoning and decision-making that influences the information processing. A set of primary age-related cognitive differences were identified:

- the reduction in working memory, defined as the *"memory that has just been perceived and refers to the capability to keep information active while we work on it"* (Fisk *et al.* 2009:19) is typically found in older adults, that affects the concept formation task. Conversely, the long-term memory, referring to a permanent storage of knowledge (i.e. semantic memory: meaning of words and directions of "on/off" switch button) does not decline with age. The prospective memory (i.e. remembering to do something in the future) can be affected in different degrees: if the task is time-based (e.g. 'do this in an hour'), older adults show deficits in performance while, if the task is event-based (e.g. 'when the alarm rings, take a pill') age-related issues are shown to be minimal.
- Visual attention, primarily involved while interacting with a device (i.e. searching a visual display) and dynamic visual attention (i.e. focusing attention in one location and then another location), show age-related declines hindering the processing of other stimuli. Only highly salient events will be captured and the smallest possible number of things will be sought to perform a task.
- Spatial cognition (i.e. translating information from a two-dimensional map into a three-dimensional image) declines with age.
- Working memory limitations have been demonstrated to affect linguistic tasks; language comprehension is intact if older adults rely on their semantic memory when the working memory is not overloaded; inferences are easily produced when semantic memory is capitalised.
- Procedural knowledge, defined as the *"knowledge about how to do perform activities"* (Fisk *et al.* 2009:19) is likely to be intact with age, because it refers to activities automatized prior to senescence that "*varies along the dimension of automaticity, from knowledge that is executed almost without thought (e.g. shifting gears or steering a car) to explicit but well-practiced routines (e.g. following a recipe)*" (Fisk *et al.* 2009:19).
- Finally, older adults process information more slowly than their younger counterparts. Age-related differences increase with task complexity and when multiple tasks are required.

In terms of Human-Computer Interaction and display design, O'Brien (2010), identified three main changes that affect the way products are used and experienced that can be mitigated with the used of the stored prior knowledge. First, 'recognition' in display design, based on familiarity parameters, is less affected by age than recollection (Nielsen

1994); the use of semantic memory can mitigate age differences for quick menus, but may be affected by menu structures, where the user relies on short-term memory and working memory (Freudenthal 1998); older adults find it difficult to discern between similar items, due to the reduced ability of the hippocampus, used to encode contextual details used for discrimination to identify differences between items too similar (Elfman, Parks, & Yonelinas, 2008 in O'Brien, 2010). Although these age-related differences have been demonstrated to a limited extent in several studies, no research has been conducted that specifically confirms these effects and facilitates behavioural predictions (O'Brien 2010).

Scholars have identified as the main design challenge the development of solutions to reduce the learning load of new tasks and accommodate the changes that the ageing process involves. Gregor *et al.* (2002) adopted a methodology to determine the *dynamic diversity* of older adults for software development by adapting its functionality upon the 'diversity' of the user; Naumann A. B. *et al.* (2010) attempted to demonstrate how the adoption of multimodal interfaces, considering touch, speech and motion control, may have benefits over the single modality interface of a mobile phone in terms of task completion and user satisfaction. Although the research demonstrated that multimodal condition was slightly better than the single modality option, the reluctance of older adults in trying new modalities of interaction is still unsolved.

1.2 The scenario of 'smart objects'

We live in a digital, interactive and interconnected world. Advances in sensor and wireless technologies have enabled a large number of artefacts to be interconnected and augmented with information technology. The scenario envisaged by Mark Weiser in the early 90's (Weiser 1991:86) of *"cheap, low-power computers that include equally convenient displays, software for ubiquitous applications and a network that ties them together"* is now a reality, primarily fuelled by the success of Radio Frequency Identification (RFID) technology, widely used for tracking objects and people within living contexts. The utility of RFID tags has been explored by Roy Want and colleagues (1999) with the intent to illustrate a series of applications of passive RFID tags into physical objects to make the case for one of the first experimentation of computing objects where object-related information are made available and clearly displayed. Applications of RFID tags have been carried out in the last decades with significant outcomes, like studies conducted by Michael Beigl *et al.* (2001) where an ordinary coffee cup augmented with computing and context-awareness capability was designed with the intent to provide instances of the ability of artefacts to

exchange information. What the researchers in this study defined as 'digital artefact' was *"an everyday artefact augmented with computing and communication, enabling it to establish and exchange information about itself with other artefacts and/or computer applications"* (Beigl *et al.* 2001:403). A few years later, further studies extended the benefit of augmented artefact towards a more human-oriented approach. Streitz *et al.* (2005:403) distinguished between a *system-oriented artefact*, where smart artefacts or the environment can take self-directed actions based on previously collected information, and *people-oriented artefacts*, able to empower functions in the foreground so that *"smart spaces make people smarter". T*he definition of people-oriented artefact introduces the concept of objects able to empower the user to take responsible and mature decisions and actions while being always firmly in control of the artefact. The ultimate definition of *smart objects* is given by Kortuem *et al.* (2010:44) defining them as *"autonomous physical/digital objects augmented by sensing, processing, and network capabilities. […] They sense, log, and interpret what's occurring within themselves and the world, act on their own, intercommunicate with each other, and exchange information with people".* This definition goes beyond the mere application of passive RFID and considers objects not only for their ability to sense and interpret what is occurring within them but mainly for their pro-active behaviour and ability to exchange information with people and other connected objects. Kortuem *et al.* (ibid.) identified three design dimensions that specify these smart objects: *awareness,* as their ability to understand (that is, sense, interpret, and react to) events and human activities occurring in the physical world; *representation,* that refers to the programming model adopted and *interaction,* that denotes the ability of the object to establish a dialogue with the user in terms of input, output, control and feedback. The resulting rich 'dialogue' established between human and artefact and the ability of the latter to inform the former are therefore key aspects that make any object endowed with *smartness*. Streitz *et al.* (2005) identified two complementary trends that justify the integration of information, communication, and sensing technologies into everyday objects: the *growing miniaturisation* of technological devices, small enough to be nearly invisible, and the *enhancement of the functionality* of everyday objects to support rich interactions and behaviours. Trials in this direction see objects that have been gradually embedded with sensors and dynamic output signals to augment their interactivity with the surrounding world. Opportunities are observed in objects becoming more appealing, engaging and entertaining at the same time (ibid.). Advanced electronic and computing

technologies are also incorporated into garments and wearable accessories to give people access to health-related and their living environment information. A representative example is 'Jawbone©'[i] designed by UP24™ (Fig. 1.1), a bracelet directly synchronised to the mobile phone of the user that unobtrusively tracks and shows the number of steps done, calories burned, sleep patterns and simplifies the way to monitor the body.

Fig.1.1 Jawbone© designed by UP24TM

Studies conducted in the field of Internet of Things (Kuniavsky 2010, Atzori, Iera *et al.* 2010) and Ambient Intelligence (Ducatel, Bogdanowicz *et al.* 2001) demonstrate how objects of the future can be progressively more aware of their surroundings in order to take self-directed actions based on previously collected information and to empower users to make decisions by taking informed and context-specific actions. Home settings could also be equipped with systems able to monitor activities of residents, take action if necessary and provide help and guidance regarding home safety (Cesta, Cortellessa *et al.* 2005, Sadri 2011, Cook, Augusto *et al.* 2009) with the help of miniaturised devices *embedded* in the background of people's premises (Aarts 2004). Future Care Floor (Klack, Möllering *et al.* 2011) shows an instrumental integration of sensors into the home setting to support old and frail people living independently at their own premises. The purpose of this technology is to detect abnormal behavioural patterns of inhabitants and activate rescue procedures in case of falls or other emergency events. A key feature of this approach is that the environment is *intelligent* in a way that is sensitive to the context, adaptive, and able to learn from the behaviour of its inhabitants in order to eventually be able to recognise emotions (Gaggioli 2005).

The restless design and promotion of smart objects have been lately fuelled by the uncontested diffusion of cheap portable wireless devices such as smartphones, tablets and smart watches enabling everyone to have a small computer in their pocket. Advances in cloud computing allow data to be collected and synchronised across multiple devices, supporting the simultaneous use of multiple smart objects either as screens and sensors. 'SmartHalo'[ii] (Fig. 1.2) is a little box connected to the handlebar of any bike to easily convert it into a smart bike. Once connected to the smartphone of the rider, SmartHalo uses multiple colours patterns to display information such as directions to follow, time remaining

to reach the destination, distance travelled, calories burned, elevation, average speed etc., that can then be viewed on the dedicated application. 'Vessyl' (Fig. 1.3) is a Smart Mug designed at Mark One[iii] that automatically knows and tracks everything the user drinks and that displays nutritional information via Bluetooth to a smartphone. These devices are in charge of collecting and processing the information from the user and/or the environment for supportive applications; what the user perceives is exclusively the result of his/her performance without being aware of the technology behind the product.

Fig.1.2 'SmartHalo': a smart biking device designed to support urban cyclists

Fig.1.3 'Vessyl': a Smart Mug designed at Mark One

Examples presented above highlight how opportunities in technological development can span from monitoring and entertainment purposes to the enhancement of social connections and health and wellbeing applications, introducing unknown product experiences with a variety of interactive solutions.

1.3 Smart objects that embed the 'ageing in place' philosophy

The over-60-year-old population of the world has doubled since 1980 and is forecast to reach two billion by 2050 due to better health care practices (WHO 2015). 'Ageing' is defined as a process of accumulation of deficits and a decrease in physiological reserves that may reduce the adaptability to stressful and change situations (Fulop, Larbi *et al.* 2010). The *ageing in place* philosophy has been indicated as a viable alternative to placement in nursing homes or in assisted living communities and research demonstrates how older adults accept to remain in their own homes and receiving care, for as long as feasibly possible (Cheek, Nikpour *et al.* 2005). Further studies have been conducted in promoting technologies for intelligent environments and adopting assistive devices; the intent was to build an environment in which many features in the home are automated and devices can

communicate with each other (Edge, Taylor *et al.* 2000). Mollenkopf *et al.* (2005) created a taxonomy of the technologies available for the ageing population including:

- compensation technology (used to make up for sensory losses and other physical or cognitive limitations);
- daily life technology (used to rehabilitate individuals who have suffered from temporary conditions/disabilities);
- low and high tech devices that are chosen to enhance the wellbeing of individuals who have no conditions to compensate for.

This latter set consists of mainstream technology purchased and accessible to people of all ages (Spinelli, G. *et al.* 2016). Within this group, off-the-shelf products for the ageing market use a broad range of modern technologies such as necklaces with emergency buttons and fall sensors integrated into mobile phones with wireless notification functionality to caregivers. For example, 'Carehub' by Efegy[iv] (Fig. 1.4), is a stand-alone control system embedded with a camera, lights and motion sensor that provides a quick and intuitive control of the device through an analog input system, allowing multiple users to have access to the information detected.

Fig. 1.4 'Carehub' by Efegy: a control system for older adults

Fig. 1.5 'UnaliWear': a smart, assistive watch activated by the voice of the user

Fig. 1.6 'Wireless Blood Pressure Monitor', design and commercialised by Withings

'UnaliWear'[v] (Fig. 1.5) is a smart watch activated by voice and provides assistance such as directions on how to get home, medication reminders and on-call emergency assistance. Voice-activated assistance connects the older user directly to an operator who will confirm if emergency assistance should be dispatched to his/her location. Fig. 1.6

shows a 'Wireless Blood Pressure Monitor' commercialised by Withings[vi] that shows through the mobile phone of the patient the status of his/her blood pressure. Data are also directly communicated to the doctor, removing the burden of the user having to remember and record this information, resulting in a smoother daily routine.

In these products, users are facilitated in the performance of their ordinary activities while objects seamlessly track their wellbeing status as a hidden caregiver would do, without the need to be concerned about the technology behind the product. Technology, defined as *"the application of scientific knowledge for practical purposes, especially in industry"*[vii] has recently produced advances with the benefit to mitigate or prevent some of the consequences of ageing (Government Office for Science, 2015). Nevertheless, ubiquitous input/output devices, such as smartphones based on Internet usage, are particularly affected by a low adoption rate, as they involve an interaction with the cognitive and sensorial system of the older adult that undergoes significant changes (Gamberini, Raya *et al.* 2006 in Spinelli *et al.* 2016). Moreover, most product interactions occur only at the product feature level rather than at the goal- or task- level, keeping a high degree of separation between the product and the goals and lifestyle choices of the user. The side effect is a perception of technology as demeaning and stigmatising, broadening the gap between the elders and their environment, sometimes resulting in frustration and isolation (Spinelli, G. *et al.* 2016). The challenge is to design daily life technologies for older adults that are easy to operate and to use (Kleinberger, Becker et al. 2007), and able to support their daily task and do not magnify their physical and cognitive weaknesses (Forlizzi 2007).

1.4 Smart objects and ageing population

Opportunities in the mitigation of the low adoption rate by older adults are unveiled by smart objects able to understand users` behavioural patterns and act accordingly that eventually reduces the learning load that new models and interfaces generally require (Sadri 2011). Examples are accounted with the twofold intent to display information in a more engaging way and embed technology into existing devices to limit the learning effort that novel devices demand.

AdhereTech[viii] designed a 'Smart Wireless Pill Bottle' (Fig. 1.7) currently used by patients in pharmaceutical and research engagements. This bottle automatically analyses user information and if doses are missed, patients can receive customisable alerts and interventions using automated phone calls and text messages. As envisioned by Fisk *et al.* (2009), the adoption of engaging sensory systems that provides redundant channels for those who have a growing lack of sensorial perception is a potential way to maximise the abilities of the older adult and create at the time, pleasant and engaging interactions. Mickael Boulay designed 'Measure less to feel more'[ix] (Fig. 1.8), a diabetes reader that claims to reduce the stress of the user by providing an emotional and engaging experience while measuring blood sugar levels. Current devices focus strictly on quantifying the blood levels with numbers with no room for personal feelings and sensations. This mundane activity is personalised by the use of a changing LED light to express how high/low the blood sugar level is instead of using numbers. 'Loop', designed by Kathryn McElroy and Joseph Weissgold,[x] (Fig.1.9) is a soft, close-fitting directional armband that provides haptic feedback to guide the user to find their way out of a crowded or dangerous situation. Through the GPS of the smartphone, the device detects the user`s position and by simply pulsing clockwise or anti-clockwise, informs the user about which direction to take. Similarly, 'Ref'[xi], designed by Jens Dyvik, is a wearable device that supports the user's awareness of their emotional skills (Fig. 1.10). Through monitoring changes in the user's pulses, this haptic device which straps onto the user's wrist, twists, curls, and nuzzles against the skin to relax or stimulate the user behaviour. This device aims to be a self-help tool that can also coach the user in practising a mind balancing breathing pattern by teaching them an intuitive body language.

Fig. 1.7 'Smart Wireless Pill Bottle', designed by AdhereTech

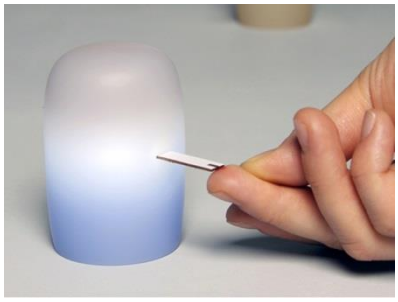


Fig. 1.8 'Measure less to feel more', designed by Mickael Boulay

Fig. 1.9 'Loop', designed by Kathryn McElroy and Joseph Weissgold

Fig. 1.10 'Ref', designed by Jens Dyvik

Although physical and cognitive changes in the ageing population require a high demand of assistive technologies, at the daily-life tasks, the Ageing in Place philosophy is supported by embedded technologies with redundant sensorial information that promote a pleasant experience with the device. Therefore, everyday assistive technologies are not considered any more medical devices because the general wellbeing of older adults, their ordinary activities, and their independence are promoted toward wellness (Bright *et al.* 2013).

1.4.1 The enhancement of sensorial stimuli in reactivation of the human agency

The ability of technologies to create a dialogue with their users and help them making informed decisions is further stressed by the agency theory. The conventional definition of human agency, referring to the ability to undertake different actions while continually re-evaluating the efficacy of these actions within changing situations (Emirbayer & Mische 1998), is now been extended to technological products, in regards to their growing context awareness and cooperation abilities, alongside responsiveness and increasing level of self-activity and actions they can perform (Rammert 2008). The accomplishment of one task is delegated to multiple actors where typologies of actions are taking place at the different level of interactions (Hollan *et al.* 2000). These interplays can be threefold (Rammert 2008) and defined as:

- *interactions,* when occurring between human actors and structured by social values and cultural meanings;
- *intra-activities,* when happening between technical agents;

- *interactivities,* when relating both people and objects and building the world of interfaces, human-computer interaction and sociotechnical systems.

The actions occurring between people and objects follow three levels of awareness: Rammert (ibid.) interprets them as different levels of an agency called 'causality', 'contingency' and 'intentionality'. *Causality* is the agency that exerts influence or has effects and is defined where a difference of state is produced; *contingency* is the capacity to act in a different way and to choose between options; *intentionality*, is when an intentional, meaningful action is allocated. The theories of *distributed cognition* (Hollan et al. 2000) and *distributed agency* (Rammert 2008) demonstrate that human action is distributed across many concurrent instances which maximise the exchange of information between human to human and human to the environment at the basic level of *causality* that the human agent will eventually convert into volitional actions.

Embedded intelligence may change the way designers conceptualise and develop technology, as it will no longer be just about the physical form of a new product, but about intangible features, such as the actualisation of the *contingency* and *intentionality* level of the human agency. In other words, technology may enhance the way information is made available at the causality level and therefore stimulate the older adult's ability to decide which action to perform and be aware of the reasons underpinning that action.

1.4.2 The enhancement of sensorial stimuli through Smart Materials

In the attempt to activate human sensorial abilities through product design and to maximise stimuli from the environment through engaging experiences, a large body of research has been published on the application of 'materials' whose dynamic properties are exploited to build a rich dialogue with the user, identified as 'material experience' approach (Karana, Pedgley *et al.* 2013). Studies have identified toolkits in the characterisations of materials through the sensorial properties exerted (Karana, Hekkert *et al.* 2010) and the influence these material features may have in the attribution of a certain meaning to the product (Karana, Hekkert *et al.* 2008, Lefteri 2007). These studies are mainly related to conventional materials and their 'static' properties, such as surface features and manufacturing properties. However, the concept of 'material' itself is constantly changing. The growing diffusion of computational features in everyday products has blurred the boundaries between materials, interactive technologies and human-computer interaction. An embedded system with computational technology, defined as a *computational composite*, could be seen as a material itself, much like any other material used to design

things (Vallgårda, Redström 2007). As Ferrara (2014:3) explains, materials in the last few decades became "*performers of change*" because of their technical capability to intervene in the matter at a molecular scale and modify it to accomplish predefined functions and performances. "*Smart Materials*" (SMs) is a new class of high-performance materials that have engineered, changeable properties that can reversibly alter their shape or colour in response to physical and/or chemical influences, e.g. light, temperature or the application of an electric field (Ritter 2007). The Knowledge Transfer Network[xii] defines SMs as: "*materials that display smart behaviours*", which happens when a material can sense a stimulus from its environment and is capable of reacting to it in a useful, reliable, reproducible and usually reversible manner. SMs also incorporate features such as *sensors and actuators*, which are either embedded within a structural material or bonded to the surface of another material allowing its control (Gandhi, Thompson 1992). The *control capabilities* permit the material to respond to an external stimulus according to a prescribed functional relationship or control algorithm. This engineered ability allows materials to be applied not only to their physical substance but also for a combination of input/output signals triggered. The development of '*smart*' materials, systems and structures shows how products can actively monitor and optimise themselves and their performances through their adaptive and responsive capabilities (Schwartz 2002). Materials, conventionally seen as substance, perceived by senses, characterised by mass and volume, are defined by more fleeting definitions, whose stable physical and aesthetics characteristics are susceptible to variation in time. What makes a material to be 'smart' is, therefore, its ability to absorb external energy, that works as an input, and to undergo certain changes in its microstructure (Ferrara, Bengisu 2014).

Due to this dynamic behaviour, SMs are characterised by two or more appearances that challenge designers to find applications other than conventional materials and to create at the time, unexpected ways to experience them. As explained by Ferrara *et al.* (ibid.), SMs give sensitivity, interactivity and communication skills qualities to everyday life objects, but their 'smartness' strictly depends on the projects they are applied to and the overall vision of designers.

1.5 Aim and objectives of this study

Within the context of this thesis, Smart Materials are investigated for their ability to reproduce certain sensorial stimuli into smart objects and are explored for the advantages those stimuli have to allow older adults understand information from novel technologies.

The combination of Smart Materials and the improvement of the 'understandability' of information conveyed by smart objects appears to be a field not fully investigated; therefore, the question at the heart of the research, as further characterised in the next chapter, is:

'How do embodied Smart Materials enhance the understandability of smart objects by the ageing population?'

In other words, the thesis aims to explore how Smart Materials embodied in a novel smart object can simplify the way older adults acquire new information, with the intent to suggest a design solution to the 'digital divide' concern and to counteract the low adoption rate of technological products by the ageing population.

In order to answer the research question and identify how the adoption of technological products for the ageing population could be supported through Smart Materials embodied into smart objects, three objectives are formulated.

First of all, within the plethora of potential scenarios experienced by older adults, the investigation requires the identification of an 'ageing in place' design scenario, by means of a set of critical areas that technology is supposed to cope with. Based on the scenario identified, the second objective regards the design of a smart object with embodied SMs and finally, the evaluation of the device is required along with a description of the similarities and differences in its interpretation by users of different ages.

As a result, the following objectives are summarised:

1. *Identify a set of critical areas in promotion of an 'ageing in place' scenario;*
2. *Design a smart object with embodied Smart Materials;*
3. *Describe how older and younger adults understand and evaluate the novel smart object.*

1.6 Significance of this study

Findings of this study will have an impact on the benefit that the combination of Smart Materials with smart objects has on the ageing population, considering their changing cognitive abilities. Under the umbrella of new product development, this research

would guide design practitioners towards a human-centred application of Smart Materials and their systematic use upon the sensorial stimuli and the human response elicited.

The improvement of smart objects for the ageing population in terms of their enhanced understandability, as suggested in this study, is expected to promote a design approach that counteracts the low technology adoption observed among the ageing population and to reduce the 'digital divide' across generations. Furthermore, the design of widely understandable technologies for the ageing population promotes 'ageing in place' practices; these smart objects are therefore expected to mitigate age-related differences in cognitive abilities and support an effective diffusion of technology in the older adult's everyday life.

1.7 Theoretical and design contribution of this study

The theoretical contribution of this research lies in the embodiment of SMs into smart objects for the ageing population in support of their learnability and in shortening the digital divide across generations. Specifically, this thesis makes the case for the embodiment of SMs as able to maximise sensorial stimuli that smart objects produce and systematically stimulate the prior knowledge and memories of older adults. The recalled memories and knowledge, are demonstrated to facilitate older adults understanding new concepts, following the principle of 'familiarity'. Therefore, the study contributes to the literature of 'prior knowledge retrieving' and 'metaphors' in a non-verbal communication by demonstrating how the application of embodied SMs may significantly facilitate older adults link the past and new knowledge with the intent to acquire new information.

The research does also contribute to the 'materials experience' theory, by providing routes for future human-centred applications and development of SMs.

The practical importance of the research question lies in the definition of a convergent human-centred design methodology that minimises the effect of trial-and-error when designing for the ageing population.

1.8 Structure of the thesis

To answer the research question, the thesis is divided into seven Chapters as described below:

Chapter 2 **The demand for embodied Smart Materials: review of 'familiar' technologies with non-linguistic metaphors**

The literature review presented in Chapter 2 examines strategies where prior knowledge of older adults can be retrieved through sensorial stimuli and used to acquire new information. A parallel is drawn between Smart Materials and their ability to embody non-linguistic metaphors for product design purposes. Two assumptions are identified and three research objectives are presented.

Chapter 3 **Research Methodology**

Chapter 3 covers the research methodology adopted, including the epistemology, theoretical perspectives, methodology and research methods adopted, along with descriptions of the data analysis strategy adopted and research quality.

Chapter 4 **Opportunities for 'ageing in place' design scenarios: insights and findings**

A design scenario for 'ageing in place' practices is identified in Chapter 4. Two methods are adopted, by means of a Cultural Probe Kit and Focus Groups, to identify critical areas to be considered when designing for the ageing population.

Chapter 5 **Designing the Smart Radio, image schema elicitation through Smart Materials**

Chapter 5 explores possibilities of SMs to be embodied into a novel device, specifically designed taking into consideration the critical areas identified in Chapter 4. An 'image-schema elicitation with SMs' workshop is presented where properties of SMs are applied to embody abstract concepts. Findings are formulated and applied to the design of a Smart Radio prototype, a novel communicative device for older adults, and its interface consisting of 32 signals embodying SMs. These signals are presented as 'Designer Model of the Function Representation'.

Chapter 6 **Findings on the evaluation of the Smart Radio**

Based on results of a pilot study for protocol evaluation, Chapter 6 presents findings from the Main Study conducted where two samples of the population are involved in evaluating the Smart Radio. Similarities and differences in the understanding of the Smart Radio between samples are discussed.

Chapter 7 **Conclusions and future research**

The Conclusions and future research Chapter (Chapter 7) summarises the findings of each study conducted against the objectives of the research. It also highlights the

research contribution and practical implications of the thesis, alongside any limitations and considerations for future research.

Endnotes

[i] https://jawbone.com/up

[ii] *https://www.smarthalo.bike*

[iii] https://www.myvessyl.com/

[iv] *http://efergy.com/carehub/*

[v] *http://www.unaliwear.com/*

[vi] http://www.withings.com/eu/blood-pressure-monitor.html

[vii] *https://en.oxforddictionaries.com/*

[viii] http://www.adheretech.com/

[ix] http://mickaelboulay.fr/index.php?/measuring-less/

content/

[x]http://productsofdesign.sva.edu/loop-haptic-directional-arm-band-by-kathryn-mcelroy-and-joseph-weissgold/

[xi] http://www.dyvikdesign.com/site/portfolio-jens/ref.html#sthash.aoswm1af.dpuf

[xii]https://connect.innovateuk.org/web/smart-materials/smart-design guide?p_p_lifecycle=0&p_p_id=profileheader_WAR_profileheaderportlet&p_p_state=normal&_profileheader_WAR profileheaderportlet_groupJoined=true

Chapter 2

The demand for embodied Smart Materials: review on 'familiar' technologies with non-linguistic metaphors

2.1 Using *familiar* technologies to make intuitive products

A few decades ago, Norman (1988) wished for artefacts whose interactions possibilities could correspond to the intentions of their user and what that user perceived as possible to do with that artifact. Two gulfs, namely *gulf of execution* and *gulf of evaluation* represent a mismatch between the individual's internal goals on the one side and, on the other side, the availability of information and how they can be used. The understanding of novel technologies is then promoted when the breadth of the two gulfs is reduced and the product understandability is so *immediate* that it becomes invisible (Norman 1988). This seems not to be in contrast with what elderly people demand: usefulness, usability and desirability (Bright, Coventry 2013) along with the immediate perception of the benefits occurring from the device (Melenhorst, Rogers *et al.* 2006). The product interface, considered as the part of the product that allows a dialogue between the product and its users (Krippendorff 2005), can be 'invisible', otherwise not noticed by users, who ultimately find the interaction immediate (Beaudouin-Lafon 2004). As imagined by Weiser (1991), products are *invisible* when individuals can become so familiar with technologies that they do not have to think how to interact with them.

The concept of 'familiar technology' has been widely investigated in relation to the instrumental adoption of users' prior knowledge. Two experiments were presented by Blackler *et al.* (2006) where a digital camera (experiment 1) and a universal remote (experiment 2) served as a starting point to evaluate criteria for intuitive interactions. Participants were purposely selected with a different prior exposure with technologies, in

order to define how their past knowledge may influence the understanding of products features never encountered before. As reported in Blackler *et al.* (2003b), prior knowledge of technology allowed participants from experiment 1 to use the features of the new products intuitively. Furthermore, some functions of the new camera shown during the experiment were discovered only by participants who self-rated themselves as 'experts' of digital cameras, meaning that not only that general technology knowledge is relevant for intuitive use but also that 'domain knowledge' helps to a correct use and understanding of a novel device. Results from experiment 2 showed similar findings to those from experiment 1 (Blackler *et al.* 2003a), demonstrating how familiar features were used more often, while unfamiliar features required more time to be used. As a conclusion of these experiments, Blackler *et al.* (2006:10) proposed a set of design principles to support the design of intuitive technologies: the use of familiar features from the same product domain; the adoption of familiar features from different domains to suggest how to use less known functions and the use of redundancy and internal consistency principles within the product.

As a result, extant literature explains how product interfaces must follow clear principles of familiarity, similarity and consistency with other existing interfaces in order to be perceived and experienced as 'intuitive' (Blackler, Hurtienne 2007) where *"a technical system is, in the context of a certain task, intuitively usable while the particular user is able to interact effectively, not consciously using previous knowledge"* (Naumann *et al.* 2007:129). The concept of intuitive interaction that involves the use of knowledge gained from other products and/or experiences is further highlighted in other studies (Blackler 2008, O'Brien, Rogers *et al.* 2008), focusing on a specific association between intuition, the speed of reaction and age of the user. Relevant insights emerged from the studies of (Blackler, Popovic *et al.* 2010) where intuition is correlated to past exposure to similar features and it is affected by age. Specifically, Blackler *et al.* (2012) found that the performance of older adults when interacting with various interfaces is affected by a decline in cognition and *familiarity* with the product features. According to studies of Fisk R. *et al.* (2009), prior experience is important for older adults using new technologies but when the experience gained with these devices is recent, fewer chances to retain it occur for older people compared with younger people. Blackler, Popovic *et al.* (ibid) discovered that 20/30-year-old people accomplish tasks in a faster time and with more intuitive use than people over 40

years old, not only due to their higher motivation but to the major exposure they have with the current technologies. Studies conducted by O' Bren (2010), reveal that appropriate use of prior experience is a key factor for a successful performance with everyday technologies.

Studies conducted on familiar technologies and on the use of prior knowledge provide an important contribution to this thesis. Findings from the experiments of Blackler, Popovic *et al.* (2010) suggest that intuition is affected by age. Although several factors such as anxiety and personal motivation may influence the overall performance of a product never encountered before, this insight contributes to establishing the first assumption of this thesis that claims that *the age of users affects the familiarity with the technology*. This means that the more familiar a product result, the more likely older adults will intuitively use it. Furthermore, the experiments conducted by Blackler *et al.* (2003b) demonstrate the importance of the domain knowledge to efficiently use new feature products while O' Bren (2010) suggests that the way prior experience is retrieved and used eventually affects the general performance of a novel device. The way prior experience is retrieved from a certain domain is, therefore, a relevant aspect to be considered when designing for intuitive products and it is further discussed in the following sections.

2.2 Prior knowledge for product innovation

Hurtienne *et al.* (2015) said that products whose usability is considered intuitive often mimic previous technologies that recall interfaces already familiar to users with fewer opportunities for innovation. The design of products that are simultaneously intuitive, innovative and inclusive is, therefore, a challenge. The emerging factor that contributes to making a product more immediate for the older adults is managing the transfer of the existing *schema* the user has of a product to the new device (Blackler, Hurtienne 2007). The term 'image schema' was defined in the cognitive linguistic literature (Johnson and Lakoff, 1987) as dynamic structures arising from perception, bodily movements, manipulation of objects, and experience of force. Gibbs and Colston (1995:349) further expanded the definition saying that "*image schemas can generally be defined as dynamic representations of spatial relations and movements in space*". For example, *up-down*, *center-periphery, in-out* are image schemas developed from recurring ordinary interactions that remain in the brain. Recent studies conducted by Hurtienne Klöckner *et al.* (2015) identified macro-categories of image schema with the intent to be applied in multiple contexts and solve the tension

between 'innovation' and 'intuitive products'. Seven image schema groups were identified: *basic* (object, substance); *space* (centre-periphery, contact, front-back, left-right, location, near-far, path, rotation, scale, up-down); *containment* (container, content, full-empty, in-out, surface); *multiplicity* (collection, count-mass, linkage, matching, merging, part-whole, splitting); *process* (cycle, iteration, superimposition); *force* (attraction, balance, blockage, compulsion, counterforce, diversion, enablement, momentum, resistance, restraint removal, self-motion); *attribute* (big-small, bright-dark, fast-slow, hard-soft, heavy-light, smooth-rough, straight, strong-weak, warm-cold). The strength of this investigation is that once the image schema is produced, it can be instantiated in different ways; rather than mimicking the physical shape of an existing interface to a new one, designers must repurpose, through different shapes, the image schema the user attached to it and make information readily available. The resulting association of the image schema with a specific existing domain of information is what Grady (1997) called *primary metaphors*, and recently renamed by Hurtienne, Klöckner *et al.* (2015) as *image-schematic metaphors*.

The adoption of 'metaphors' into product interfaces has the power to augment the perception of reality by extrapolating information from well-established memories and past knowledge. Krippendorff *et al.* (2007) explain how *non-linguistic metaphors*, those metaphors grounded in the domain of artefacts, shift practices and experiences from the context of familiar source domains of information to less familiar target domains through making understandable situations that users struggle to comprehend. The theory of metaphors has, therefore, a relevant contribution in this thesis, being defined as a viable solution to help older adults retrieving their past experiences and use that knowledge to make informed decisions. The definition of the second assumption of this thesis lies in this ground claiming that *non-linguistic metaphors contribute to better understanding new technologies*.

2.3 Metaphors, analogies and product designs

Metaphors are alongside *analogies* traditionally adopted in verbal expressions to enhance the way information is understood and communicated; their differences lie in the way two different domains are related and the quality of new knowledge they infer. Gentner (1983) defines analogy as a relational structure applied from one domain to another (e.g. "*The Xl2 star system in the Andromeda galaxy is like our solar system*"), while

metaphors are predominantly relational comparisons with a specific focus on the attributes they match (e.g., "*She is a giraffe*," used to convey that she is tall). The crucial aspect of metaphorical language is the transfer of information from a source domain (familiar) to a target domain (unfamiliar area or situation) enabling people to use specific prior knowledge to understand novel or unfamiliar situations (Neale, Carroll 1997). This process of attribute sharing makes metaphors a cognitive phenomenon that goes beyond the linguistic tricks of verbal language being pervasive in everyday thought and actions and becoming a powerful tool for new knowledge acquisition (Lakoff, Johnson 1980). Alongside metaphors, that are a figurative expression which interprets a thing or action through an implied comparison with something else, analogies work as an 'illustration' of an idea through another familiar one (Hey, Linsey *et al.* 2008). This general distinction shows how these two approaches work: analogy could be adopted for an incremental acquisition of knowledge where the two domains of knowledge are not completely disconnected but they shared similar relations and structures; while metaphors could support the creation of radically new inferences. Therefore, metaphors are comparison statements whose primary function in learning is to stimulate active learner-initiated thought process (Carroll, Mack 1985).

The building principle of the *theory of interaction* developed by Black (1954) affirms that metaphors do not merely recall already known similarities, but they *create* the similarity. When two terms are associated in a metaphorical way, it is not important how much the reader shall know the literal meaning of the two words, but the system of *associated commonplaces* they evoke. The effectiveness of metaphors is not whether commonplaces are true or not, but that they should be readily and freely evoked. To use Black's words: "*Metaphor is, in this view, a filter where the principal subject is 'seen through' the metaphorical expression or the principal subject is 'projected upon' the field of the subsidiary subject. Through this perspective, certain aspects of the subsidiary subject go in the background while others stand out to the attention of the reader*" (Black 1954:288). Later studies conducted by Carroll and Mack (Carroll, Mack 1985) defined metaphorical comparisons as open-ended, leading the reader to a pragmatic analysis of the learning situation. The active learning theory of Carrol and Mack, along with Black's (1954) interaction theory, claims that matches and mismatches between the source and the target domains are both viewed as playing a significant role for the learner because they stimulate

thought and maximise the efficacy of the metaphor as a learning vehicle (Carroll, Mack 1985). The pragmatic approach of Carroll and Mack gives a fundamental contribution: metaphorical learning should be considered as an *active process*, providing the user clues for *abductive inferences* (generating hypothesis on basis of very limited information) and *inductive inferences* (verifying hypothesis within the same limitations of information) through which learners construct *procedural knowledge* of the system encountered which is the kind of knowledge that does not senesce (Fisk, Rogers *et al.* 2009), as explained in paragraph 1.3.1. Lakoff and Johnson (1980) described metaphorical structuring as partial, being able to hide certain aspects and to disclose others more relevant and identified three main groups of metaphors:

- *Orientational metaphors* are those metaphors (such as 'Happy is up', 'more is up') formed by a systematic correlation between human emotions (for example happiness) and our sensory-motor experiences (for example erect posture). Simple spatial concepts, such as *Up* and *Down*, are easily understood because of their immediate association with the human spatial experience. These spatial concepts emerge from interaction with the physical environment (we have bodies and we stand erect) and within a vast background of cultural beliefs;

- *Ontological metaphors* involve the projection of entity or substance status on something that does not have that status. For example, the metaphor '*time is a moving object'* is based on the correlation between an object moving toward us and the time it takes to get to us;

- *Structural metaphors* are systematic correlates that explain thoughts and actions in terms of other experiences or activities. For example, the metaphor '*argument is war*' involves the overlapping of the multidimensional structure of the concept '*war*' upon the corresponding structure of the concept '*conversation*', organising experiences into defined structures.

Scholars are continuously exploring new applications of metaphors and their role in the design process. Studies conducted in the field of interaction design (Neale, Carroll 1997, Saffer 2005) envisaged a key role of metaphors as a tool to simplify the way people interact with products at the digital interface level and advocated for tools and methods to support

the use of metaphors in interface design. Metaphors are identified as a design tool that helps to translate the information emerging through the adoption of non-visual senses, such as sound and touch, into concrete product properties (Özcan, Sonneveld 2009). Further studies (Hey, Linsey *et al.* 2008) made a distinction between the adoption of metaphors and analogies in the design process where metaphors are mainly used to understand early stage design situations, while analogies are preferred in the concept generation phase. Johnson (2013) studied how metaphors arise unconsciously from experiential patterns relating to the body's movements and its interaction with objects (e.g. a container and a movement in-out) and called them *embodied schemata*. The resulting metaphor goes beyond the linguistic conventions and embodied schemata are extended to define abstract concepts, defined as *embodied metaphors*. Studies (Heracleous, Jacobs 2008, Antle, Corness *et al.* 2009) have extended this concept into the design field suggesting that embodied metaphors can be applied to understand intangible concepts through tangible artefacts where metaphors can be physically manipulated for reason making. Specifically, Bakker, Antle *et al.* (2012) adopted an iterative approach to design Moving Sounds (MoSo) Tangibles, a learning system where embodied schemata are adapted to defined embodied metaphors to be used by children to structure their understanding of musical sound concepts (pitch, volume, tempo). A five phases study was conducted, consisting of identifying embodied metaphors, creating low-fidelity prototypes based on the identified metaphors, evaluating metaphors in these prototypes, creating high-fidelity prototypes and evaluating these prototypes. Through an investigation with over 150 children, findings reveal that all participants were able to successfully interact with the artefact and to link the input provided by the embodied schemata to a specific sound output. In a recent study, Cila (2013:5) developed the concept of *product metaphor,* defined as: *"any kind of product that is shaped to reference the physical properties (e.g., form, sound, movement, smell, and so on) of another distinct entity for particular expressive purposes".* Two intentions may inspire designers to adopt product metaphors: a pragmatic intention, aiming to reduce the workload of the user in understanding the product functions; experiential intention, when a rich sensorial and emotional product experience is provided Cila (ibid.).

The attempt to embody metaphors into a physical and interactive product is an undisputed challenge because metaphors are mainly discussed in the context of language Cila (ibid.).To date, there is limited research in the area of exploring metaphors in regards to their systematic adoption and the corresponding user response. Moreover, non-linguistic metaphors can easily be misinterpreted as the resemblance of appearances without clear information on the way the product should be used and experienced (Krippendorff *et al.* 2007). The need to identify and adopt a strategy that explains how metaphors can be physically reproduced is, therefore, imperative. This will eventually serve to demonstrate that non-linguistic metaphors provide an effective vehicle of information that, at the sensorial level, can help older adults recognise prior experience and allow them to freely make cognitive links to acquire new information.

2.3.1 Metaphorical mapping with Smart Materials

The process of association begins with a person learning new information that, at some point, faces a new problem and must remember a suitable idea source to solve it (Hey *et al.* 2008). Retrieving an appropriate analogy or metaphor is the most cognitively difficult step but once a source is remembered, a *mapping* is created between the source and the new target situation. Inferences are created by developing these mappings. This 'mapping of knowledge' from one situation to another (source domain to target domain) refers to the act of building a conceptual correspondence between a target and a source domain of information. In a verbal metaphor, the correspondence between domains occurs with words, while in non-linguistic metaphors it occurs with tangible features (Hey, Linsey *et al.* 2008). What distinguishes non-linguistic metaphors from linguistic metaphors is the way both source and target are associated into a physical form. The way certain properties are projected from a source onto a target domain may undertake certain *mapping strategies* (Cila 2013:91). A mapping can be 'literal' when the source perceptual properties are adapted to the visual language expressed by the physical properties of the target; it can also be 'abstract' when the designer extracts the latent properties of the source and infuse the target with them. Therefore, designers have a key role in the identification of an appropriate mapping strategy. When a mapping preserves the conventional identity of the product, it will be 'target-driven', while it will be 'source-driven' when the source is emphasised. However, the mapping of knowledge not always guarantees the generation of

a successful metaphor. Markussen *et al.* (2012) introduced the *blending theory* by connecting the product metaphor theory with the theory of product meaning and explaining that a product metaphor may be generated by a cross-modal sensory experience in product meaning and not just by its appearance. This theory further explains that contradictory forms of meaning can violate the source–target principle and that meaning attribution evolves over time through the interaction with the product. The 'blend' is, therefore, to be intended as an integration of multiple inputs into a 'third space', representing an emerging new meaning.

In this thesis the dynamic and sensory-oriented properties characterising Smart Materials (SMs) are envisioned as a vehicle for metaphorical messages, where the information conveyed is physically represented by an optimal result at the sensory and cognitive level. This solution has been chosen in the attempt to identify a systematic way to physically reproduce an abstract concept into a physical target domain to retrieve user's prior knowledge and allow him/her to intuitively understand new information. Within this thesis, the 'embodied SMs', are defined as SMs embedded into product design through the adoption of a metaphorical structure and are believed to reactivate sensorial memories established in past knowledge of the older adults to independently achieve acquaintance of novel information.

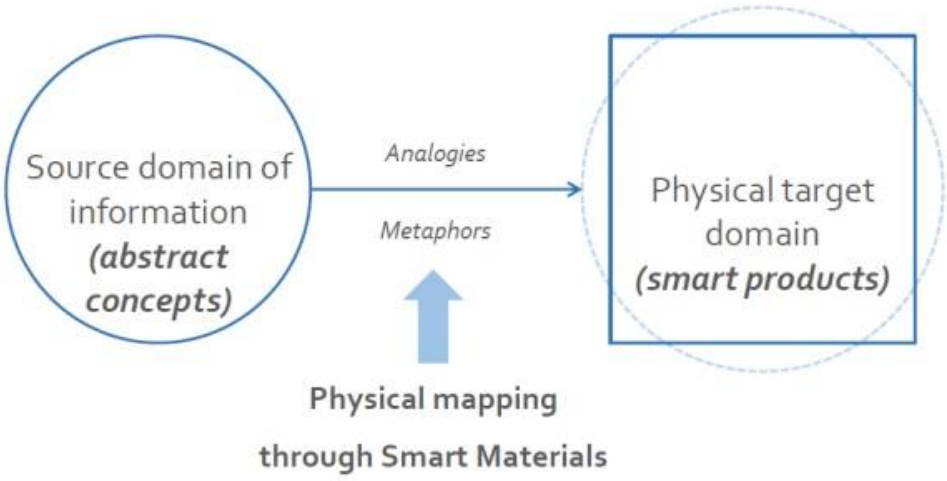


Fig. 2.1 Physical mapping between the source domain and target domain. Extended model from J. Hey et al. (2008)

As shown in Fig. 2.1, the application of Smart Materials as a *physical mapping* is then grounded in this vision, where priority is given to the investigation of the means that transfer the message from an abstract concept to a physical target domain. The *smartness* of materials is considered, in this vision, not as an intrinsic property of the material itself but as a function of its application and its ability to help older adults to understand messages coming from the environment that would not be otherwise acknowledged.

2.4 Smart Materials families in product designs and sensorial changes produced

SMs in the last decades have been classified mainly for their embedded physical properties (piezoelectric materials, electro-rheological fluid, etc.) with specific attention to their ability to work as sensors, actuators, to change properties, and exchange energy or matter (Gandhi, Thompson 1992, Banks, Smith *et al.* 1996, Culshaw, de Vries 1997, Srinivasan, McFarland 2001, Addington, Schodek 2005). A relatively new classification (Innovate UK)[i] has combined the SMs` families with the respective stimulus/response triggered. This classification concerns the potentiality materials have to receive and give back electrical, magnetic, optical, thermal, mechanical and chemical input and output. The classification based on stimulus/response opens up the debate on the interpretation of the opportunities these materials might have at an experiential level. SMs have been so far predominantly applied for their functional and engineered features, and their potential in supporting the user/product interaction has been largely unexplored.

Recent studies highlight the potential of SMs in the way they can also be used as interfaces (Nijholt, Giusti *et al.* 2012) with the aim to sensibly utilise readily-available, engineered materials as physical interfaces to convey information to the user. Ritter (2007) in his research on SMs for architecture, interior and design identifies a plethora of applications at the product design level where SMs go beyond their functionality to serve as a dynamic, responsive and engaging interface.

For the purpose of this thesis, four families of SMs are identified for the potential to convey an enhanced sensorial stimulus in a product design context and being able to create significant sensorial changes in both visual and haptic stimuli domain:

Light Emitting Materials: The Light-Emitting Materials family includes those energy-exchanging materials that produce light when their molecules are excited by the effect of energy, e.g. the effects of light or an electrical field (Ritter 2007). Luminescence, the general phenomenon of light emission, can be produced in different ways; when the light release is immediate the term *fluorescence* is used, while the term *phosphorescence* is adopted when the light emission is delayed to several microseconds or milliseconds (Addington, Schodek 2005). ElectroLuminescence (EL) materials have an applied voltage as a source of excitation and the light emission is based on a sandwich of insulating layers and a pigmented layer in between two conductive layers. The pigmented layer, with deposited pigments of phosphorus on it, contains some scattered impurities that when a voltage is applied, are hit by the electrons that freely move through the phosphorus and produce light. EL films and cables are two of the products developed from this technology with the primary advantage over incandescent light bulbs that, with appropriate flexible layer components, curved substrates can be clad on multiple surfaces (Ritter 2007). Other materials, such as semiconductors, emit light through the recombination of holes-electrons when a voltage introduces the charge carrier. This is the fundamental principle behind the light-emitting diodes (LED) (Addington, Schodek 2005). Similarly, Organic Light-Emitting Diodes (OLED) are flat LEDs based on organic, semiconductor polymers, that emit cold light by the absorption of electrons. The OLED panels generally consist of several functional layers placed one upon the other: the bottom layer, e.g. a glass plate, acts as a substrate to support the layers above it; the anode, e.g. indium tin oxide; the hole transport layer; intermediate layer between the ITO and the HTL layers generally adopted to produce a smooth surface; the emitter layer on top of the HTL layer, which is formed with certain percentage of pigment (approx. from 5 % up to 100 %); the electron transport layer, on which a cathode of e.g. calcium or aluminium is deposited; a covering layer on top, e.g. a glass plate. The application of an electrical field stimulates pigments in the emitter layer, where positive and negative charges meet and produce white or coloured cold light, depending on the pigment used (Ritter 2007).

Philips designed the interactive wall 'Lumiblade'[ii], based on modular OLED panels arranged to create an illuminated surface of several square metres with integrated motion sensors that react with the user and the surrounding environment (Fig. 2.2). Lumiblade is

an experimental project aimed to explore the pleasantness of new light sources and unexpected interaction possibilities. Electroluminescent materials are used by Mitchell Page and Andrew Vande Moere (2008) to maximise the way abstract data are represented and communicated. Through a user-centered design approach, they conducted an evaluation of a wearable visualisation system for team sports and designed 'TeamAwear', consisting of a set of basketball jerseys with electroluminescent wires embedded (Fig. 2.3). Jerseys are wirelessly controlled to represent game-related information on the players in real-time to enhance the awareness and understanding of game-related public information for both the players and the audience.

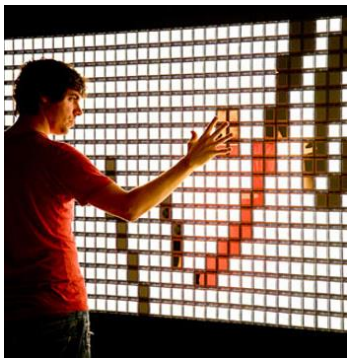


Fig. 2.2 'Lumiblade', by Philips, is a modular OLED wall that creates an interactive illuminated surface

Fig. 2.3 Mitchell Page and Andrew Vande Moere (2007). 'TeamAwear' is a set of basketball jerseys with embedded electroluminescent wires

Changing Shape Materials: Changing Shape Materials are those property-changing Smart Materials that are able to reversibly change their shape and/or dimensions in response to one or more stimuli (Ritter 2007). Shape Memory Alloy (SMA) and Shape Memory Polymers (SMP) are mainly known for their properties to remember and recover from large strains to a previously memorised shape without permanent deformation. This process is due to a phase transformation that enables the material to deform due to the twinning nature of crystals rather than the conventional 'dislocation slip mechanism', proper of the crystal nature, and allows for a complete recovery of strains. The transformation temperature range can be controlled by altering the alloy composition and

processing parameters. Typically, SMAs are available with transitions in the temperature range of - 40°C to >120°C (Schwartz 2002).

Thermobimetals (TB) are considered laminated composite materials that consist of at least two components, usually bands or strips, made from metals with different thermal expansion coefficients, permanently bonded to one another, for example by plating. The two materials work as active-passive movement actuators: the component with the lower coefficient of thermal expansion is called passive, the one with the higher coefficient active. Depending on the changing temperature and their geometries, the composite takes up a reversible curved shape and can be used for various applications and purposes (Ritter 2007).

Magnetostrictive materials are materials that change their shape (strain) and volume when subjected to a magnetic field (ibid). This characteristic can be observed in nearly all ferromagnetic materials, such as nickel, iron and cobalt where the strain exhibited is in the order of 0.001% and the change in volume is very small. Similar to magnetostriction, electrostriction[iii] is a property of materials that produces a change of dimension under the application of an electric field and is not a reversible process. Although the electrostrictive effect can be found in all materials, it is usually too weak to use practically. Electrostrictive ceramics are commonly used as these exhibit a relevant strain.

Electroactive polymers (EAP), known as 'artificial muscles' (Bar-Cohen 2000), are artificial actuators that emulate the behaviour of human muscles, exhibiting a large strain in response to electrical stimulation. These materials are mainly polymer-based actuators that can generate strains superior to shape memory alloys (SMA) with higher response speed and greater resilience. EAP are capable of strains up to 380%, are extremely flexible, light, thin, and transparent and can basically be tailored to any size or shape (Ritter 2007). These materials are generally used as automating parts of mechanical devices, often replacing traditional components like gears (Bar-Cohen 2000).

Studies on materials that change dynamically their shape have recently interested scholars in the field of interaction design. In the extensive review conducted by Rasmussen *et al.*, (2012), eight types of potential changing shapes are identified through the examination of 44 papers where changing shapes solutions are explored and contextualised into product designs. Six of the eight groups identified (orientation, form,

volume, texture, viscosity, spatiality) characterise shapes that change their structure through continuous deformation where the remaining two groups (adding/subtracting, permeability) identify changes when shapes are split, perforated, or united. Two further parameters identify the transition from a shape to another: kinetic parameters that consider the physical attributes of the transformation (frequency, tempo, speed) and expressive parameters that account for how transformations are perceived.

Despite the well-known use of Shape Memory Alloy in the medical field (Morgan 2004), multiple applications can be classified for 'non-medical' purposes (Van Humbeeck 1999, Saul, Xu *et al.* 2010) where SMAs are gaining an important position to explore new expressive possibilities. The nature of SMAs that allows them to be lighter and more silent than traditional actuators, has pushed researchers to design different sets of motion by combining the changing shape alloys with different materials and underneath layers. Coelho *et al.* (2011) created actuated and responsive interfaces like the 'Shutters Project' (Fig. 2.4); Qi, Buechley (2012) investigated techniques and approaches for working with SMAs and paper, and introduced a group of young students to circuits and paper crafting, inspiring a deeper interest in electronics (Fig. 2.5). The pendant light 'Vola' (Fig.2.6), designed by the Japanese designers Isao Hosoe with Peter Solom for Luxo, is a lamp that when turned off is found with the wings down, but once turned on the wings begin to slowly rise until fully open. The SMAs allow the movement to be accomplished in a smooth and reversible way. The metal scaffold expands with the heat of the light bulb pushing on a lever which opens the wings and closes when heat is removed. 'Surflex' (Coelho, Ishii *et al.* 2008) combines the physical properties of Shape-Memory Alloy with a foam panel to create a surface that can be electronically controlled to undertake certain deformations. Shape Shift[iv] is a dynamic wall designed by Manuel Kretzer that uses Electro-Active Polymers as ultra-lightweight, flexible material with the ability to electrically change shape without the need for mechanical actuators; Doris Kim Sung[v] investigates the potentialities of Thermobimetals to build a kinetic architecture that autonomously reacts to changing environment temperature to self-regulate buildings. Interactive 'blade of grass' made by Shape-Memory Alloy can be electrically controlled to communicate intuitive information to users through their appearance and movement capabilities that make them particularly

well suited for giving directions in indoor environments, or for ambient persuasive guidance and entertainment (Minuto, Nijholt 2012).

Fig. 2.4 Shutters' flaps have embedded SMA wires controlled with a circuit board concealed in the wooden panel. (Coelho et al. 2011)

Fig. 2.5 Wall hanging constructed using chained curling mechanisms. (Qi, Buechley 2012)

Fig. 2.6 Pendant Light 'Vola' by Isao Hosoe and Peter Solomon

Rheological Changing Materials: Rheological fluids are those liquids whose viscosity properties can be modified by an external stimulus (Lozada, Roselier et al. 2010). This stimulus can be a magnetic or electric field and, in both cases, the external field acts on the micron sized particles in suspension into the carrier fluid. These particles form chains along the magnetic or electric flux lines so as the apparent viscosity of the fluid increases as the external field intensity increases. The material properties themselves are similar but their integration is different. These fluids present great potentialities in terms of product experiences in the way they can contribute to enhancing the haptic aspect of an interface. For example, as shown in Figure 2.7, electrorheological fluids can open the possibility of producing a façade cladding that changes properties such as transparency, reflectivity, colour and even shape, through a computer controlled system that enables the creation of pulsating animations, running images and dark sparkling pictures. Magneto-rheological interfaces are investigated (Jansen 2010) through a device named 'MudPad' where the surface is controlled to provide localised active haptic feedback (Fig. 2.8). The magnetic field is applied to stiffen the liquid locally so as to create a tangible path. The importance of a local feedback is furthermore stressed where the authors highlight that especially on touch devices that allow multiple points of input, a richer feedback channel is needed. The

ability to produce this kind of localised multi-point actuation allows users to explore an interface by touch and opens up new possibilities for feedback design.

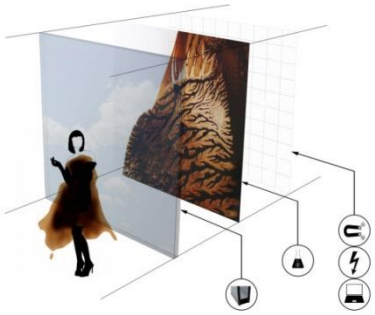


Fig. 2.7 Space Group Architects designed a 'magnetic architecture', using magnetism to allow façades to change translucency, colours and more

Fig. 2.8 'MudPad' is a system that provides localised haptic feedback independently at multiple points. (Jansen 2010)

Colour Changing Materials: Colour Changing Materials, technically called chromogenic Smart Materials, are materials in which a change in an external stimulus (such as light, temperature or chemical environment) produces a change of the absorption of reflectance of its optical properties (Papaefthimiou 2010). To date, changing colour properties have been applied mainly in mirror, glazing and display products with switchable technologies, where the user can autonomously change the transparency or the glare effect of a window (Lampert 2004). Addington (2005) identifies five groups of chromogenic Smart Materials: Photochromic materials are those materials that absorb radiant energy which causes a reversible change of a single chemical species between two different energy states. Photochromic materials absorb electromagnetic energy in the ultraviolet region to produce an intrinsic property change. Depending on the incident energy, the material switches between the reflectively and absorptivity parts of the visible spectrum. The molecule used for photochromic dyes appears colourless in its unactivated form. When exposed to photons of particular wavelengths, the molecular structure is altered into an excited state, and thus it begins to reflect at longer wavelengths in the visible spectrum. On removal of the ultraviolet (UV) source, the molecule will revert to its original state. Thermochromic materials absorb heat, which leads to a thermally induced chemical reaction or phase transformation. They have properties that undergo reversible changes

when the surrounding temperature is changed. Mechanochromics materials have altered optical properties when the material is subjected to stresses and deformations associated with external forces. Many polymers have been designed to exhibit these kinds of properties. The traditional household device for imprinting raised text onto plastic strips utilises a plastic of this type. The raised text that results from a mechanical deformation shows through as a different colour. Chemochromism is an example of a chemical reaction taking place that results in a colour change. Many chemicals are chemo-chromic and the exact mechanism differs between them, though generally the proximity of some other chemical species will cause one of two outcomes: an electron that was previously participating in one chemical bond in one position may move to another position, where its presence (or its absence on the other bond) causes the molecule to absorb a certain colour of light. Electrochromism is broadly defined as a reversible colour change of a material caused by application of an electric current or potential. An electrochromic window, for example, darkens or lightens electronically. A small voltage causes the glazing material to darken, and reversing the voltage causes it to lighten. There are three main classes of materials that change colour when electrically activated: *electrochromic, liquid crystals* and *suspended particles*. These technologies are not constituent materials, but consist of multi-layer assemblies of different materials working together (Addington, Michelle 2005).

The application of colours to achieve expressive results, to catch the attention, hide or highlight certain details has been broadly applied in design studies (Ferrara and Bengisu, 2014). The attachment of a certain meaning to colours and its emotional and psychological effects can be scientifically determined as studies on colour perception reveal (Itten *et al.* 1970), where it has been demonstrated that colours can influence the personal sensitivity to cold/warm affecting the blood circulation: blue/green colours slow it down, while red/orange colours stimulate it. Changing Colour Materials can be used as food labels for smart packaging that can sense the physical and chemical parameters of the product and communicate its quality, safety, shelf-life and usability (Kuswandi, Wicaksono *et al.* 2011). A more satisfactory and effective experience is built through a human-human interaction model made of reciprocal communication and reactions (Ferrara, Bengisu 2014). In their design of Smart Vacuum cleaner (Vyas, Poelman *et al.* 2012), materials that change colour are used to indicate the bag level on the external surface of the product to communicate

whether the vacuum cleaner is collecting dust or the area is clean and so facilitate the cleaning activity. The modification of colour allows the material to work as an interface with no need of screen display, therefore conveying messages and information to the user in a more immediate way. In addition, 'Radiate Athletics'[vi] is a training garment that changes colour based on the heat released by the user body, showing which muscles are actually burning calories (Fig. 2.9). Radiate Athletics uses Thermochromic inks and dyes that change colour as the temperature changes, revealing the current level of user performance in terms of output of heat. This progressive detection and communication of the body's changing parameters creates a narrative that stimulates the user to perform the sports activity. Furniture thermochromic ink painted, can change in optical properties revealing the shape of the user body like in 'Linger a Little Longer'[vii] designed by Jay Watson.

Fig. 2.9 'Radiate Athletics' is a training garment that shows which muscles are actually burning calories through thermochromic dye of the fabric

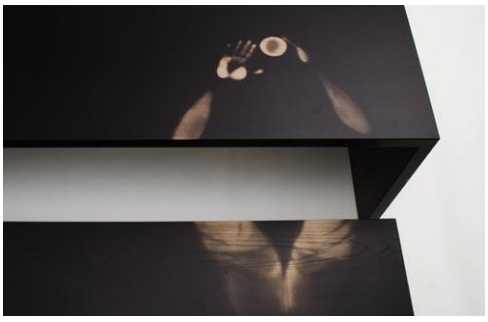


Fig. 2.10 'Linger a Little Longer' by Jay Watson is a set of indoor furniture that reveals the shape of the users using them

Designers and engineers are deploying properties of SMs to enhance the experience unleashed by products and unlock design opportunities for creative applications. It is, therefore, reasonable to imagine that products that embed SMs will not accomplish only a functional feature of the product, but they will mainly support a more meaningful and immediate interaction with users. Given that uses of SMs into product design are based on explorative applications, there seems to be no rationale that can robustly account for the specific matching of SMs to metaphorical language. Nevertheless, a clear understanding of how users perceive, respond and capitalise their experience with engineered materials embedded in everyday products is missing. Based on the concept that materials per se are neutral and are invested with intelligence only within the framework of their contextualization and interaction with the user, benefits from the application of SMs

should not only be regarded as add-on interfaces in product development, but as integral constituents of the way they are experienced at the emotional and cognitive level. Table 2.1 summarises the main SMs identified as representatives of the four families. They are described based on the triggers that induce a relevant change in their structure, the effects produced and the sensorial stimuli produced.

Table 2.1 List of main materials identified and their corresponding Smart Materials family. Triggers and effects are clarified, along with the sensorial stimuli produced

Smart Material Family	Name of the material	Trigger	Effects	Sensorial Stimuli Produced
LIGHT EMITTING MATERIALS	Fluorescent Materials	Absorption of the invisible ultraviolet component of daylight	Simultaneous light emission, clear under overcast skies or at dusk, clear in darkened rooms, extreme contrast of bright and dark	**Visual**
	Phosphorescent Materials	Absorption of the invisible ultraviolet component of daylight	Delayed light emission, afterglow luminescence, visibility aid safety-related applications	**Visual**
	Electroluminescent Material	Electric field (1.5MV/cm)	Cold, uniform light, smooth flicker-free, luminous surfaces, flexible luminous panel, curved substrate, blends in seamlessly with the environment, visual overlay of digital information on a real world object Intensity of light and colour change can be manipulated quickly by altering the voltage or/and frequency, create emotional light patterns	**Visual**
	Organic Light	Electric field	Coloured cold light, pleasant,	**Visual**

	Emitting Diode		non-dazzling light, thin substrate	
CHANGING SHAPE MATERIALS	Thermobimetals	Change in temperature	Continuous, linear movement, variable force spring, used as actuators	**Visual/haptic**
	Shape Memory Alloy (SMA)	Change in temperature (from -40°C up to 120°C): • Due to environmental conditions • Due to induced heat (electric field)	Recover the original shape, compression/elongation, active/passive damping, actuation functions (e.g. kettle switch)	**Visual/haptic**
	Magnetostrictive/ Electrostrictive Materials	• Magnetic field (50-200 KA/m) • Electric field (40KV/cm)	Reversibly change strain (giant magnetostriction = 0.1%) Actuators (linear response)	**Visual/haptic (too small to be perceived)**
	Electroactive Polymers (EAP)	High voltages (~5000 V)	Reversible change of shape Strain (strains up to 380%) Bend, stretch, contraction-shrinkage, curving response, gripper effect, inchworm motion, human muscle replacement	**Visual/haptic**

RHEOLOGICAL CHANGING MATERIALS	Magnetorheological/Electrorheological Materials	• MR fluids: magnetic field • ER fluids: electric field, high voltage (~2kV) and low current (~10mA)	Tactile sensing, feels a resistive force, haptic interfaces, provide the needed force in real time, generate the sensation of touch Controlled damping or braking forces, high stiffness and damping	**Haptic**
CHANGING COLOUR MATERIALS	Photochromic Materials	Absorption of UV light (Increase of incident light)	Transmittance of light - Change in colour, colours gradually fade away, seamlessness in response, darken in response to the intensity of the sunlight, moderation (control) of daylight. Control of transmission of solar radiation	**Visual**
	Thermochromic Materials	Heat - switching temperature from -30 up to 120 °C) (continuous temperature exposure)	Coloured pattern slowly changes from dull to colourful. Adapt its transmittance behaviour to a given climatic situation. Change of specular light. Show patterns temporarily	**Visual**
	Electrochromic Materials	Power during switching (1–5V Direct Current)	Show specular reflection, shift gradually and reversibly between the dark and transparent states (1 minute), smooth gradual transitions when switched, decrease the frequency of discomfort glare. Provide visual privacy for indoor applications	**Visual**
	Mechanochromics Materials	Externally induced forces (react to oxygen)	Altered optical properties, reversible change of colour	**Visual**

	Chemochromics Materials	Reacts to different chemical input	Altered optical properties, change of reflectance/transmittance	**Visual**

2.5 Summary of the Chapter

This chapter reviewed the design opportunities for familiar technologies and highlights how the retrieving of prior knowledge to support people understanding information with embodied SMs has never been encountered before. Two assumptions are identified:

1. The primary assumption of this thesis is that there is an inverse correlation between ageing and familiarity with technology which means that the older the user is, the more difficult it is for them to make use of technology.
2. The pursuit of an efficient way to facilitate older adults to acquire new knowledge is identified on non-linguistic metaphors that are widely proved to simplify the way prior experience is used in order to understand new information. Therefore, the second assumption of this thesis suggests that embedded non-linguistic metaphors could contribute to better understanding of new technologies.

Research on materials' properties investigated at a product design level with the intent to activate human sensorial abilities and communicate emotions, has led to the identification of embodied Smart Materials as potential means of physical mapping between the source-target domain in a non-linguistic metaphor. The rich and versatile properties can be beforehand designed to recall past knowledge of older adults and facilitate the understanding of new information when embodied into a new technology. Four families of SMs are presented as representatives of the main sensorial stimuli they can reproduce at a visual/haptic level.

Endnotes

i https://connect.innovateuk.org/web/smart-materials/smart-design

ii http://www.lighting.philips.com/main/products/oled.html

iii http://www.trstechnologies.com/Materials/Electrostrictive-Ceramics

iv http://materiability.com/shapeshift/

v DO|SU Studio Architectre: BLOOM. 2013. DO|SU Studio Architectre: BLOOM. [ONLINE] Available at: http://dosustudioarchitecture.blogspot.gr/2012/01/messerli.html.

vi http://www.radiateathletics.com/

vii http://www.jaywatsondesign.com/

Chapter 3

Research methodology

3.1 Introduction

The literature review conducted in Chapter 2 highlighted the intent to reduce age-related cognitive differences in the promotion of a greater technology adoption by older adults through the embodiment of SMs into smart objects. The opportunity sought in this research is to explore the interactive qualities of SMs in combination with non-linguistic metaphors into a novel device to stimulate a sensorial response of older adult users that may eventually use their own prior knowledge to acquire new information. As introduced in Chapter 1, such novel device ought to be contextualised into the rising 'ageing in place' scenario, where a plethora of smart objects are designed to incentivise a personalised support of older adults in their own premises.

The methodological framework presented in this Chapter reflects a qualitative inductive approach, where both ethnographic and phenomenological inspired studies are applied as data gathering and evaluation techniques in fulfilment of the three objectives of this thesis, as discussed in Chapter 1.

The following sections describe the philosophical stance that informs the research methodology and a justification of methods and instruments adopted. The research approach was inspired by studies conducted by Crotty (1998); four different elements are taken into consideration to justify the decisions taken and the logical structure underpinning the research:

1. *Epistemology*: the theory of knowledge embedded in the theoretical perspective and thereby in the methodology;

2. *Theoretical perspective*: the philosophical stance informing the methodology;

3. *Research methodology*: the strategy, plan of action, process or design decisions behind the selection and adoption of techniques to achieve the desired outcomes;

4. *Methods:* the techniques or procedures used to gather and analyse the data related to the research question.

The research was structured by following an inductive, qualitative research approach and motivations behind these preferences are discussed in the following sections.

3.2 Epistemology

Crotty (1998:8) defines epistemology as *"a way of understanding and explaining how we know what we know"* while Maynard (1994:10) indicated that: *"epistemology is concerned with providing a philosophical grounding for deciding what kinds of knowledge are possible and how we can ensure that they are both adequate and legitimate"*. Three main epistemologies can better explain how to embody a certain understanding. *Objectivism*, where reality exists apart from the operation of any consciousness; *constructionism* where truth comes into existence through the engagement of the human agent with the realities in the world, and *subjectivism*, where meaning or truth is not the result of an interplay between subject and object but it is imposed on the object by the subject.

This research undertakes 'constructionism' as an epistemological stance in light of what was discussed in Chapters 1 and 2, fulfilling the intent to overcome the duality of smart of objects/end user towards the holistic interplay of smart objects/human agent. Objects have been identified as 'smart' when they are able to establish a dialogue with the users and their changing cognitive abilities. The relevant criteria for the adoption of a constructionist approach is that technology finds its role in the interaction with the users; users re-establish their own cognitive abilities as human agents in the discovery of the technology. In the definition of the constructionist approach, Crotty (1998:42) claims that 'a' meaning is constructed by the human beings as they engage with the world they are interpreting: *"constructionism is the view that all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context"*. The role of the researcher, as adopted in this thesis, is to understand and reconstruct people's meanings and experiences trying to reach a common consensus.

3.3 Theoretical perspective

A theoretical perspective provides a context for the research process and a basis for its criteria and logic. Crotty (1998:7) defines it as: "*The philosophical stance informing the methodology and thus providing a context for the process and grounding its logic and criteria*". The most influential theoretical perspectives are: *positivism* (reality consists of what is perceived by senses and can be measured through observation), *post-positivism* (reality is differently experienced among individuals), *interpretivism* (Gray, 2013), alongside the recently rediscovered *pragmatism* (knowledge emerges out of actions and situations rather than previous conditions), (Creswell, 2013). The interpretivism stance, based on the assumption that natural reality and social reality are different and must, therefore, be investigated through different methods and that the world is filtered through the classification schemes of the mind (Gray, 2013), has been adopted in this research. Applying an interpretivist theoretical perspective to understand how the adoption of technological products for the ageing population could be supported through embodied Smart Materials into product designs, is based on the view that the acquisition of new knowledge is promoted by retrieving the old user's past memories and experience that have been built upon the reality they have been living in.

3.4 Research methodology

The research methodology is the strategy and the plan of action adopted alongside the account of the rationale provided for the methods selected and how methods are employed (Crotty, 1998). The research methodology is the practical application of both epistemology and theoretical perspectives influenced by the choices of the researcher and overall requirements of the research. It defines the research approach, clarifying if the research begins with a theoretical model (deductive approach) or if this model should emerge from the data gathered (inductive approach) (Gray, 2013). It also explains the general purpose of the investigation, that can be either exploratory, descriptive or explanatory and the research strategy, that can employ qualitative, quantitative or mixed methods along with the specific choice of methods for data gathering. These three parameters and choices adopted in this thesis are explained in the following paragraphs.

RESEARCH APPROACH: as defined by Gray (ibid.), the deductive approach starts with the hypothesis testing and aims to confirm, refute, or modify the general theory through empirical observations and experimentation. The inductive process starts with data collection that is analysed to define if relational patterns between variables emerge in

order to develop a theory. The process of the elaboration of small facts and gradually moving toward theories and hypothesis based on them is defined as inductive, while a deductive process applies an overall theory to a specific case. In support of the adoption of an inductive approach, this research started collecting data with the intent to establish a new line of enquiry. As demonstrated in Chapter 1 and 2, no complete theories were available from which deduce a proposition for testing. As defined by Gray (2013), the inductive approach unveils unexpected relationships among variables and therefore is adopted in this research to explore and collect data from different sources of evidence, seeking for the internal logic of the subject explored without a strict theoretical model that dictates an external logic to the phenomenon under investigation.

RESEARCH PURPOSE: as expressed by Robson *et al.* (2016), and Gray (2013), the purpose of a study can be threefold: *exploratory*, *descriptive,* or *explanatory*. Exploratory studies occur when there is not enough knowledge about a phenomenon and seek to further explore whether more insight can be achieved through research; these studies are mainly conducted through literature surveys, focus group interviews and talking with experts in the field. Descriptive studies provide a general understanding of a phenomenon as it occurs; these studies highlight a real situation as it is and they remark on how things are connected together but only with a limited knowledge of the reason why an episode has occurred. Finally, explanatory studies seek to ask *why* and *how* an episode occurs, instead of the '*what*' question answered in a descriptive study.
In this thesis, the adoption of an exploratory research paradigm seemed appropriate to inform the research question because of the dual perspective of the investigation highlighted in Chapter 2: the understanding of targeted users, including their personal experiences and relationship with existing products to support an 'ageing in place' scenario, and the evaluation of an 'intervention', by means of the prototype of a novel device where SMs embodied non-linguistic metaphors. The exploratory foundation of this thesis relies on the need to validate the proposed solution and asking for future descriptive studies once the phenomenon has a verified occurrence.

RESEARCH STRATEGY: two approaches are traditionally considered when designing research studies: a *quantitative approach*, applied to investigate or measure the degree in which a phenomenon occurs, and a *qualitative approach*, applied to investigate the nature of a phenomenon (Blessing and Chakrabarti, 2009). As expressed by Creswell (2013), in a qualitative research, a central research question, a statement that addresses the

studies in the most general form, is stated possibly followed by associated sub-questions. In a quantitative study, the purpose is shaped by one or more research questions and one or more hypothesis. A hypothesis is a prediction that the researcher establishes among unknown variables. The testing of the hypothesis considers statistical procedures where inferences about a sample of the population are highlighted. For this thesis, one central question is formulated in relation to a specific qualitative strategy of inquiry that conveyed an open and emerging design. Moreover, the intent of this research is to investigate the nature of a phenomenon, aiming at developing a theoretical ground for future studies, which justifies the need to adopt a qualitative research approach. Qualitative research is intended to understand, describe, and interpret social phenomenon 'from the inside', without the adoption of any specialised settings, such as laboratories etc. This understanding can be carried out in different ways mainly focused on the access to the experiences, interactions, and documents in their natural context with the aim to develop concepts and hypothesis (Flick, 2008). In this thesis, the adoption of ethnographic-inspired techniques conducted for the first two studies was justified by the need to acquire an understanding of the cultural aspects, motivations, beliefs, meanings of the cultural group under investigation the older adults, and eventually, provide insights on the emerging focus of inquiry. E*thnographic methods,* used to explore the nature of cultural or social phenomenon by making reports on these events through an 'immersion' of the observer in the field (Gray, 2013), were adopted to observe the user within his/her own living context rather than under conditions designed by the researcher, as explained by Hammersley M. *et al.* (2007). Ethnographic studies inspired the adoption of two methods: an unobtrusive observation of the participants at first, and then an informal conversation with older adults. The observation of a small-scale sample was preferred to facilitate in-depth and effective studies, as theorized by Hammersley M. *et al.* (ibid). Being inspired by ethnographic studies procedures, data were collected through the observation of users' life documents, events and meaningful events; within the wide range of methods to be potentially adopted, a non-obtrusive method (Cultural Probe Kit) has been primarily used to minimise the negative effects of the intrusive presence of the researcher and obtain unbiased probes. In combination with the first method adopted, a direct talk in the shape of Focus Group with older adults has been carried out to deeply understand the issues emerging from the Cultural Probes activity and effectively finalise a design scenario that contextualises the concept of a novel device to be assessed.

The second step of investigation of this thesis, inspired by *phenomenological studies*, consists of a preliminary generative workshop with designers followed by a questionnaire-based study. The aim is to understand the human experience related to a given phenomenon by the means of a novel device to be evaluated and the intent to highlight factors that were not part of the initial research focus, in line with phenomenological research theory (Gray, 2013). The logic underpinning these studies is inductive and the goal is not the generalisation of data to a larger population, but a contextual description and analysis (ibid.) that will eventually lead to future theorisation. The need of a generative workshop with designers was deemed necessary to convey the information from the ethnographic-inspired studies, based on the observation of existing behavioural patterns of the targeted users, toward a design contextualization, through the interaction with the prototype of a novel device. The evaluation of the novel device by selected participants was expected to provide expected/unexpected factors that may promote technology adoption practices by an ageing population. The exploratory nature of the research and the need to provide evidence on the occurrence of the proposed solutions required the selection of a participant sample that was considered relevant to the investigation. Therefore, the adoption of a *quasi-experiment-inspired* study with two groups of participants specifically selected (the experimental group and the control group) and not assigned randomly was adopted. A qualitative questionnaire was designed and similarities/differences between participant samples were described and discussed. This technique differs from the scientific *experiment paradigm*, where the randomly selected experimental group receives a 'treatment' and results are compared with the control group that does not receive the treatment (Gray, 2013). The two samples selected in this study did not differ in any treatment received, but rather in their age and their general level of familiarity with the technology, as further explained in following sections. A summary of the research method approach used in this thesis is shown in Table 3.1.

Table 3.1 Research method approach used in this thesis

Epistemology	Constructionism
Theoretical perspective	Interpretivism
Research Methodology	**RESEARCH APPROACH:** Inductive **RESEARCH PURPOSE:** Exploratory **RESEARCH STRATEGY:** Qualitative research (ethnographic-inspired studies and phenomenological inspired studies)
Methods	ETHNOGRAPHIC-INSPIRED STUDIES Cultural probe Focus group PHENOMENOLOGICAL INSPIRED STUDIES Image Schema elicitation with SMs workshop Quasi-experiment-inspired study: questionnaire for Smart Radio evaluation

3.5 Research methods for data collection

The following section discusses the four methods adopted are for this research, Cultural Probes, Focus Groups, Image Schema elicitation with SMs workshop and a questionnaire for the evaluation of the Smart Radio. Criteria for the selection of participant samples and techniques for data analysis are also explained.

3.5.1 Selection of participants

The process of sampling has a relevant impact on the overall quality of the research. Differences among qualitative and quantitative research approaches are also ascribed in the sample selection techniques. In quantitative research, the sample selection entails the use of *probability sampling* techniques that involves random samples of the population in a relatively large number of units to better represent the population as a whole (Gray, 2013). In qualitative research, samples should be representative in terms of the way they represent the relevance of the phenomenon to explore (Flick, 2008), where researchers are interested in people who are concerned and experienced with the issue under

investigation. The samples were selected in order to minimise the effect of 'diversity' among participants, as auspicated by Flick (ibid). The primary focus was to select a representative sample whose experience with technologies could contribute to answering the research question and maximise the efficacy of each study. Therefore, a *typical case sampling technique* (Patton, 1990) has been adopted for the Cultural Probe Kit and Focus Group within two Age UK branches in London, assuming that their members had experienced some 'typical' age-related issues before, relevant for the purpose of this research. Moreover, for the Image Schema elicitation with SMs workshop, participants were recruited from Brunel University London Masters and Ph.D. students in Product design, as they are considered as experts in the idea-generation process. For the user evaluation of the Smart Radio, the *extreme cases sample technique* (Patton 1990) was adopted in order to have one experimental group and one control group where the 'age' factor and the general level of familiarity with the technology were the variables considered. As specified by Patton (1990) and reiterated in Flick (2008) and Gray (2013), purposive sampling could happen in the selection of *extreme* or deviant cases where the field under study is explored from its extremity to identify differences in outcome.

The distribution of the participants for each of the four studies conducted as part of this research is discussed below:

- Participants for the **Cultural Probe Kit** were recruited through the Age UK Hillingdon branch (London). Participants' selection criteria included anyone over 50 years old who self-classified as eager to live independently. All participants were English/British and they reported no specific conditions/disabilities regarding their health status. Seven participants (all females) whose mean age was 70.8 (minimum = 56, maximum = 95), took part in the study.
- The **Focus Group** was conducted at the Open School East, in Hackney (East London). Participants' selection criteria included anyone who experienced difficulties with technologies on a daily base and eager to learn how to use them. The focus group was performed in two sessions of five and six participants respectively (8 females, 3 males) whose mean age was 62 (Minimum = 50, Maximum = 81, 1 not specified). Participants were all members of the Age UK local group and attendants of the 'Computer and Tablet Learning Group'. This study included English/British/Irish participants with no distinction of ethnicity, cultural, economic background, and physical condition.

- Participants for the **image schema elicitation with SMs workshop** were PhD students in Product design and Master Students of the Integrated Product Design Course at Brunel University London. Nine participants (6 female, 3 males) whose mean age was 25 (Minimum = 22, Maximum = 32) took part in a two-hour activity at Brunel University London. This study included students with experience on design for the ageing population, interaction design, and material science, as they were considering to adopt SMs as product interfaces in future designs.

- The **questionnaire** for the Smart Radio evaluation consisted of a pilot study and the main study, inspired by the quasi-experiment procedure. Participants for the pilot study were 17 (7 = females, 10 = males), divided as 13 younger adults (mean age = 25) and 4 older adults (mean age = 74.2). Younger adults were all PhD students and BSc students in Product Design at Brunel University London, while older adults were recruited from the reading group at Brunel University London and at the Open School East, in Hackney (East London).

  A total number of 62 participants took part in the main study (females = 40, males = 22,) whose age span was from 21 to 84 years old (median age = 59.5). Participants were distributed in this way:

  - Under-60 years old: N = 31, age span from 21 to 59 years old, mean age = 35.6 years old; males = 14, females = 17;

  - Over-60 years old: N = 31, age span from 60 to 84 years old, mean age = 71.5 years old; male = 8, female = 23.

Participants were conveniently selected to fill two age brackets: under 60 years old and over 60 years old, according to the findings of the pilot study. Under-60-year-old participants were recruited from Brunel University London students and employees (last year undergraduate students in Human Factors, PhD students in Design, staff members, visiting students), while the over-60-year-old were selected through the 50+ group in Brunel University London, Age UK Hackney branch, a nursing house in Uxbridge (London) and the Uxbridge Library. This study included English/British participants with no distinction of ethnicity, economic background, and physical condition but with a high motivation to provide their experience and feedback in the assessment of a novel device. Younger adult participants of the pilot study and under-60-year-old participants of the main study were

assumed to be technology literate, while both older adults groups of the pilot study and over-60-year-old participants of the main questionnaire were considered to have limited prior exposure to technology.

3.5.2 Cultural Probes Kit

One of the key aspects emerging from Chapter 1 was the contextualisation of technology for the ageing population within an 'ageing in place' scenario. The exploratory nature of this research makes the scene for a preliminary observation of targeted users in the attempt to define the recurrent aspects of their life and highlight the role that smart objects may have to support them. The challenge was to gain a true understanding of the older adults' behaviours, attitudes, and experiences without the subjectivity of the researcher. A *Cultural Probe Kit* was adopted as a first method consisting of a booklet of activities given to participants for self-documentation. This method, in line with the methodology designed and adopted by Gaver *et al.* (1999), consisted of a booklet of activities exclusively designed to collect inspirational responses from participants and to unveil unexpected ideas, beliefs and desires, aesthetic preferences and cultural concerns without the 'intrusiveness' of the researcher. The probes collected did not lead directly to final solutions, but allowed the researcher to get a deeper understanding of the texture of the living spaces of the targeted user with the purpose to subsequently shape design solutions to accommodate these (Gaver *et al.* 1999).

Advantages and limitations of a Cultural Probe Kit as a research method

The adoption of this method was justified by significants applications in studies where the observation of the relationship between the ageing population and technology was relevant. Wherton J. *et al.* (2012) applied the cultural probe kit to facilitate the pursuit of ethnographic data in domestic settings and facilitate the co-production of assisted living technologies. In the review conducted by these authors, three main relevant areas regarding the application of the kit emerged: *domestic environment*, in relation to connections between everyday activities and living spaces; *social network and supports*, in order to understand the supportive role of social network and how technology can cope with social isolation; *health and assistive living*, with the intent to explore daily living requirements in care setting and to understand the pervasiveness of health applications to support physiotherapy home exercises. The review of Wherton *et al.* (ibid.) suggests that the Cultural Probes Kit offers a relatively unobtrusive way of providing insights into everyday people's life to understand how the physical environment had an impact on the

health, independence, and quality of life of an older adult. In spite of these advantages, Crabtree et al. (2003:8) explain that the primary limitation of the use of probes is their apparent triviality that may lead researchers to underestimate the material collected and miss relevant information. A further limitation lies in the common misinterpretation of the focus of the analysis; as Crabtree (ibid.) explains, booklets, diaries, and pictures are not the 'data' themselves, but rather *"the situated character of everyday life in various care settings as elaborated by participant's accounts of their daily rhythms, routines, and abiding concerns. Such accounts supplement and augment insights gained from direct observation and are generated through cooperative analysis of the returned probe material".* In other words, the collected probes must be used as triggers for analysis with the intent to convert participants into active enquirers of their everyday lives, rather than passive subjects of our research.

In this thesis, this limitation has been tackled by designing each activity with the intent to stimulate participants to reflect upon their life and their relationship with technological products. Each activity by itself may result incomplete; the sum of all the activities provided a complete understanding of the daily life of each participant and the role of technologies in their everyday life. Furthermore, data were used to design a set of broad themes, characterising older adults' life, to be further validated and discussed in the Focus Group activity.

Data collection

The qualitative data collected through the Cultural Probes consisted of a number of written diaries, cards, and maps that uncovered unexpected directions broadening the perspective of the researcher on the topic. Participants were visited on at least three separate occasions. On the first visit, the researcher explained the purpose of the study and asked participants for considering to have a role in the study; an information sheet with details about the research was left with them. During the second visit, the researcher presented the *Cultural Probes Kit* (booklet of activities) and explained each activity in detail, emphasising how they could choose which, if any, to complete. On the third visit (approximately 10 days later) kits and booklets were collected. The instruments included in the kit are described in the following paragraph.

Instruments

The Cultural Probes Kit could include as many activities as the researcher deems to be essential and appropriate in the fulfilment of his objective. The original kit, designed by Gaver *et al.* (1999), was composed of a set of postcards with random images, seven maps with an accompanying inquiry to explore the attitude of elders toward their living environment, a camera, a photo album, and a daily diary, considered necessary to inspire creative responses among the design team. Subsequently, Crabtree *et al.* (2003) included a voice-activated dictaphone, a polaroid camera and a scrapbook with 'post-it' notes, pen, pencil, and crayons; Riche *et al.* (2010) included a 'relationship maps' probe in which participants were invited to highlight with stickers the level of interaction with other people; Wherton *et al.* (2012) also asked participants to clarify things they were comfortable with and concerned about in a list of 'likes' and 'dislikes'. The selection of instruments for this thesis has been tailored to meet the requirements of the research and to keep a high level of simplicity and playfulness alongside a reduced intrusion of the researcher that might have had an impact on the data generation. The Cultural Probe Kit adopted in this thesis consisted of an A4 booklet containing five activities to help capture information on physical, emotional, social and environmental factors related to the users' health and independent living. The first two pages included two different sketches: a *Body Outline,* where participants could indicate areas where they experience pain, discomfort or ability decline and a *Home Plan* where they could indicate meaningful objects and relevant activities performed within their homes. The body outline was presented with a human shape in the middle of a blank page with the description: *"we would like you to use the outline of a human body below to indicate areas where you usually experience pain, discomfort, decline or positive feelings within the following days"* and then at the bottom of the page: *"How do you usually behave to alleviate pain? Positive feelings: how do you improve them? Please give us some quick information about."* The Home Plan activity was introduced with a blank page and the description: *"We ask you to draw down a map of your home, indicating any meaningful object you use and activities you perform that are relevant to you."*

Postcard - A hypothetical postcard was the first activity of the booklet. Each participant was asked to imagine sending it to a friend to whom they had to explain the following: what was their favourite object, the last object they bought and what they would like to buy for themselves in the future.

Daily Diary - Through the diary activity, participants were asked to record their ordinary activities and events within a time span of seven days. The activity was introduced with the description: *"We invite you to reflect upon different aspects of each of the following day and think about what event affected you both positively and negatively"*. Each day had two A4 pages allocated to it, the first of which was further divided into three sections for Morning, Afternoon, and Evening respectively and the last one asking: "*What was 'meaningful' for you about today?*" and "*How could today have been better?*" These questions were included to encourage participants to reflect on different aspects of the day and think about what events affected them in both positive and negative ways.

Map of objects – Participants were asked to draw one mind map where they would indicate the relationship they have with objects in their daily life. Each page included a shadow silhouette in the centre of the page with 'Me' written underneath, representing the participant. The activity was illustrated with an example and some coloured stickers were provided to represent positive (green stickers), neutral (orange stickers) and negative (red stickers) moods/feelings. Through this exercise, the activity aimed at evoking emotional attachment or disregard to objects/products of an everyday life that users cared to mention.

Participants were invited to complete as many activities they liked. A sample of the Cultural Probe Kit can be observed in **Appendix A.**

3.5.3 Focus group

A focus group has been adopted as a second method of enquiry to discuss with older adults the themes identified in the Cultural Probe. The intent was to identify critical areas that future smart objects should deal with to promote an 'ageing in place' scenario where embodied SMs can be contextualised and evaluated.

Advantages and limitations of a Focus Group as a research method

The increasing importance of focus groups, especially to obtain insights into the research topic, their versatility and ability to generate discussion about shared and unshared attitudes and experiences is well proved in literature (Gray, 2013). Furthermore, focus groups have the potential to advance theoretical understanding of a process, to provide valuable insights and design guidelines for future product iterations (Fisk *et al.*, 2012). Focus groups also allow an exploratory collection of qualitative data on technology use, providing insight into the details of actual usage, as well as the perceived advantages

and disadvantages of technology in different domains (Krueger and Casey, 2014). Although the organisation of focus groups can follow a well-defined methodology (Gray, 2013), special considerations for older adults participants are lacking in the literature. Research studies performed by Barret *et al*. (2010) and Krueger and Casey (2014) compensate this gap: when involving older adults the simplicity and understandability of questions are imperative. Recommendations also include facilitating the activity by starting the discussion with a general introduction to the topic, alongside background information about the study that will reinforce comprehension and memory in older people (Barrett *et al.* 2000). However, the main benefit in the adoption of focus groups with older adults is the efficacy in the identification of major themes and information from special audiences, which provides more than what researchers can achieve with the one-to-one interview. The reason can be found in the freedom of response and interaction participants have, without the limitations imposed by close-ended questions (Krueger and Casey, 2014).

As Krueger and Casey (ibid.) affirmed, focus groups deploy their full potential at the exploratory stage of the research, when themes of a subject are unexplored and key points of an investigation must be identified. Specifically, the approach of Kitzinger (1995), where participant samples have a homogeneous composition with no distinction in sub-groups to highlight contextualised discourses, was adopted in this thesis. Interaction within the group is a central analytical resource of information for Kitzinger, that stimulates participants in a vibrant discussion and unexpected directions mainly for the generation of a new theory rather than the testing of it. As further explained by Kitzinger, data from focus group can be hardly generalised therefore, results were used to inspire conceptual insights. This limitation is a consequence of the adoption of a focus group in ethnographic studies, where less control over proceedings than with the individual interview is guaranteed (Bryman 2015). Data were carefully transcribed and coded to inform the so defined 'critical areas' that may inspire solutions for new smart objects design. A common drawback of focus groups as reported in research is that participants may be reticent to take part in the conversation and they may perceive a general discomfort (ibid.). This issue was tackled by creating a smaller group of participants, setting brief ice-breaking questions and guiding the conversation where participants were directly called to participate. This allowed the researcher be informed about each other's motivations for holding a certain view.

Data collection

The focus group was structured to allow participants to freely discuss the topic and give them the opportunity to interact with each other. Therefore, the 11 older adults who appeared keen to take part in the focus group, were split into two groups of five and six participants respectively, to guarantee their active participation and avoid confusion and overlapping voices during the conversation. Each focus group discussion started with a presentation of the researcher, an explanation of the purpose of the study and ground rules, according with what Gray (2013) dictated, such as: ask for permission to use recording equipment, ask people to speak up, listen while other are speaking; emphasis was put on the nature of the focus group as a discussion, rather than an interview. Participants were asked to introduce themselves and answer the following 'icebreaker' question: "*After you give us your name, can you please tell us in just a sentence or two, about the most frustrating thing recently happened in your life?*".

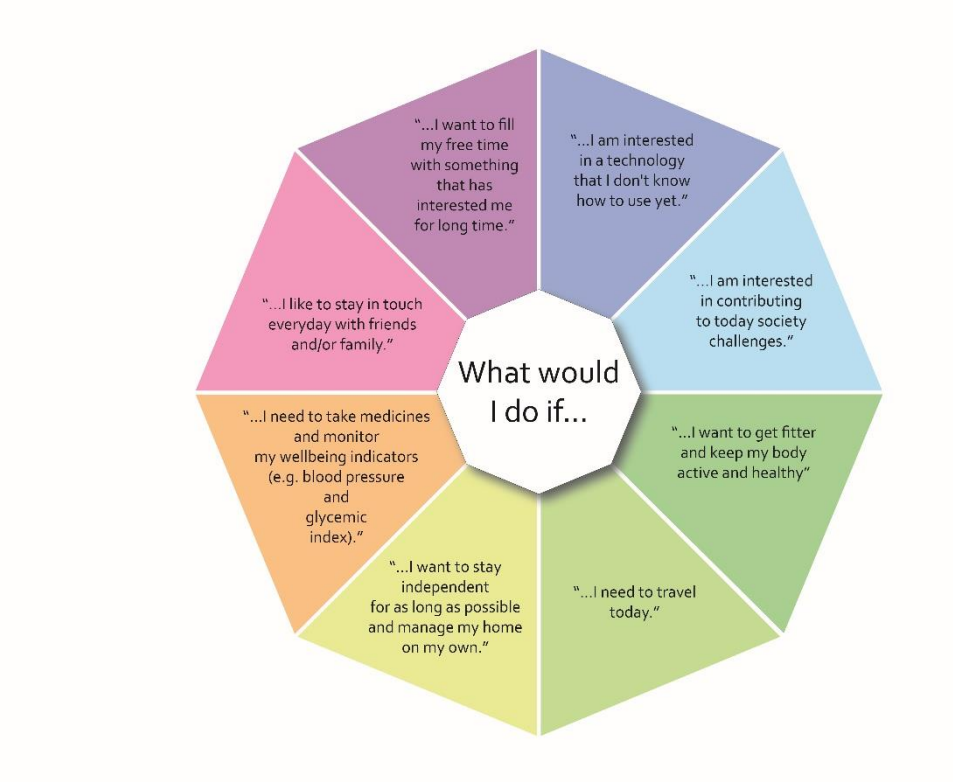


Fig. 3.1 Octagon Chart with the eight daily-life situations discussed during the Focus Group

The first minutes of the focus group were dedicated to allowing participants to remember occurring problems and difficulties they experience in their daily activities, as well as different types of frustrations. Questions such as: "*As you have gotten older, what*

tasks have become harder for you to do?" and "*Do you ever have to interact with things around that make you nervous or uncomfortable?*" were asked. In order to encourage general discussion on these topics and get further details about the findings of the Cultural Probe Kit activity, the Focus Group was guided through the use of daily-life situations (Fig. 3.1), specifically designed to debate about hypothetical situations older adults may have experienced. These daily life situations were designed upon the main 'themes' identified through the Cultural Probe Kit activity, by means of *conventional products vs novel technologies, social involvement, keep the body active, mobility, be independent, health care and wellbeing practices, being in touch* and *new challenges*. Participants were asked to describe their coping strategies for each of the situation proposed. The activity started with the statement: "*What would I do if….?*" and the daily-life situations where:

1. "*…I am interested in a technology that I don't know how to use yet*";
2. "*…I am interested in contributing to today society challenges*";
3. "*…I want to get fitter and keep my body active and healthy*";
4. "*…I need to travel today*";
5. "*…I want to stay independent for as long as possible and manage my home on my own*";
6. "*…I need to take medication and to monitor my wellbeing indicators (e.g. blood pressure and glycemic index*";
7. "*…I like to stay in touch every day with friends and/or family*";
8. "*…I want to fill my free time with something that has interested me for a long time*".

The researcher asked participants to share their personal experiences and describe meaningful events relating to these situations. Each session lasted one hour.

Instruments

The focus group was run at the Open School East, Age UK branches of Hackney (East London), where participants were recruited. Participants were supplied with an A3 template of the daily-life situations to be discussed (Fig. 3.1), while the researcher had a flipchart where he highlighted, in a mind map style, the key point emerging during the discussion. In order to keep the conversation as simple as possible, participants were asked to orally discuss the topic under investigation, without needing to produce any written

descriptions of their experiences. Both sessions were recorded and transcripted afterwards.

3.5.4 Image Schema elicitation with SMs – Workshop with designers

The adoption of workshops as a strategy for the identification of image schemas is a well-defined practice. Hurtienne and colleagues (2015) structured an image schema design methodology where the design activity consists of a workshop aimed at interpreting insights from a previous study and evaluating the mock-up of a new interface. Nazli Cila in her doctoral research (2013) performed a series of workshops with design students to better understand the mechanism of metaphor generation. Within this research, the workshop has been selected as a suitable method to explore opportunities for the SMs properties to represent image schemas to embody non-linguistic metaphors and therefore support the physical representation of abstract concepts.

Advantages and limitations of a workshop as a research method

The main limitation in the adoption of a workshop as a research method lies in the context-specific nature of the activity itself, where the researcher is involved as a facilitator of a situation and a group of participants is encouraged to work on a particular problem (Robson 1993), as outcomes generated in an 'artificial' setting may not be generally applicable outside of the context in which they were created. Having multiple participants working on a given task increases the potential diversity of approaches and ideas generated and invites participants to structure each other's ideas in a way which would not occur if participants contributed individually. In this thesis, participants were selected as 'experts' in the field of design, with extensive prior experience in design for the ageing population and applications of materials in product design. Their role was not to act as representatives of a 'real world' phenomenon, but rather to be able to manage a creative, generative activity that would have been difficult to carry out with targeted users. A large amount of visual materials, concepts and suggestions gathered further supported the adoption of a workshop activity as a generative tool that helped the definition of a novel smart object.

Data collection

The workshop started with a presentation of the intent of the research and an explanation of the SMs properties involved in the design session. Supported materials and timings were provided alongside a full explanation of the task to be performed. Participants were asked to individually design the interface of a hypothetical new communicative

device, which would be able to wirelessly communicate with a connected twin device the feelings and mood of the user using it. No constraints were given; the hypothetical new device was introduced as a plain white box, that allowed the participants to free their creativity and consider it in any possible way they would want. The task considered the physical representation of two expressions of human status linked to the 'arousal' status of the user (shifting between 'high stimulation' towards 'low stimulation') through the adoption of the dynamic properties associated with the four families of SMs selected (as highlighted in Chapter 2, section 2.4). A brief definition of the 'arousal' level of the human status to be represented with the SMs properties was provided: *high stimulation* was defined as an astonished, amazed, longing, surprised, concentrated, eager, curious status and the *low stimulation* was introduced as a composed, waiting, passive, deferent status.

Instruments

Participants were supplied with samples of *Light Emitting Materials* (Fig. 3.2), *Changing Shape Materials* (Fig. 3.3), *Rheological Changing Materials* (Fig. 3.4) and *Changing Colour Materials* (Fig. 3.5) and four posters summarising the main properties of each family of SMs (**Appendix B**).

Fig. 3.2 Sample of Electroluminescent panel

Fig. 3.3 Shape memory alloy embedded into fabrics

Fig. 3.4 Ferrofluid sample in a water bottle

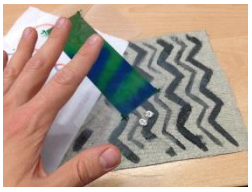


Fig. 3.5 Sample of thermochromic inks on fabric

An explanatory video displaying the dynamic effects of the SMs under study was projected in the loop for the whole duration of the workshop. Figure 3.6 shows the A3 template provided to each designer consisting of a list of SMs properties on one column and two blank columns to depict the high/low stimulation effects. Participants were asked to fill the white boxes with their sketches, where SMs served as a representation of the indicated 'arousal' level. Figure 3.7 shows four mood boards which were presented to participants to explain the sensorial possibilities of the SMs and to act as an inspiration to facilitate the creativity process. The workshop was performed at Brunel University London premises and lasted for two hours.

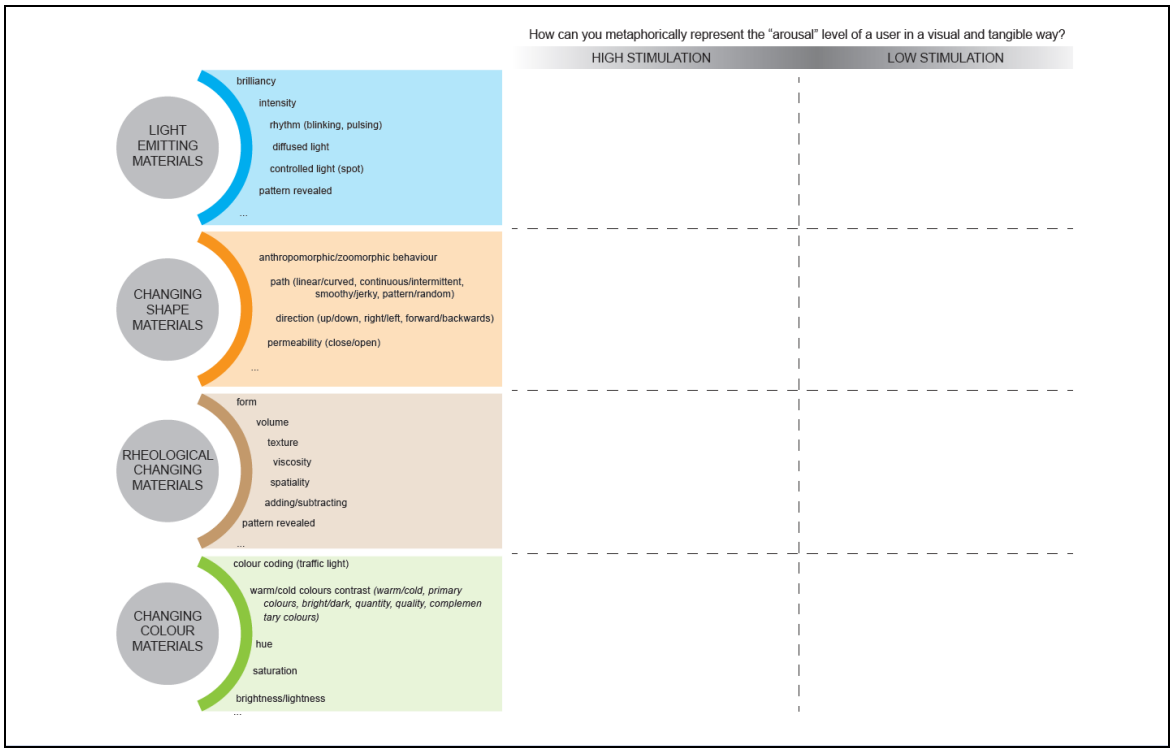


Fig. 3.6 Template provided to each designer consisting of a list of SMs properties (on the left) and two blank columns to depict the high/low stimulation status

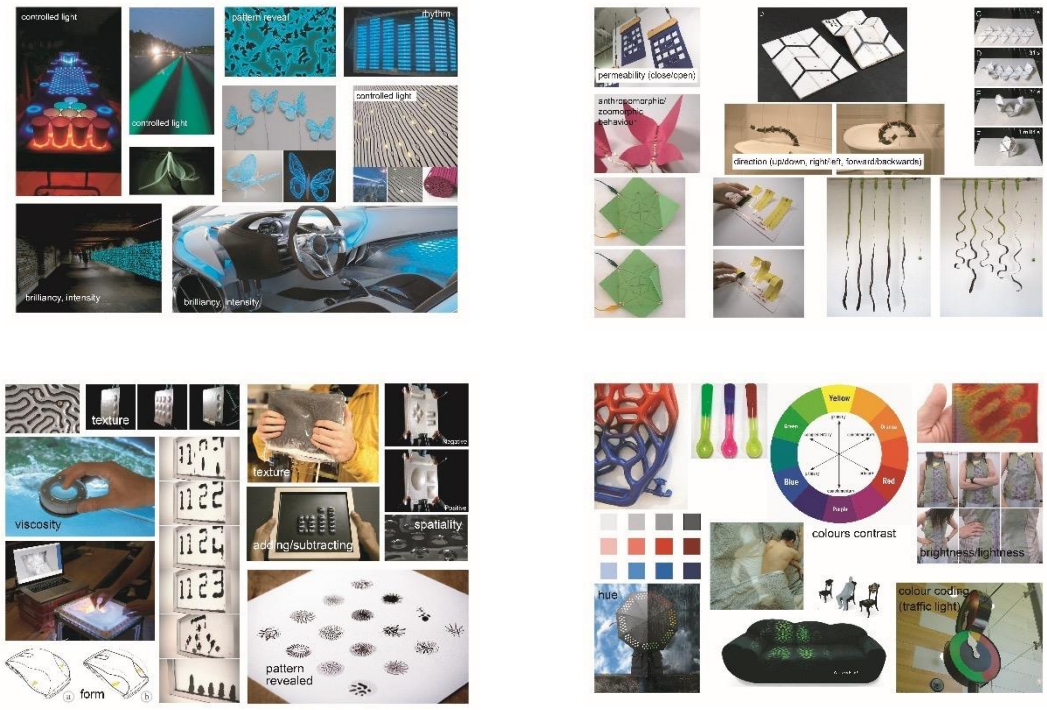


Fig. 3.7 Mood boards visually representing various design opportunities of the four SMs families

3.5.5 Smart Radio: design of the device and evaluation questionnaire

The last method adopted consisted of the evaluation of the Smart Radio, a novel device specifically designed to embody non-linguistic metaphors with SMs and was built in line with the design criteria identified. The Smart Radio was designed to have the shape of a conventional analog radio, but instead of broadcasting music, the Smart Radio would share information about the people using it. This would be achieved through a wireless connection with other devices which would allow for the exchange of information among peers. This exchange of information would help alleviate feelings of loneliness, enhance the sense of belonging and promote ageing in place.

The Smart Radio was designed to display embodied analogical/metaphorical messages on its top surface and it allows for four groups of interactions, each of those based on the four families of SMs identified. Each group of SMs showed eight signals, by the meaning of four analogical and four metaphorical messages:

- Analogical messages were selected to communicate the 'availability of the user' connected with four different statuses available: 'offline', 'listening in', 'listening to' and 'fully active'. These were represented by the dynamic on/off alternation of two symbols by means of 'ear' and 'lips' appearing on the surface of the Smart Radio. SMs have been adopted to enhance the appearance of these symbols in order to have alternation of lighting symbols (*Light Emitting Materials*), movable flaps revealing underneath symbols (*Shape Changing Materials*), popping up and tangible symbols (*Rheological Changing Materials*) and appearing symbols with a traffic light colour coding scheme (*Changing Colour Materials*).
- In order to render the metaphorical messages, a 'rhythm' was used to interpret the level of 'intensity' and 'activity' of a hypothetical user connected, namely: 'the user is highly stimulated', 'the user is stimulated but quiet', 'the user is active but relaxed' and 'the user is highly relaxed'. The level of activity of the user with *Light Emitting Materials* was interpreted by four actions were the alternation of blinking and pulsing light communicates whether the user is exercising (fast blinking light), walking (slow blinking light), eating (fast pulsing light) or watching television/reading/sleeping (slow pulsing light). The use of *Shape Changing Materials* conveyed the idea of the actions performed by creating a sharp shape, a smooth shape, a double curved shape, and slow pace movement. The use of *Rheological Changing Materials* conveyed a haptic feedback with a series of popping up 'bubbles' by representing a high contrast of shapes, high

contrast of shape with a spatial gap in between bubbles, no contrast of shape, no contrast of shape with a spatial gap in between bubbles. The use of *Changing Colour Materials* allowed for the display of primary colours contrast, warm/cold colours contrast, quality contrast with low definition and quality contrast with high definition.

The 'Designer Model of the Function Representation' emerging from the Image Schema elicitation with SMs activity, has been applied in the shape of 32 SMs signals. This mental model linked the signifiers (the Smart Material) with the signified (the hypothetical activity of the user connected) in what the researcher interpreted as the best pair and was therefore used as an initial benchmark to evaluate the responses of participants. A questionnaire-based study has been adopted as the main method for data gathering. Two questionnaires were adopted: a Technology Familiarity (TF) questionnaire, by which assess the level of prior exposure participants had with radio related products and a main questionnaire for the Smart Radio evaluation.

Advantages and limitations of the evaluation questionnaire

Questionnaires are data gathering tools commonly used for the relatively simple data analysis they allow, based on closed questions, and the lack of interviewers' bias (Gray 2013). The main advantage in the adoption of questionnaires is that a large number of respondents can be reached at a little cost. In this thesis, the evaluation of the Smart Radio was considered to provide timely information about the understanding of the device by the groups involved. The need to highlight commonalities and differences in the interpretation of the device guided the researcher to a questionnaire-based study where his personal interpretation of the feedback and bias were minimised. The adoption of ranking questions, for both the Technology Familiarity questionnaire and the main questionnaire, simplified the process of data gathering and allowed a greater response from all the participants. The main questionnaire ended with three open questions to allow for freedom and spontaneity in the interpretation of the Smart Radio. The main limitation of this approach is that these questions required more effort from respondents, which would result in impatience to complete the activity. The data gathering was therefore simplified with the researcher transcribing the answers of the participants, while the three questions were used as a starting point for a semi-structured interview. This simplification resulted necessarily when interviewing over-60-year-old participants, who were often reluctant to be involved in time-consuming activities.

Data collection

Participants were asked to individually complete two questionnaires: the Technology Familiarity questionnaire (**Appendix C**) and the Smart Radio evaluation questionnaire (**Appendix D**). The latter included four sections, each of them referring to a different family of SMs. In each section, participants were given a list of signals and their potential meanings and were asked to provide one association of meaning to each signal and to give a 1-3 score based on the strength and intuitiveness of the identified association. For example, a score of 'one' would be used to describe a weak, poor association, and a score of 'three' an intuitive and powerful association. An option of 'other' was also available to participants, to allow them to chose an alternative meaning to a signal from the ones proposed to them. Participants were asked to hypothetically use the Smart Radio to browse information from four other users connected to it and were asked to evaluate the meaning of each received signal that signified the activity of the selected user. Three open questions at the end of the main questionnaire were included to let participants freely discuss their preferred signals and ways to improve the device.

Instruments

Instrumentation and materials were shown as follows:

- Technology Familiarity questionnaire (**Appendix C**) a pre-test aimed at defining the level of familiarity with the product category of each participant;
- The Smart Radio evaluation questionnaire (**Appendix D**) divided into 4 sections (one for each family of SMs);
- Smart Radio prototype with the 32 interactions designed (4 groups of 8 tangible and interactive materials demonstrators);

3.6 Qualitative Data Analysis

According to Gray (2013), the analysis of qualitative data is a procedure by which data are endowed with meaning through a process of disaggregation into smaller parts and their logical reconnection into new concepts leading to fresh descriptions. Multiple approaches can be adopted based on the structure of the study. The most commonly adopted is content analysis, which considers the criteria of selection by which to categorise data collected beforehand. Grounded theory is another commonly adopted qualitative data approach in which there are no a priori criteria assumed and they eventually emerge

through the process of data collection and analysis itself. Gray (2013) also identifies the *thematic analysis* approach where a 'theme' incorporates relevant elements about the data in relation to the research question, clarifying a level of *patterned meanings* within data based on a multitude of *codes* identified. As defined by Gibbs (2008) coding is a way of categorising the text with the intent to build a 'scaffold' of thematic ideas about it and involves a thorough analysis of the probes or text transcribed. The act of coding, as defined by Gibbs (ibid.) includes a process of abstraction and interpretation that slowly moves away from mere descriptive statements to the definition of categories, that encloses descriptive codes and analytic codes, based on the understanding of the data from the researcher. A data-driven coding approach, when categories emerged from the data during the study, has been preferred among the concept-driven data, where criteria of coding selection are beforehand designed; this preference allowed the researcher to keep an open mind on the topic, with less bias and expectations resulting appropriate for the qualitative definition of potential design patterns and inspiration to build a design scenario for the ageing population. A data-driven approach has guided the data analysis with the identification of descriptive codes and main themes that identify them. The appropriateness of each theme identified has been considered based upon two parameters, as suggested by Gray (2013):

1. the recurrence of the theme across the data set;
2. its relevance to answer the research question.

Furthermore, codes were identified in the description of acts, behaviour, meaningful events, ordinary activities, personal interpretations, relationships between people, living conditions experienced and living settings. In order to retrieve text from codes, each extract has been labelled, so as to define from which document or participant it came from. In addition to a thematic analysis, the quasi-experiment has been analysed through a frequency analysis, where results have been converted into percentages and described through the feedback provided by participants. The frequency analysis has been associated with descriptive statistics and the adoption of a non-parametric test to further highlight differences in the distribution of answers. Data collected with this method have been further qualitatively explained and justified through feedback gathered with the three open questions at the end of the Smart Radio evaluation questionnaire.

3.7 Research quality: accuracy, reliability and ethics

According to Gibbs (2008:91), the *validity* of a research occurs when *"explanations are really true or accurate and correctly capture what is actually happening"*. As further explained by Flick (2009), a distinction is made between external and internal validity; the external validity refers to the possibility of findings to be generalised across social settings, while the internal validity is based on the distance between the constructions of the researcher and the constructions of those being researched, assuming that the product of research reflects the subjectivity of the researcher. In order to demonstrate that the account, as reported by the researcher, reflects what was actually expressed by participants of the study, a set of measures were adopted, as dictated by Gibbs (2008). Table 3.2 show the procedures adopted in this thesis to preserve the accuracy of the data collected.

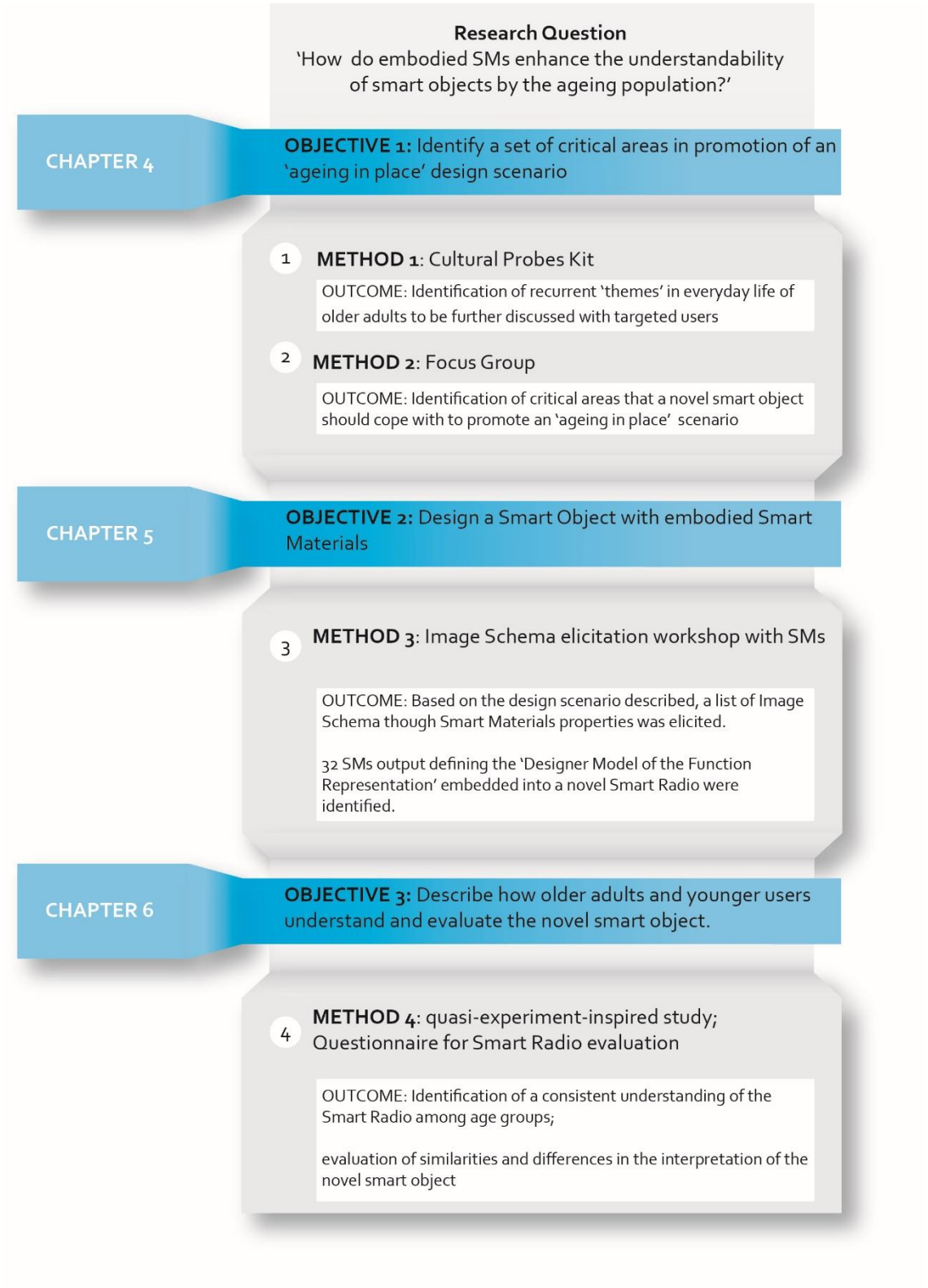
Table 3.2 Measures adopted to preserve the accuracy of data collected

	ACCURACY MEASURES ADOPTED
GENERAL MEASURE	· Throughout the thesis, the contextual nature of the accounts and descriptions of respondents has been stressed. Excerpts are provided to proof the validity of each the claims made. · Contradictory descriptions presented by respondents are shown. · Frequent peer debriefing sessions were run with people not directly involved in the research (Light Touch Matter European Projects partners) to enhance the accuracy of the account with feedback from people other than the lead researcher.
CULTURAL PROBE KIT and FOCUS GROUP	· Findings from the Cultural Probe Kit were thoroughly discussed by participants of the focus group, evaluating their relevance and importance. · The researcher transcribed the main issues emerging from the focus group into two mind maps where participants had the chance to further check the appropriateness of the information recorded. · Two different groups of participants were sampled to take part in the Cultural Probe Kit activity and Focus group to strengthen the external validity with a generalisation across different cultural

	settings.
IMAGE SCHEMA ELICITATION WITH SMs WORKSHOP	· Participants were asked to explain the process of reasoning adopted in the design of their concept; the researcher transcribed the information and asked for confirmation.
SMART RADIO: EVALUATION QUESTIONNAIRE	· A pilot study was performed as an exploratory evaluation of the protocol adopted aimed at evaluating factors hindering the data collection. · During the main study, feedback from participants emerging from the three open questions was transcribed by the researcher and double checked and approved by participants.

A second parameter to be considered is the robustness of findings, defined as *reliability* (Gray, 2013). As explained by Bryman (2015), reliability can be both external and internal, where 'external' refers to the degree of a study to be replicated, which is challenging to achieve in a qualitative study, while the 'internal' occurs when findings are agreed by more than one observer. The reliability of findings has been preserved through a thorough process of transcription of data in each study conducted, where the reliability of transcripts was checked through the subsequent nature of the investigation. Findings of each study were used as starting point of the following study in order to minimise the possibility of misinterpretations from the researcher and allows, in contrast, a process of clarification of the data collected. Table 3.3 depicts how findings from each study have been used as input for the following study. Moreover, the findings of each individual study were discussed with academics, reviewed by other independent researchers and disseminated through internal reports within partners of the Light Touch Matter (L.T.M.) European Project.

Table 3.3 Overview of the methods adopted; outcomes are highlighted as input for the following studies



The four studies conducted have been approved by the Ethics Committee of Brunel University London, in full respect of the ethics guidelines provided. Participants of each study received a two page 'Participant Information Sheet' with a clear explanation of the procedure of the study/experiment, the motivation supporting their selection as suitable participant, the absence of any risk, data treatment, and dissemination procedure, the possibility to withdraw from the study at any time without giving a reason for withdrawing and contact details of the researcher and supervisory team. These were given to participants before they agree to participate in any studies, allowing them plenty of time to make an informed decision about their participation in a study. A sample of the 'Participant Information Sheet' can be viewed in **Appendix E**. The Participant Information Sheet further guaranteed that all information collected would be kept strictly confidential and that any information recorded about the participant would have their personal details removed.

Participant data was anonymised at the early stage of data management and fictitious names were used to describe participants throughout the dissemination of the research findings in publications and project documentations. Furthermore, participants were required to sign a 'Consent Form' (**Appendix F**) to confirm their agreement to take part in the study. The Consent Form included a list of the participants' rights and responsibilities, such as the possibility to withdraw from the study at any stage and the permission for the recording of the study.

3.8 The role of the researcher

As reported by Castellan (2010), in quantitative studies researchers have a neutral role attempting to discover relationships among variables. Nevertheless, in qualitative studies, the researcher might be tempted to interpret and understand the meanings constructed by participants and make sense of the things encountered. A 'reflexivity' approach, through which the researcher can critically reflect on his own influence on the research process with specific actions, has been adopted where the researcher's influence on the sample has been constantly minimised. In participant observation studies, a well-defined scheme of the participants' observer's role is provided by Gold (1958). The observer can be: 'complete participant', when the researcher is a member of the social setting and his/her identity is not known; 'participant-as-observer', when members of the social setting are aware of the researcher's status; 'observer-as-participant', when the researcher is an interviewer with little or no interaction with members and 'complete observer', when the researcher does not interact with people at all. As further explained by Bryman (2015),

moving towards the model of the researcher as a 'complete observer' involves a process of 'detachment' from the social setting under investigation. Furthermore, the model of being a 'complete participant' allows for a deep immersion in it. In this thesis, the role of the researcher has been chosen to be a 'complete observer' in the first activity (Cultural Probe Kit) where the researcher had no influence on the participants of the study. For the remaining activities, the role of 'observer-as-participant' was adopted by the researcher, in order to facilitate the process of data gathering without any influence on the participants of the study.

3.9 Summary of the chapter

This Chapter provided a detailed overview of the research method approach used in this thesis. The constructionism approach as the epistemological stance is adopted to stress the interplay between technology and human agent, where technology helps the user re-establishing his own cognitive abilities. The adoption of an interpretivist theoretical perspective further highlights the need for the retrieval of contextual past experiences and memories of older adults that are built upon the reality where they live in, in order to acquire new information. The overall methodological framework presented in this Chapter follows an exploratory, qualitative and inductive approach, where data collected from different sources of evidence are explored seeking for internal logic without a strict theoretical model that could exert an external logic to the phenomenon under investigation.

Four different methods are adopted to answer the research question and to accomplish the three objectives identified. Ethnographic inspired studies (Cultural Probe Kit activity and Focus Group) were conducted to observe the users within their own living context and explore the nature of their cultural or social background. Phenomenological inspired studies (Image Schema elicitation with SMs workshop and questionnaire for the evaluation of the Smart Radio) were also conducted to describe the efficacy of the phenomenon under observation, by means of evaluating the understandability of the Smart Radio. Consequentiality between studies has been sought to guarantee the robustness of findings and to further stress the holistic approach adopted in this research.

Chapter 4

Opportunities for 'ageing in place' design scenarios: insights and findings

4.1 Introduction

The literature review conducted in Chapter 1 and Chapter 2 highlighted the importance to contextualise any technology intended for the ageing population within an 'ageing in place' design scenario. The identification of a design scenario, by means of critical areas that a novel device will eventually consider to cope with, allowed the definition of a hypothetical new device for the ageing population with embodied SMs and facilitated its evaluation in the main study (Chapter 6). In line with the strategy explained in Chapter 3, where the need of a direct observation of the user emerged as a starting point of the investigation, the Cultural Probes Kit was considered as a relatively unobtrusive way of providing insights into the everyday life of people to reveal their habits and everyday patterns. The adoption of the Cultural Probes Kit technique in this research clarified how the physical environment has an impact on the health, independence and quality of life of the participants and therefore, an extrapolation of recurrent 'themes' characterising the everyday life of the sample was conducted. 'Themes' were further translated into eight daily-life situations and discussed in a Focus Group session. The Focus Group discussion was carried out to establish a direct dialogue with targeted users and stimulate a rich and active discussion about the daily-life situations identified to deduce a set of critical areas. Insights revealed how *the enhancement of motivation to support independent living* and the *facilitation of communication and social exchange*, are two critical areas that technological products should help older adults to deal with.

4.2 Cultural Probe Kit

The Cultural Probe Kit was part of a research strategy (Chapter 3) of pursuing qualitative data in a responsive way with the aim to acquire information about targeted

users toward unexpected clues, everyday experiences, and anecdotes. This section presents findings from the Cultural Probe Kit, gathered from older adults within their living settings. Findings informed how technologies can support ordinary activities of the observed participants and provided a general understanding of their feelings and emotional aspects. Overall, the Cultural Probe Kit generated a set of rich information to inform whether smart objects should operate at a physical or more an empathic and relational level.

Table 4.1 List of participants' demographic data and activities completed

Personal details				Activities completed				
participant	age	gender	nationality	Body outline	Home plan	Postcard	Daily Diary	Map of Objects
1	75	F	English	√	√	√	√	√
2	60	F	English	√	√	√	√	√
3	95	F	English	√	√	√	√	√
4	73	F	British	√	√	√	√	√
5	78	F	British	√	not completed	not completed	√	not completed
6	59	F	British	√	√	√	√	√
7	56	F	British	not completed	not completed	not completed	√	√

Thirty Cultural Probe Kits were distributed among the guests of the Age UK Hillingdon branch in London, but only seven participants returned the Kit. Table 4.1 shows the participants and the activities of the Kit performed. All participants were females; a strong reluctance in taking part in the study was reported by the male members of the Age UK group. Few participants reported that they did not understand the purpose of the study and others found the activities too difficult to be performed. A small group of the Age UK group was willing to take part in the study and although they were supplied with the kit, they did not return it back to the researcher. Difficulties in the participants' commitment to complete this study are ascribed to the low motivation of older adults shown in any activity that does not provide an immediate benefit, as expressed in Chapter 2 (Melenhorst *et al.*

2006). Moreover, the loss of memory and the decreasing ability to stay focused on a lengthy activity refrained them to undertake the study (Fisk, Rogers *et al.* 2009). Some of the participants were observed to forget their kits on the table where the study was introduced, despite the efforts of both the researcher and the Age UK facilitator to constantly remind them of the purpose of the study.

In order to incentivise their motivation, members of the group were invited to fill the booklet of activities during their leisure time at Age UK premises. All members who accepted to take part in the study reported how they preferred to complete the booklet at their own premises, where they could better be focused on the activities and spend time on them. The completion of individual activities was heterogeneous: six participants (7th missing) completed the 'body outline'; five participants completed the 'home plan' (7th and 5th missing); five participants completed the 'postcard activity' (5th and 7th missing) and finally, six participants out of seven (5th missing) completed the 'maps of objects' activity. All participants completed the 'Daily Diary' activity. Despite the seemingly low response, the dedication of the participants in completing these activities allowed the gathered of data to inform the research with relevant details about their everyday habits, priorities and the role technology has in the ordinary life of an older adult.

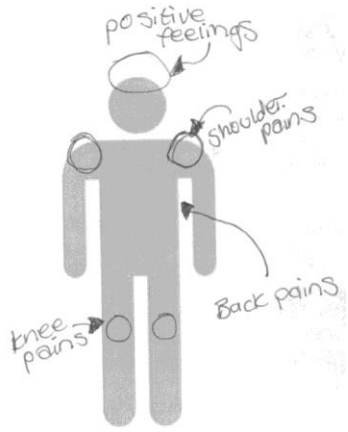


Fig. 4.1 Example of 'body outline' activities by participant 1 where body issues are managed through "positive feelings"

4.2.1 The 'body outline' activity

The adoption of the 'body outline' activity was intended to inform about the main physical difficulties experienced by participants and their general attitudes in coping with them. Participant 1 reported three main symptoms experiences, such as shoulder pain, knee pain and back pain and she further circled the head of the body outline with a sign "positive feelings" (Fig. 4.1). She explained how she managed pains: *"stretching, exercising, take pain killers and think positive, socialise. I try to keep positive in thoughts, I socialise with family and friends; I have suffered from arthritis for years and I have attended an eight-week program of pain management"*. Participant 2 simply reported back and legs pain with the adoption of exercises and pills from the doctor as a strategy to alleviate pain: *"If you keep moving it*

alleviates pain". Participant 3 reported how she used asthma inhaler twice a day, she controlled the blood pressure by medication, and she suffered from back pain due to the curvature of the spine that she relieved with paracetamol intake. She further wrote on a blank side of the page her solution to her health symptoms: *"stay positive and active as possible"*. Participant 4 indicated four points of pain: neck, shoulders, forearm and feet. Her solution was to medication and exercise with, the addition of: *"praying and looking for the good in people and circumstances"*. Similarly, participant 5 found painkillers and daily exercise to relieve the chest, stomach and legs pain she experienced. Participant 6 reported 'fear' as the main symptom experience in relation to the head, alongside pain in arms, wrist ache and cramps in feet.

4.2.2 The 'home plan' activity

The home 'plan activity' was adopted to get an overview of the living settings of participants directly from their own perspectives, without the intrusion of the researcher. Participant 1 drew her home as divided into a bedroom, bathroom, living room and kitchen with basic furniture and appliances highlighted (Fig. 4.2): bed, wardrobe, bedside lamp, chair, sofa, cupboard, toaster, cooker and sink. Interestingly, outside the outline of the home, she drew a few objects that she considered meaningful: a dish with cutlery, a crosswords book, knitting needles and wool, a book. Participant 2 sketched a neat map of her house, consisting of a mere description of rooms with no objects in them. Conversely, participant 3 provided a detailed description of her house. The main door leads to a passage and a toilet on the left, equipped with walk-in shower, radiator and wash basin and a walk-in storage on the right. Just beyond the storage, on the right, the kitchen has cupboards, electric stoves, microwave, fridge and a radiator. The house continues to the living room, equipped with an electric relax-chair, coffee table, china cabinet, TV and storage cupboard, a radiator. Finally, the bedroom has an automatic bed, a dressing table with a large mirror, a bedside cabinet and a radiator. Participant 4 made a home plan adopting the collage techniques that stressed the role objects have in her life (Fig. 4.3). From the collage, conventional objects, such as beds, sofa, desks, kitchen equipment, television and a sewing machine have a relevant role in the house. Participant 6 drew only two rooms of the house: the living room and the bedroom. In the living room, she sketched the coffee table: *"so I can reach my items easily, because of my weakness in both arms and hands"*; and the sofa: *"comfortable, high back is good for resting my head and neck"*. Furthermore, next to the

bed, the e-book reader is depicted, because: *"I use to read before I fall asleep and it is easier for me to handle it rather than a print format"*.

Fig. 4.2 Example of 'Home plan' activity from participant 1 where meaningful objects, such as a dish with cutlery, a crosswords book, the knitting needles and wool, a book are depicted

Fig. 4.3 Example of 'Home plan' activity from participant 4 where a collage technique was adopted

The descriptions, through sketches and collages, allowed a prioritisation of products that older adults love being surrounded with. Although only 5 participants completed this activity, it was essential for the identification of recurrent objects that older adults love to spend time with.

4.2.3 The 'postcard' activity

The 'postcard' activity was designed to guide participants in the definition of their relationship with every-day objects by adopting a playful and friendly template. Participant 1 said: *"Favourite objects are a Teddy Bear and a doll. The last object bought was a doll from a charity shop. I would like to buy myself a new TV for Christmas"*.

Participant 2 wrote: *"Dear Delia, just a line to let you know I have bought myself a laptop and I love the clock you got me. I would like to get an old grandfather clock. Best wishes"*. Participant 3 said her favourite object was the electric shopping scooter; the last object she bought was a new *"dressy dress"* (Fig. 4.4). Interestingly, she said she would like to buy: *"a laptop computer, but age prevents me wasting the money, as I have no idea of using it. Rose"*. Participant 4 wrote: *"Dear Sandra, my favourite object is my Bible; it gives me all the support and answers within its pages. The last object I bought was a special gadget for lifting poached*

eggs". She further explained how she would like to buy for herself a foot massager to *"relieve the pain in my feet"*. Finally, participant 5 said her favourite object was the Bible, the last object she bought was a dress to wear on holiday and that she would like to buy herself a tablet.

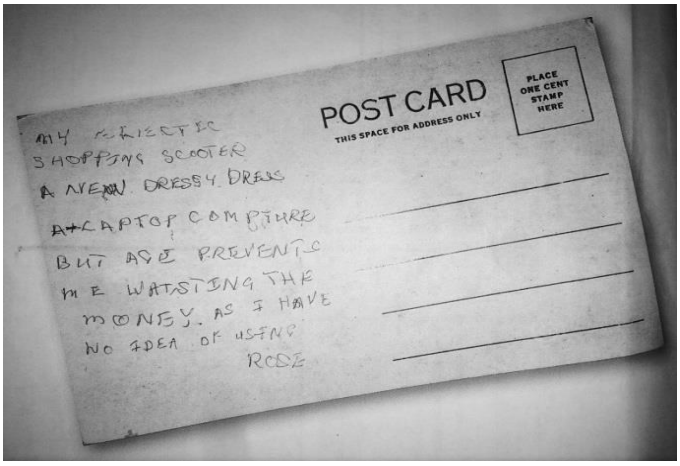


Fig. 4.4 Example of 'postcard activity' by participant 3 where concerns about purchasing a laptop are expressed

This activity allowed a simple, but a clear understanding of participants' wishes regarding everyday products. The familiar template of a postcard allowed for a short and direct response that completed the information acquired through the previous activity. While the 'home plan' activity revealed existing products and home settings, the 'postcard' activity asked participants to specifically express what product may be beneficial for their everyday life.

4.2.4 The 'daily diary' activity

The 'Daily Diary' activity provided information about the daily life structure of participants. Table 4.2 summarises the key points identified through the 'Daily Diary' activity. Extended description of the findings can be found in **Appendix G.1**.

4.2.5 The 'map of objects' activity

In the 'map of objects' activity, participants were invited to qualitatively express the relationship they have with their objects with the intent to understand how products are adopted in their life. Participant 1 listed three objects, respectively linked to a positive feeling and mood, such as the word-search booklet that helps her be relaxed; neutral mood, such as

Table 4.2 Salient aspects of the 'Daily Diary' activity divided by participants and days where each information was recorded

Participant 7	Participant 6	Participant 5	Participant 4	Participant 3	Participant 2	Participant 1		
Time with daughter and a skype call with her son	Body care	ordinary daily routine every day	Bible reading and prayer time every morning. MacMillan Coffee Morning. Parkinson group with her husband	Body care every morning		Exercises to help arthritis every morning Satisfaction in solving a kitchen problem. Need of socialising.	**1**	**Days**
Self-organised book group at a friend's house	Shopping activities could be a challenge due to weak arms		Parkinson group with her husband	Hair dresses	Gardening is "therapeutic calming"	Attendance to a social group where to meet friends. word search/crossword to kill the time	**2**	
Gardening and vegetables cropping. the need of socialising	Fear of storm		Time with a daughter. Prayer meeting	Socialising activities in the communal lounge. tapestry working		Church in the morning	**3**	
	Church in the morning		Parkinson group with her husband.		Volunteering		**4**	
Need of socialising			Volunteering for other AGE UK members.	Socialising activities in the communal lounge			**5**	
Barbequing with very old friends	Time with family and friends			Friends gathering			**6**	
			Prayer meeting	Not able to attend church service			**7**	

a cooking pan because cooking could sometimes be boring; negative mood, such as the shower hose because it was not working as it should. Participant 2 listed two objects: the new phone, linked with a neutral mood, because *"is amazing, even connecting to the internet but I don't work how to use it"*, and the old phone, associated with a negative mood, because: *"I preferred my old phone to my new one it just does not explain what the gadgets are for or how to use them"*. Participant 3 described her electric scooter with both positive and negative stickers; positive because: *"it gets me out to meet people instead of being house bound"* and negative because: *"I'm left handed but all scooters have right-hand controls; it would be helpful if they had a dual control"*. Participant 4 described positively her computer because: *"it is very useful for looking up maps – items I am considering purchasing or health problems"* but also neutrally, because she had to constantly ask her son and grand-daughter to sort out any problem with it, and negatively, because: *"my understanding of how it works is very limited. Because I find it difficult I give up easily. I have not mastered emails"* (Fig. 4.5). Participant 6 drew a mobile phone beside a green sticker saying, *"contact with friends + family"*. She further sketched a television and a computer with the neutral, orange sticker with no description on them. Participant 7 described as positive mood connected objects, the photo album and calendar of her holiday saying: *"thrilled with the pictures and quality I think we will treasure for years"*. With negative mood, she reported the barbeque because: *"is falling to pieces, need to buy a new one!"*

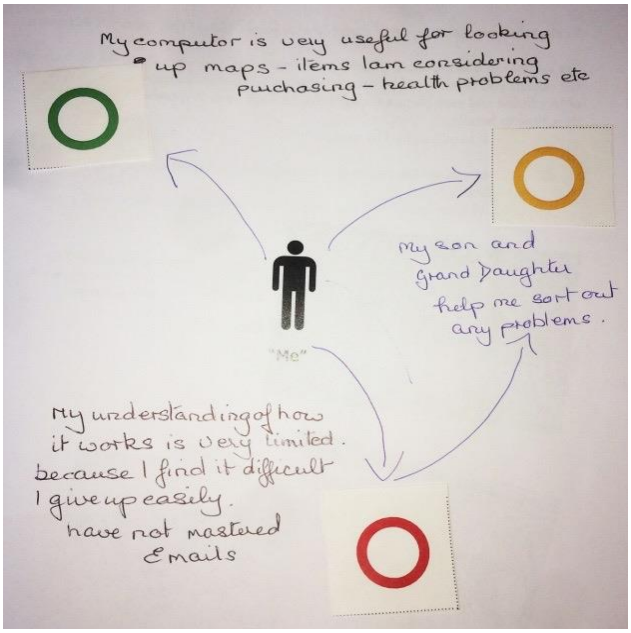


Fig. 4.5 Example of 'map of objects' by participant 4 where difficulties in understanding how to use a laptop are expressed

This activity further invited participants to express their opinion about their ordinary products with the specific intent to understand how they feel when interacting with them. The information recorded, highlighted relevant emotional patterns that would not acknowledged otherwise.

4.2.6 'Themes' emerging from the Cultural Probes

The process of coding has been carried out through a thorough familiarisation with the probes collected and a preliminary identification of the descriptive codes that helped achieving the first objective of the research. As explained in Chapter 3, section 3.5, a thematic analysis was performed with the intent to cluster data collected into main 'themes'.

Descriptions provided, as observed in the 'Daily Diary' and 'map of object' activities, helped to analyse visual materials, where the description was not always provided. The generation of salient 'themes' was performed through the convergent adoption of descriptive and analytic codes, as explained in Chapter 3, Section 3.5. Fig. 4.6 shows how probes have been primarily categorised into descriptive codes with the help of notes, marks and labelled stickers; each sticker had a section for the description of the code and a second one for the preliminary category representing the code. Fig. 4.7 shows how each descriptive code has been clustered into descriptive categories and analytic codes (the four numbered labelled stickers in Figure 4.7); these codes were further grouped into a corresponding main 'theme' (social involvement, in figure 4.7). The complete list of 103 descriptive codes and corresponding categories and analytic codes can be viewed in **Appendix G.2**. Eight 'themes' were subsequently identified:

Conventional products vs novel technologies. The sample reported a constant use of 'conventional' objects the older adults are entertained by. Books, sewing machine and crosswords booklets appear to be dominant in their homes, while barely any technological products are considered as 'acceptable' or 'desired' way to spend time with. Participant 4 depicted her sewing machine in her bedroom, the most intimate room of the house (Fig. 4.3); participant 1 highlighted the importance of her pastime activities by visually representing them around her house in the 'home plan' activity (Fig. 4.1): knitting, cooking, crosswords booklets and books. Similar activities are reported by participant 4 in her 'Daily

Diary' activities when doing Sudoku, crosswords and watching television become the most relevant activities performed in her days.

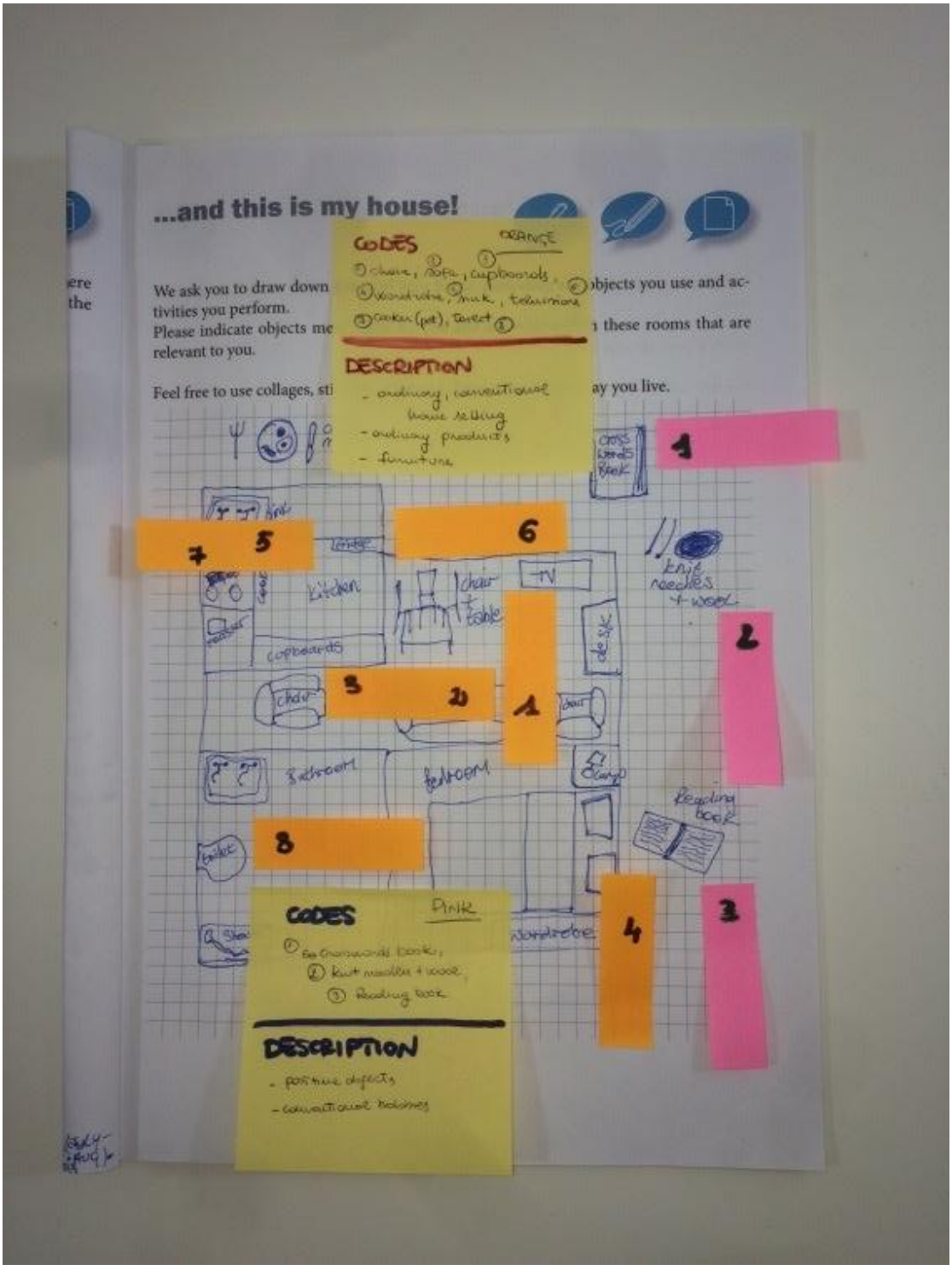


Fig 4.6 Identification of descriptive codes within probes

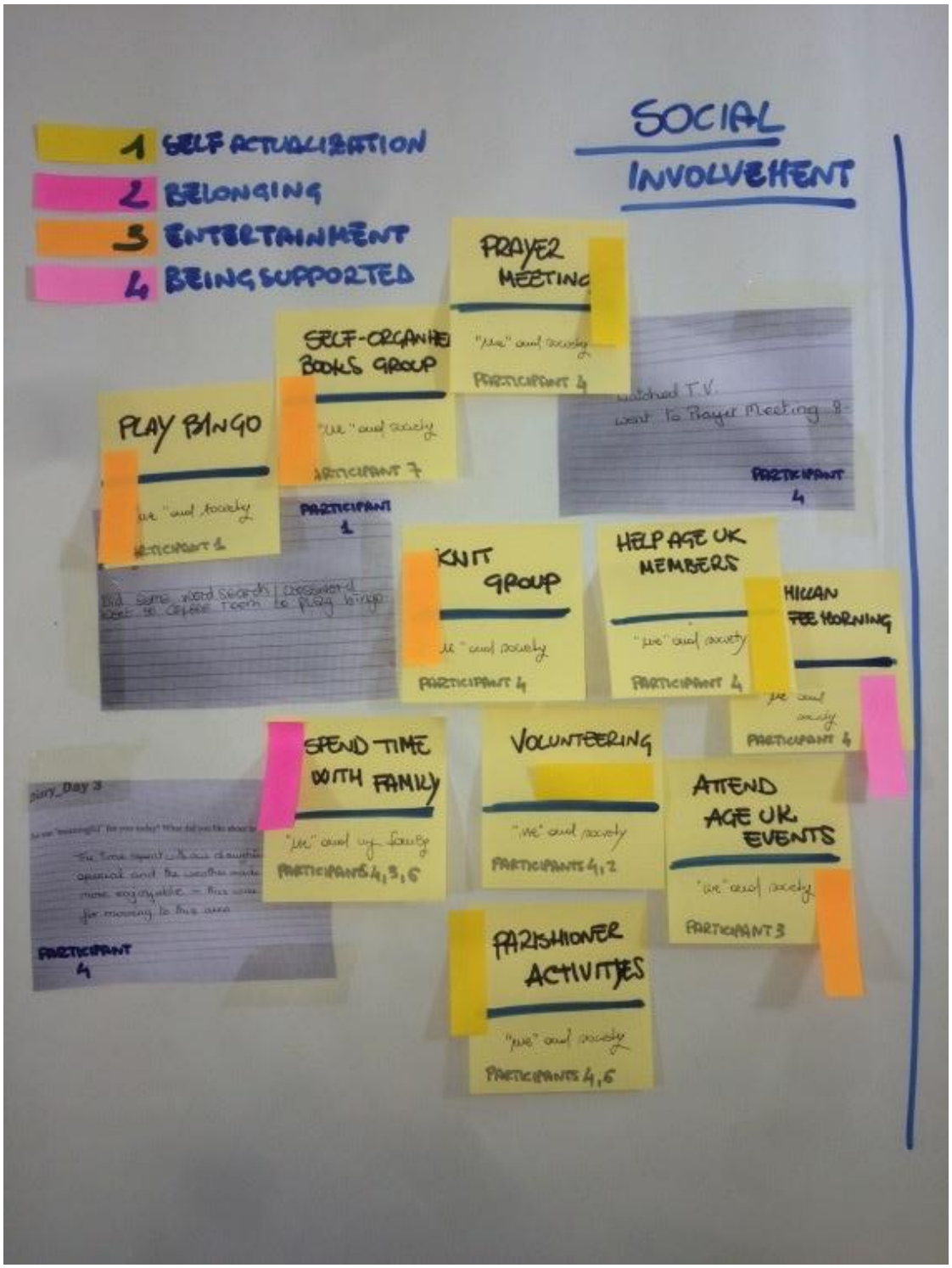


Fig 4.7 Identification of analytic codes and main themes

Participant 6 described the importance of an ordinary object to provide an immediate benefit and relief from physical pain: the coffee table allows her to always have within reach her useful items, while her sofa guarantees an immediate rest to her upper limbs.

Participant 4 described her Bible as a source of reassurance and mental comfort, while the desired object is a foot massager, for an immediate physical benefit. The Bible is also the favourite object for Participant 5, meaning her need of an emotional support above anything else. Nonetheless, the relationship that older adults have with technological products appears to be controversial. Participants revealed the desire to purchase technological products to improve their independence and knowledge about the world, such as participant 5, who wants to buy herself a tablet, but her limited exposure to these products kept her away from purchasing them. Participant 2 in the 'map of objects' activity showed her enthusiasm about her new smartphone and subsequently the frustration not understanding how it works. A similar case is reported by Participant 4, who clarified how she found her computer useful but her limited expertise restricts her from the full use of the product with the consequent lack of motivation and frustration. Elderly people usually take responsibility for their poor experience with technologies and participant 3 clearly stated in the 'postcard activity' that her desire to buy a laptop was 'dampened' by the complexity of using it. Despite their curiosity and growing interest in technological products, participants reported the need to rely on someone else to understand how to use them. Participant 4 reported (through an orange sticker in the 'map of objects' activity) how uneasy she found to be asking for help from her son and granddaughter to *"… help me sort out any problems with my computer"*. Participant 3 reported also a usability problem with her scooter, which was designed for right-handed people, while she was left-handed, wishing for dual control. The management of problems with technology and the need of a third-party help is a common problem that impinges on the very idea of independence that the elderly people involved in the study were very attached to. Figure 4.8 visually describes this theme, along with the descriptive codes, categories and analytic codes observed.

Social involvement. The recognition of oneself as an individual worthy of respect has also emerged as a pivotal theme in this study. The sense of having produced something new and original, to have made a lasting contribution to their mind and body is a specific goal needed to be pursued by the increase of personal self-confidence within society. The relevance of this theme emerged when participants discussed a deep sense of belonging in sharing activities with peers. Self-confidence within the society for participant 4, meant being able to support her spouse suffering from Parkinson's disease, regularly attending the MacMillan Coffee Morning, helping needy people with grocery and reaching the local Age UK agency to allow them to be involved in social activities. Knitting as a hobby is also

shared with peers in a dedicated group at the local library. The daily management of her husband's disease works as a test bench for her self-worth, which is rewarded when she can manage her husband's daily routines. Participant 4 comments: "*Even though I can no longer do a lot of things, it is good to be useful and help family*". Finally, participant 7 reported the importance of the self-organised meetings with peers as a stimulus also for recreational activities; in her case, they established a book group where to discuss books recently read. Figure 4.9 depicts the second theme identified together with its descriptive codes, categories and analytic codes.

Keep the body active. Physical and cognitive exercise were reported as a reasonable means to keep a healthy lifestyle, hence independence, as long as possible. The concept of a correlation between the *positive state of mind* and *healthy body* seems well established in participants' life. Participant 1 depicted in the 'body outline' activity her main symptoms with a clear reference to positive feelings as a source of pain alleviation, in combination with a rigorous daily exercise routine (Fig. 4.1). Participant 2 improved the concept by claiming that being active and positive at the same time alleviates pain. Participant 3 noted in her Diary that exercising every day was a way to keep her arthritis under control so that she could attend religious services weekly; despite needing a carer for daily activities such as bathing, she kept a daily exercise routine (armchair pedalling) to avoid a deterioration of her physical health. Similarly, Participant 4 completed this concept by adding an optimistic life approach where faith plays an important role alongside a positive attitude in both "*people and circumstances*". Figure 4.10 summarises categories, descriptive and analytical codes in support of the third theme identified.

Mobility. An emerging issue among participants was observed in the growing physical impairments that dramatically reduce their freedom of 'movement', resulting in an anguishing isolation. This concern mainly emerged from the description of participant 3, where she clearly stressed the sense of separation from the "world outside". She described how the electric scooter is a fundamental means to meet her friends: "*it gets me out to meet people instead of being house bound*" and how her physical impairments sometimes hinder her freedom of movement and refrain her to attend the parish services. Therefore, a deep sense of trust on someone else, like her son and caregiver, to break this isolation is profoundly felt by this lady and by participants 4 and 7 where the occasional visits of their offspring were considered as extremely meaningful. Figure 4.11 show the codes underpinning this theme.

Be independent. Beside social contacts, much of the pastime activities seemed still to be related to housekeeping, especially gardening. Participant 2 reported in the 'Daily Diary' how they found gardening to be "*therapeutic and calming*" in contrast with the boredom of watching television. Gardening seemed to be an easy activity, appreciated also by participants 5 and 7. Difficulties in being able to independently managing their house were experienced by all participants. Participant 1 had to call the maintenance service to fix a light, while participant 3 needed a carer for to help her with bathing and dressing activities. Simple activities such as reading and shopping were severely affected due to the ageing process; participant 6 explained how an e-book reader simplifies the reading activity because it is lighter for her to be held, while participant 5 reported her frustration for not being able to hold grocery bags anymore due to a decreasing stamina in her upper limbs. Figure 4.12 depicts the codes related to this theme.

Health-care and wellbeing practices. Participants further described their body as regularly being affected by generalised pain that can be alleviated with the use of painkillers. They also highlighted a growing concern about health issues that can be partially alleviated by adopting a positive and proactive attitude. Three participants out of seven described a daily consumption of medicines regulated by a meticulous daily routine. Participant 1 highlighted the source of physical pain and she reported how during an 8-week programme of pain management she learned how to keep positive thoughts that can deflect her thoughts from pain. Participant 2 reported the regular consumption of medicine to alleviate back and legs pain, while participant 3 described her thorough daily routine based on pills intake and body management, starting with the regular use of an asthma inhaler twice a day, and a constant check of her blood pressure and consumption of paracetamol to alleviate back pain. In Figure 4.13, categories, descriptive and analytic codes underpinning this theme are shown.

Being in touch. A concept of 'being in touch' emerged from two participants. Participant 1 explained how social events are important for socialising and meeting friends, as there were no other ways for her to be in touch with them. Participants did not seem to rely on any form of communication technology to enhance their social opportunities. Parish services and social events are, above all, the most popular ways to be in touch with peers and have the chance to have a break from their ordinary life. Only two participants seemed to be inclined to improve their communication possibilities through the adoption of technology; participant 7 reported how a simple Skype call with her son was considered as

meaningful and participant 6 considered her mobile phone as very important because it allowed her to be in touch with friends and family (from the 'map of objects' activity). Figure 4.14 show the codes identified in support of this theme.

New challenges. Participants revealed a multitude of intimate wishes, desires and multiple ways they would like to spend time with. The desire to be entertained and to spend time with peers can be observed in the persistent pursuit of social activities, either at local Age UK branches (participant 3) or at the local Church (participant 6). This wish is pervasive throughout findings and is identifiable with the need of defeating the insistent ageing processes. Participants recognised the need to adopt a positive attitude with daily resolutions and small goals to carry on in their lives; the need to spend leisure time in a more productive way such as playing the piano is expressed in the 'Daily Diary' of participant 6 while the desire to purchase new devices was described by participants 2 and 3. Figure 4.15 depicts the codes underpinning this theme.

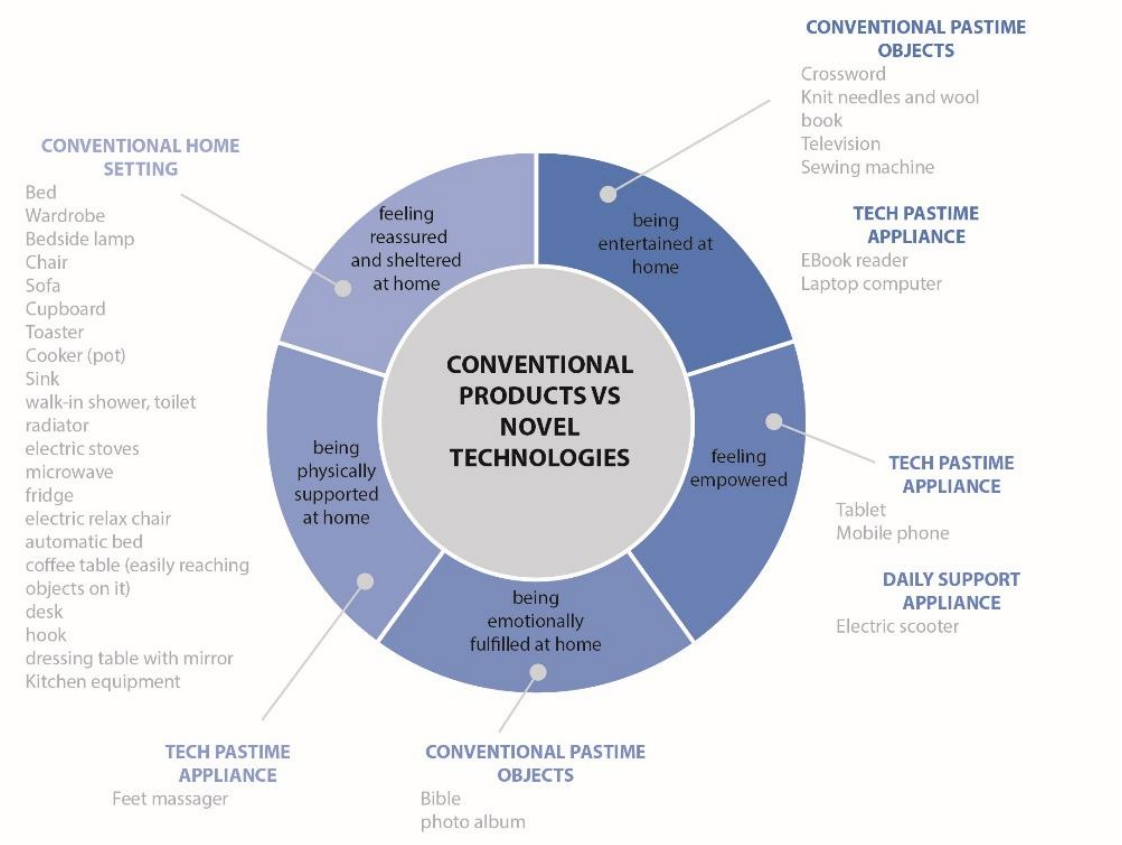


Fig 4.8 First theme identified from the Cultural Probes Kit activity, including descriptive codes (in grey), their categories (in blue shades) and analytic codes (outer ring)

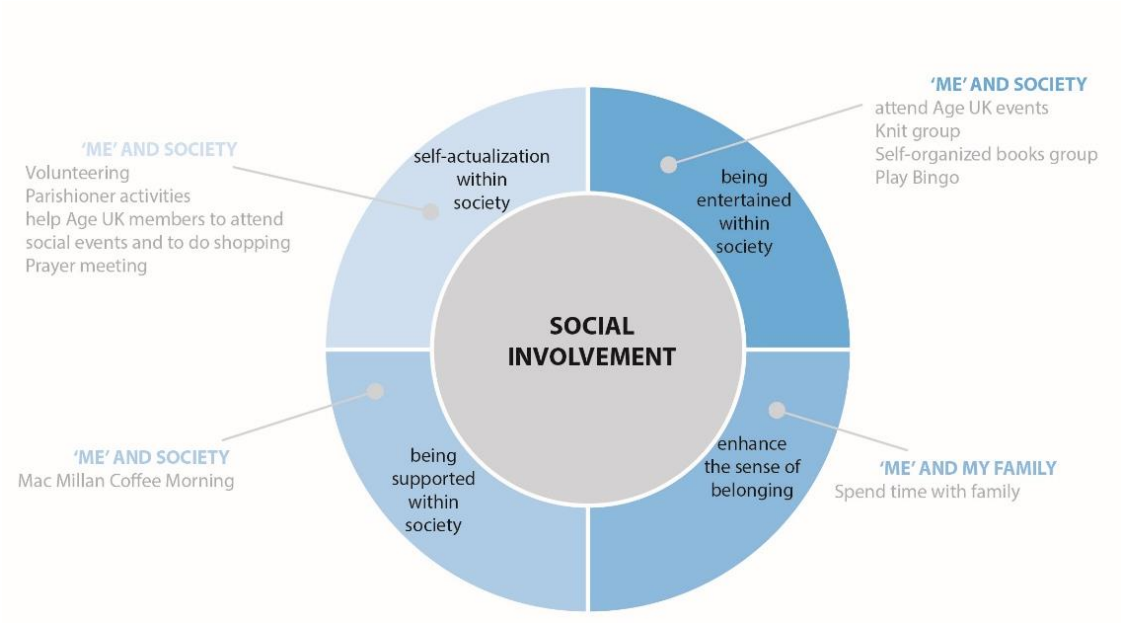
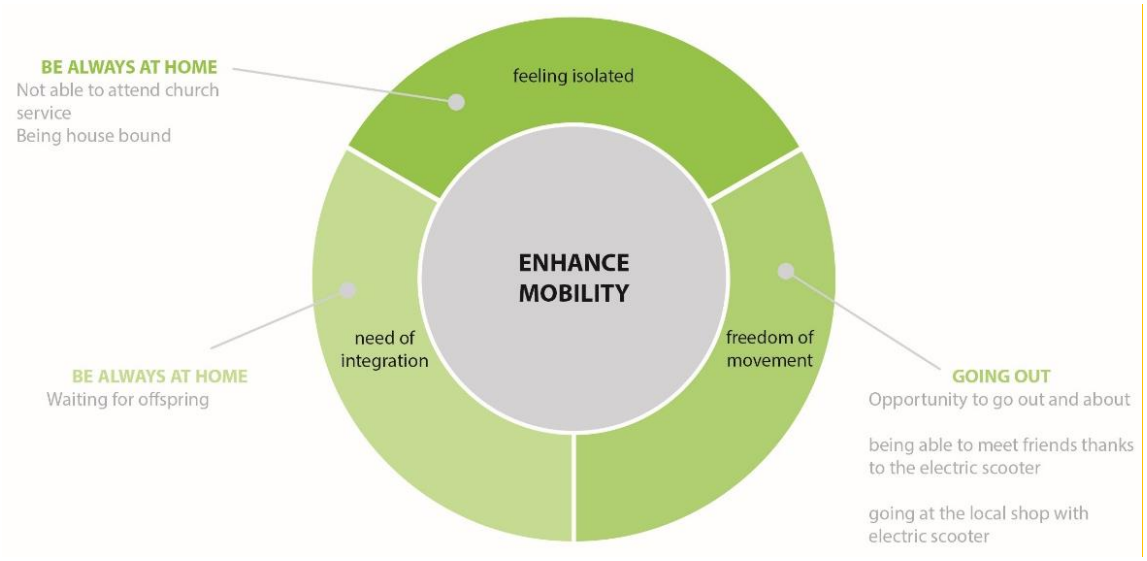


Fig 4.9 Second theme identified from the Cultural Probes Kit activity, including descriptive codes (in grey), their categories (in blue shades) and analytic codes (outer ring)

Fig 4.10 Third theme identified from the Cultural Probes Kit activity, including descriptive codes (in grey), their categories (in light green shades) and analytic codes (outer ring)



4.11 Fourth theme identified from the Cultural Probes Kit activity, including descriptive codes (in grey), their categories (in green shades) and analytic codes (outer ring)

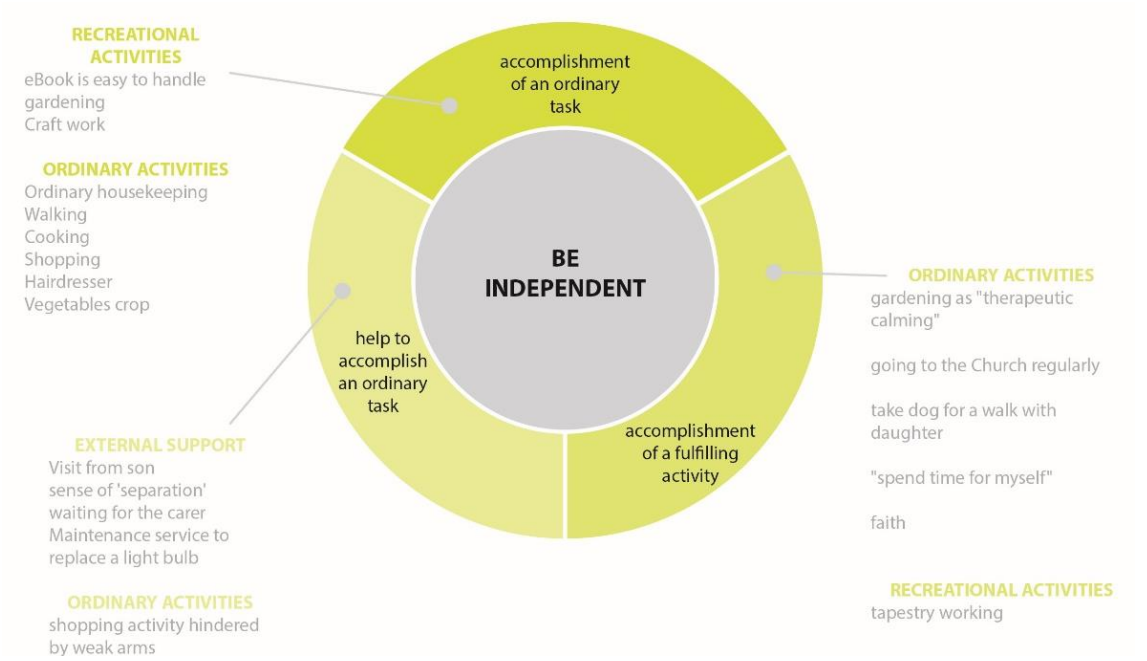


Fig 4.12 Fifth theme identified from the Cultural Probes Kit activity, including descriptive codes (in grey), their categories (in yellow shades) and analytic codes (outer ring)

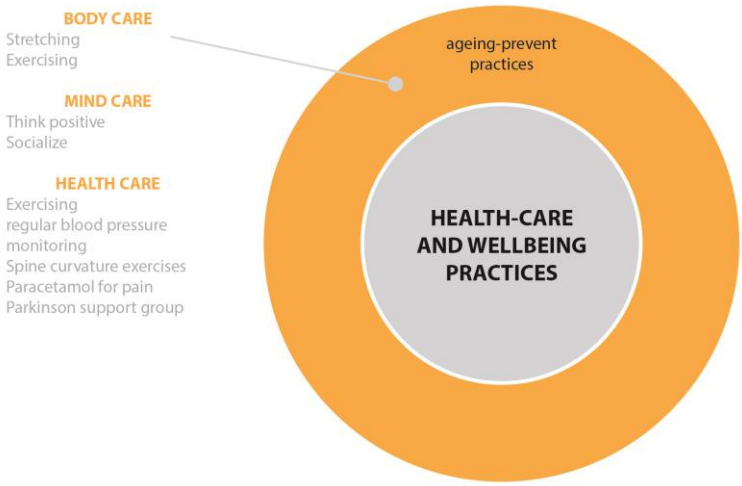


Fig 4.13 Sixth theme identified from the Cultural Probes Kit activity, including descriptive codes (in grey), their categories (in orange) and analytic codes (outer ring)

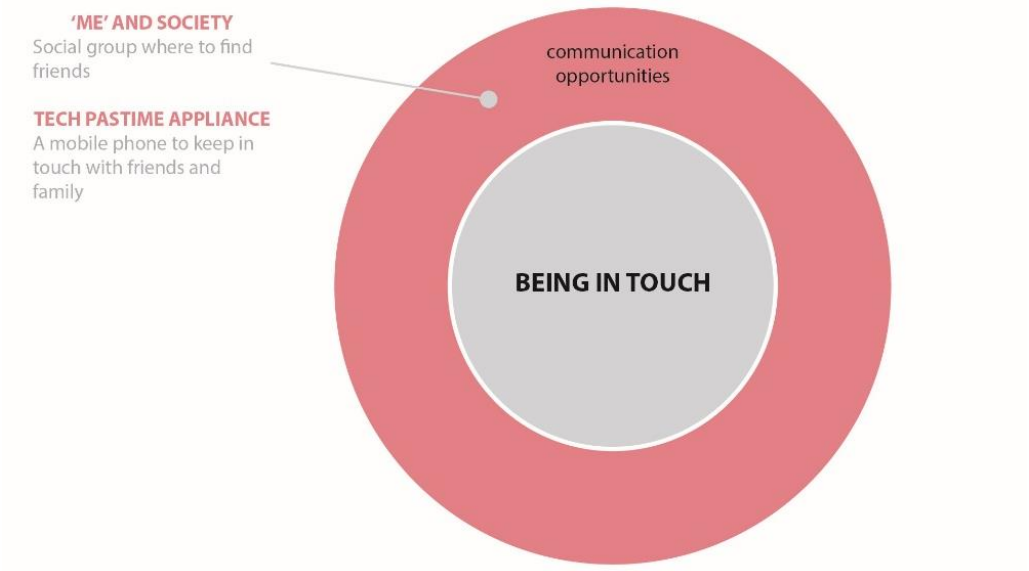


Fig 4.14 Seventh theme identified from the Cultural Probes Kit activity, including descriptive codes (in grey), their categories (in pink) and analytic codes (outer ring)

Fig 4.15 Eighth theme identified from the Cultural Probes Kit activity, including descriptive codes (in grey), their categories (in purple) and analytic codes (outer ring)

In conclusion, the themes identified revealed that:

1. **Conventional products vs novel technologies:** although older adults show preferences for conventional products, they also demonstrate interest in adopting new products; however, their limited technology literacy makes them reconsider their purchases;

2. **Social involvement:** the re-establishment of self-esteem and self-confidence occurs within their role in the society they are living in;

3. **Keep the body active:** older adults follow a daily routine including rigorous exercises to keep their body active and healthy;

4. **Enhance mobility:** reduction of mobility could be an issue for older adults, that enhances a vivid sense of isolation;

5. **Be independent:** the ability to deal with household chores is a way for older adults to still feel active and independent;

6. **Health-care and wellbeing practices:** older adults check their health status on a daily basis, with a regular consumption of medications and painkiller to alleviate pain;

7. **Being in touch:** communication between peers relies mainly on social activities and not on technological devices;

8. **New challenges:** older adults have wishes and unspoken needs that are not always fulfilled in their daily life.

4.3 Focus Group

The Focus Group method has been adopted to further discuss and narrow down the eight themes identified through the direct dialogue with targeted users. Eleven participants took part in the activity and they were split into two groups; two Focus Group sessions were run and this procedure allowed each participant to have an active role during the conversation. Participants responded positively at the Focus Group with a high level of engagement. The topic of the conversation was explored with interest and participation, with a lot of insights about the participants' personal experiences. At the end of each session, participants thanked the researcher for the opportunity they had to freely talk about their needs and concerns and they showed their willingness to take part in future studies.

Table 4.3 List of participants of the Focus Group

Group 1				Group 2			
Fictional name	age	gender	nationality	Fictional name	age	gender	Nationality
Janet	66	F	British	Paul	80	M	British
Mary	70	F	Irish	Ellie	73	F	British
Anne	/	F	British	Jack	64	M	British
Melanie	65	F	British	Rob	50	M	African
Katy	81	F	English	Jenny	76	F	British
				Patty	58	F	British

Table 4.3 shows the fictional names of the participants and their personal details. The activity started with an introduction and a warm-up question, asking participants to briefly explain the most frustrating thing recently happened in their daily life.

Mary (Female, 70-year-old) started the conversation expressing her concern about the use of Internet; she said: "*the Internet is too much for us; you buy something like a tablet and there is suddenly another new product available. To me is such a waste!*" At the question of the researcher, if she preferred to have fewer options available, she commented: "*Yes! You can have only a product and renew it. Take the mobile phones for example (she shows a smartphone); there is a lot in the market and you do not know which one is the best.*" The

participant showed an old mobile phone and she explained that it was exclusively used as an address book since she recently bought a smart phone but she was unable to transfer her contact details on it. At the question on how was she able to manage between the two phones, she described that she first browses telephone numbers on the old phone, then dials them on the new one to make the call and then saves the number on the new phone. In this way, the process of saving a phone number seems clear and effortless. Katy (Female, 81-year-old) contributed to the discussion by reporting that her friend, who is 75 years old, encounters the same difficulties in understanding her smartphone and that she coped with this problem through the simultaneous adoption of an old device whose functionalities appeared clearer. Katy further explained how she was willing to help her friend writing down notes and instructions but unfortunately, she did not succeed because her friend "can't really get it." Rob (Male, 50-year-old) reported his need to have a 'memory aid' such as a device that reminds him when to take his medication, and monitors the daily nutrient income by checking the patient's saliva; he said: *"I have a friend who is a developer; he designed a program for people with mental health issue and I like the idea that we can heal ourselves. I have no idea if I had enough minerals and vitamins today; we need a machine able to give us this deal of insights."* Other participants appreciated this idea and they agreed about the usefulness of knowing the right nutrients to consume on a daily base. Participants unanimously agree that such 'self-monitoring' devices would simplify their life. Furthermore, Ellie (Female, 73-year-old) expressed her desire to have *"a new brain"*, meaning that the ageing process was affecting mainly her memory; Paul (Male, 80-year-old), complained about the need of writing notes to remember everyday actions, while Rob appeared comfortable in the regular use of a dictaphone. Patty (Female, 58-year-old) found difficult to motivate herself every morning to get up and embark on everyday activities. She felt like she was not as active as she used to be in the past and she perceived her body as 'changing', with recurrent pain. In order to motivate herself, she explained her dedication on volunteering and how willing she was in organising social groups to make her feel the responsibility to help people and keep her mind highly motivated. She also discussed a number of good practices suggested by her friends, like going to bed early in order to get the right amount of sleep and relaxation that will incentivise a healthy lifestyle. Jack (Male, 64-year-old) reported health issues with his knees that he regularly treated by walking and keeping the body active as much as he can. He discussed how he used to be very active, walking 3-4 miles a day and when the knee problem occurred, he felt 'isolated'. He

described his awareness of his body getting older and how he was fearful of *"forgetting things"*. He further explained the need for motivation to fill his day with activities and fight the frustration of having nothing to do. Another participant (Rob) suggested Jack considers buying an electric bicycle but Jack explained how fearful he was of cycling around London given his knees issues.

At the end of the preliminary conversation, The Octagon Chart (Fig. 3.2 – Chapter 3) depicting eight every-day situations, as emerged from the eight themes identified, was explained. Participants were further informed to discuss each situation individually, in order to stimulate and simplify the process of note taking. A full report of the participants' accounts is found in **Appendix H.1**.

The **situation one** (*…I am interested in a technology that I don't know how to use yet*) was introduced, and participants were asked to imagine how they would behave if they had purchased a new device, which was perceived as helpful, but they do not know how to use it. Participants reported difficulties when interacting with a new device and commented on how they were fearful in making wrong actions, or even breaking the device while trying to understand how to use it. Their recurrent solution was to rely on someone's else help, although they were aware that practice and dedication are important attitudes to becoming an expert and confident in the use of new technology. Motivation in persisting practising is often incentivised by the support of children, family's members and friends. Participants commented on being greatly satisfied when they managed to use a new device and accomplish tasks on their own.

In **situation two**, participants were asked to assume they were *interested in contributing to today's society challenges* and asked to identify and explain any good practices potentially adopted. Participants appeared considerate of charity and volunteering issues. They appeared dedicated to promoting cultural events across younger generations along with supporting socially isolated people with companionship and spending time with them. These activities were considered by participants as meaningful and emotionally fulfilling.

In **situation three** (*…I want to get fitter and keep my body active and healthy*), participants commented how they walked every day and how they loved to dance. Participants appeared willing to challenge themselves to be as active as they can be; they further explained they prefer activities that can empower the full body, such as practising a Caribbean dance that involves the whole body. Furthermore, they commented how

dedicated they were to keep an active lifestyle that in the event where there was no dancing class available, simple activities would be performed at home, such as going up and down the stairs. Having a personal trainer was seen by participants as a great source of motivation for their physical wellbeing. A growing lack of motivation was reported as a recurrent feeling they need to cope with that can be solved with engaging and stimulating activities.

In **situation four** (*…I need to travel today*) all participants considered the bus the most comfortable mode of transport to move around the city, as none of them would drive a car. At the question on how they found out which bus to take in case of need, they promptly replied that they are always aware of the journey and they never had the need to change their plan. If their required help, they commented that they would be confident in seeking for information at the bus station and reading maps. Only two participants (Jack and Rob) appeared happy to use voice commands on their mobile phones for directions and search engines as Google.

In **situation five** (*…I want to stay independent for as long as possible and manage my home on my own*) participants expressed their pride in claiming that they are all independent. Housekeeping activities were getting progressively hard for everyone, especially due to decreasing body performance such as pain caused by stretching arms. Nevertheless, participants did not perceive ordinary housekeeping activities as extremely difficult. Despite their confidence in managing their independence, the need to find someone to share intimate aspects of life and everyday activities was highlighted by all participants.

Talking about **situation six** (*…I need to take medicines and monitor my wellbeing indicators (e.g. blood pressure and glycemic index*), participants reported how difficult they found to deal with memory loss, that hinders their self-care and adherence to medication. All of the participants relied on general practitioners (GPs) to check their health status.

In **situation seven** (*…I like to stay in touch every day with friends and/or family*) participants were asked to explain how they keep in touch with their peers. They all agreed that phone, especially the landline, is a good way to stay in touch. The landline is preferred over the mobile phone because it is free. Socialising is a good way to be in touch with friends, meet people and be up to date about future events.

In **situation eight** (*…I want to fill my free time with something that has interested me for a long time*) participants were asked to focus on what was missing from their daily life and identify potential solutions to fill this gap. Technology exclusion topic emerged when talking about this scenario. Participants expressed the need to be more 'technology literate' and highlighted the importance of courses organised by Age UK and local Churches that aimed to improve their technology skills.

Upon completion of this activity, the researcher asked participants to summarise in one sentence how their life could be improved. Anne (Female, age not declared) wished that her husband, who unfortunately passed away a few years ago, could be here and help her with certain housekeeping activities, such as vacuuming and cleaning. Melanie (Female, 65-year-old) complained she used to do a lot of things a few years back and how at the moment she needs something to make her feel *"stronger, healthier and independent again."* Janet (Female, 66-year-old) stressed the need of a companion to go out with: she explained her desire to go to the cinema and the difficulty in finding peers to take her around. Katy (Female, 81-year-old) would really like to learn to swim and trying to fight her fear of water and injections. She said she was scared of flights and she could successfully manage to fight this fear and she is determined to fight for her other concerns: *"I need some help, some counselling"*. Mary (Female, 70-year-old) claimed her daughter was a counsellor and with her support and commitment, she was able to gain her confidence again. Ellie (Female, 73-year-old) reported her need for stress and pain relief; Paul (Male, 80-year-old) would wish to be able to improve his memory; Patty (Female, 58-year-old) required some motivation in carrying on with her life; Jack (Male, 64-year-old) was looking for *"crystallized purpose or interests that actually grip me, motivate me. I finished my work no long ago and I haven't really got anything positive so far"*. Jenny (Female, 76-year-old), said she was always worried about her health condition and she would like to reduce her concerns. Rob (Male, 50-year-old), wished for a self-monitoring machine that would improve his life.

4.4 Identified 'areas' for 'ageing in place' scenarios

Findings from the Focus Group were further classified into 59 codes with corresponding categories and analytic codes. The full list of codes can be seen in **Appendix H.2**. Figure 4.17 shows one of the mind maps captured during the Focus Group activity that helped in the identification of codes and screening of data through notes and labels.

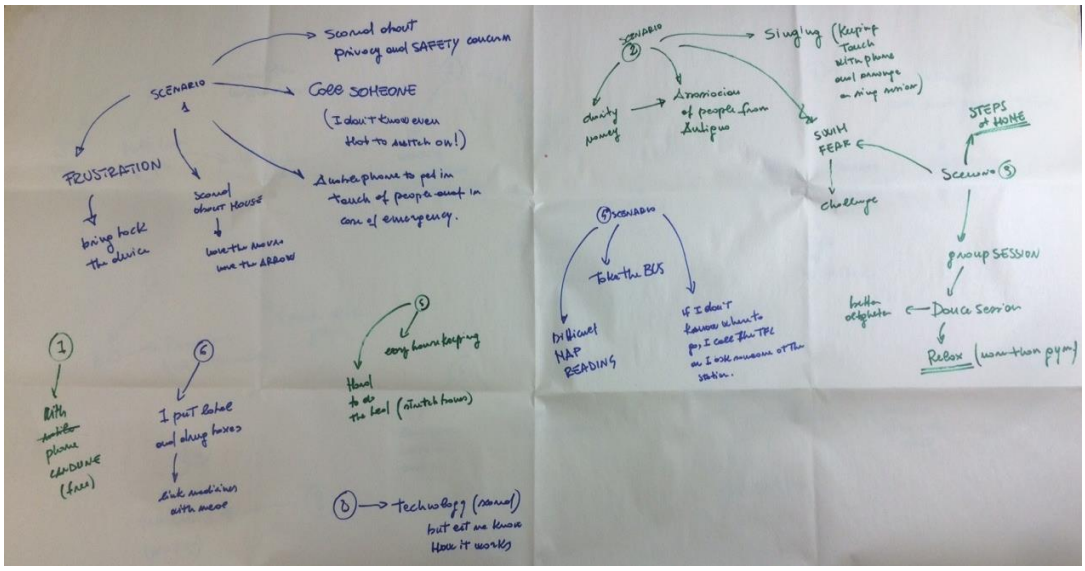


Fig 4.17 Data mind map as depicted during the first session of the Focus Group

Enhance motivation to foster an independent living. Participants highlighted how important it was for them to be able to maintain the highest level of independence as a sense of living without unwanted constraints, in order to preserve their quality of life and keep living in their own homes for as long as possible. Despite some activities, such as housekeeping which was reported as getting increasingly difficult, participants were all happy with the degree of independence they enjoyed in their life and the way they were in control of it. In spite of a sense of optimism related to the acceptance of their lifestyle, participants showed a deep fear of loss of memory that could potentially threaten their independence. Rob, a 50-year-old man, reported the use of a dictaphone to record what to do and prevent the loss of important everyday details and information. Being in control of their health and keeping an active and independent lifestyle were two recurring topics among the participants that further revealed how successfully they managed the challenges of living in a big city. Participants did not mention any problems with travelling in and out of the city both by buses and trains. Buses were preferred over other modes of transport for financial reasons, e.g. in London people over 60 years old are given a free bus pass, and because it was considered to be the means of transport with the least number of barriers. Jenny and Ellie, two ladies respectively 76 and 73 years old, explained how they were comfortable in asking for information at the ticket desk of the bus/train station. This kind of behaviour was approved by all participants, who seemed to be perfectly comfortable and in control of such situations. Loneliness seems to be referred to as one of

the main problems with the elderly experience in their daily activity. Jack, a 64-year-old man, said: *"performing daily tasks is not perceived as hard and challenging as living alone"* and Ellie (Female, 73-year-old) reinforced this point declaring the desire to improve her life by *"focusing on an interest that fills my days"*. Achieving goals as a result of their focus and perseverance highlights the need for motivation in carrying on with their daily life. Nonetheless, the low motivation experienced seems to be caused by a state of perceived isolation that most of the participants were experiencing due to the diminishing ability to be in control of their everyday life. Jack (Male, 64-year- old) mentioned that he perceived his body as 'ageing' and this consequently created a state of dissatisfaction and demotivation that he could not deal with; similarly, Paul, an 80-year-old man, reported that he was keen to be involved in social activities but the lack of motivation refrained him from doing so. In regard to everyday tasks and challenges, problems regarding the use of technological products emerged frequently and were the main reason for the low adoption rate and generalised demotivation. Even the simplest tasks seemed inaccessible on products that had unfamiliar interfaces and Mary, a 70-year-old lady, stated how she was unable to even switch on her new tablet. Janet (Female, 66-year-old) reported how afraid she was of touching the laptop, especially the mouse. She said: *"…the arrow drives me crazy and I don't know where to click"*. The majority of the older adults who were interviewed were unable to appreciate the benefits of technology-based products as the interface language was inaccessible and stopped them from developing an understanding of what the technology can do for them. The lack of consistency also created an information overload that acts as a deterrent to using more than one device simultaneously. Participants reported that it was very frustrating to spend time understanding how a new device works when an even newer one is already available on the market. Melanie (Female 65-year-old) carried her brand new mobile phone in her pursue together with an old handset: as she had been unable to understand how to transfer the contacts lists to the new phone. As a result, she kept using the old one and the new simultaneously. Participants also reported of being afraid of selecting and performing the wrong functions on technological products that might result in an irretrievable course of actions leading to unrecoverable failures. The focus groups discussions highlighted that the elderly did not include the adoption and use of technology-based products as a way to build their self-confidence and self-esteem. Decreased memory also makes the integration and simultaneous use of devices, which have different and inconsistent interaction styles,

progressively difficult. What emerged from the study was a difficulty in building a mental model that can explain the functionality of a product and that can underpin a non-mnemonic understanding of the device. Participants stressed the importance of an adaptable product that can be easily adjusted to their requirements. Participants also explained that they wish to have devices that keep them on a tight routine so that they could feel they are making small but significant steps towards the achievement of their goals. Rob (Male, 50-year-old), reported how useful it would be to have a device that motivated him to undertake a healthy lifestyle, by suggesting what activities to perform during the day and reminding him to take medication.

Facilitate communication and social interactions/participation. The second critical area identified was informed by a strong commitment in accomplishing daily activities that are deeply corroborated by their social exchanges. Participants revealed how they regularly gather with friends and family with a great sense of satisfaction that positively influences their wellbeing. The importance of socialisation as self-actualisation is widely approved among participants but not always achieved. As reported by Rob, a 50-year-old man, some people are lonely and isolated with fewer chances to communicate and share their life. Jack (Male, 64-year-old), who retired recently, struggled to find anything else to do in his life and attending social activities and spending time with other people was for him a way to fill his days with new 'meanings'. Patty (Female, 58-year-old) stressed the importance to always be in touch with motivating people. She said that she could manage to cope with her fear of swimming with the help and challenging support of her instructor. She reported that the instructor was the instrumental factor that kept her swimming going and that without him, she wouldn't have felt the motivation to keep practising. Sports activities also provided motivation both for the sense of belonging they instilled and for the motivation coming from peers to keep at it. Participants in the Focus Groups reported with great enthusiasm how they enjoyed attending the singing and dancing groups to be entertained and challenged and, at the same time, to keep an active life through the support of friends. Participants further reported difficulties in the adoption of technology-based communication tools; their strong inexperience in the use of Internet and, therefore, social networks, limited their possibility to exchange information with family and peers. The social activities were recorded as primarily important to keep the older adults' mind and body active, but also to share both signs of progress and fears, that would not be otherwise experienced. Their deep desire of socialisation and being in touch with others was also

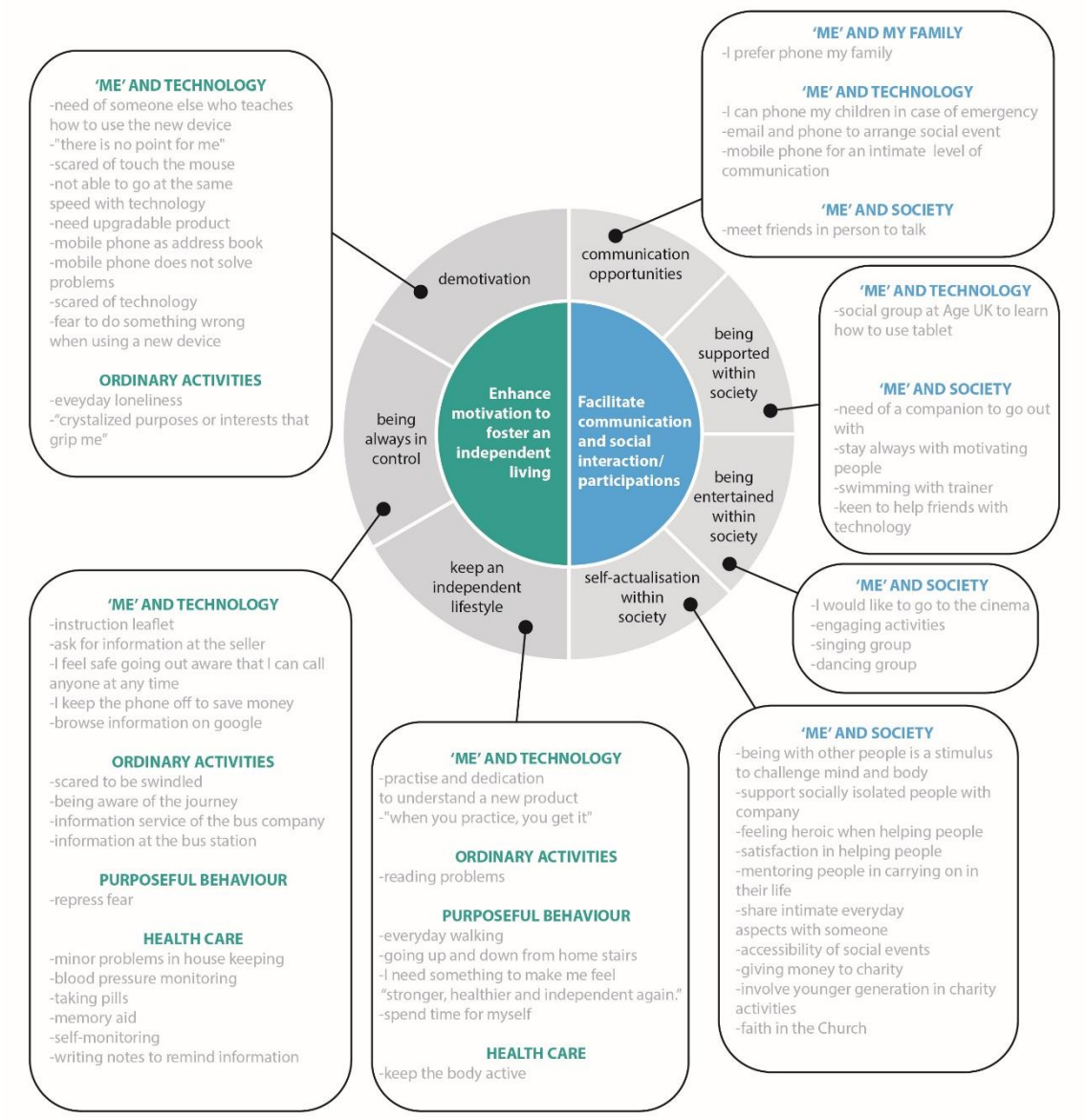


Fig. 4.18 Two critical areas identified, namely: enhance motivation to foster independent living and facilitate communication and social interaction/participation, along with codes that helped identified them

demonstrated by the volunteering activities reported. Paul (Male, 80-year-old), was glad to help lonely people by providing companionship; Patty (Female, 58-year-old) considered volunteering as "*a way to keep your mind always occupied in doing something and helps you to carry on in your life*". These activities, considered as strategies to stay active physically and mentally, gained a specific meaning when shared among peers. Sharing experiences and achievements was reported to nurture their self-confidence and motivation. Melanie (Female, 65-year-old) was proud of herself when she accomplished to send messages with the new mobile phone and she proudly shared her experience at the Age UK group while

Rob mentioned that he felt "*heroic*" when he was able to help with the integration of refugees in society.

These two critical areas identified are representatives of positive goals that older adults pursue to keep the control of their life. While facilitating communication could be seen a functional step, the defeat of loneliness towards an independent life can be achieved through the establishment of the emotional feeling of belonging and overall 'being a part of'. For the scope of this, the two critical areas were considered at the same level as they would all benefit from design interventions discussed in the next Chapter. Fig. 4.18 shows the two critical areas identified that constitute a design scenario supporting 'ageing in place' practices.

4.5 Summary of the Chapter

The study presented in this Chapter was based on the observation of targeted users through the adoption of two methods, Cultural Probe Kit and Focus Group, with the objective to get a deep understanding of the everyday experiences of older adults and the role that technology could eventually have to improve them. Through a convergent inductive approach, evidence are collected into two critical areas (*enhance motivation to foster an independent living* and *facilitate communication and social interaction/participation*) that will be used in this thesis as a constitute of one design scenario that addresses the identification of a hypothetical novel device for the ageing population. This will eventually allow the exploration of the embodied Smart Materials.

Empirical data gathered from both Cultural Probes Kit and Focus Group activities demonstrate how the main concern of the elders was to maintain their life at their home as long as possible without any specific constraints. What emerged from both studies was a general sense of reluctance in asking for someone else helps them to perform activities such as housekeeping and grocery shopping.

Physical impairments related to age concerns are often increased by a cognitive decline that restrains them to understand how to use technological devices that could help them to 'age in place'. Despite their interest and curiosity in purchasing new products, the growing loss of memory and the sensorial perception they experience does not help them in understanding how to use either a smartphone or a computer. As reported in the current findings, older adults are often worried about using technological products; they fear the unfamiliar and redundant interfaces whose languages are far from being understood. In

their houses, technological products are not relevant, having not being perceived as meaningful; even talking about technological products is for them unpleasant due to their unfamiliarity with the topic. Empirical data gathered from the Cultural Probes Kit highlighted that these products are deemed as intrusive and not part of the users' world. To preserve their daily routine and the sheltered environment of their houses, they preferred to be surrounded by familiar and fully understandable products to spend time with. This limitation increases the gap between the technological development of products and their adoption by this growing niche of the population.

From a behavioural point of view, the kind of support elderly people require is to push their mind and body through different daily activities and being included into a community where they can share their fears and achievements. The leisure activities they perform help them to spend time with and maintain their health status through an active lifestyle. A key role is played by trainers or caregivers, who encourage them to reach specific targets and motivate them to fill their days with social activities. Despite the lack of motivation often experienced, older adults appear willing to set goals to be achieved and share with friends such as attending a aerobics class, exercise every day and manage body's pain through a positive mental attitude. The need to fight loneliness is satisfied with social events, such as the visit of a relative or a friend. Nevertheless, a deep sense of sadness once those activities are finished was recorded. In this view, technology must be supportive in the way it keeps the user active and positive in sharing their achievements among peers and in the way, it guides this process through a simplified communication.

Chapter 5

Designing the Smart Radio, Image Schema elicitation through Smart Materials

5.1 Introduction

The generation of non-linguistic metaphors requires a transfer of information, or 'mapping', from a selected source domain towards features and attributes of a target domain, as discussed in Chapter 2, section 2.3.1. The mapping of knowledge has, therefore, the role to translate abstract information into physical representations. In Chapter 2 section 2.2, the importance of 'image schemas' to bridge the past and the new knowledge while generating 'metaphors' is clarified. Image schemas and their metaphorical extensions are demonstrated to yield more intuitive interactions (Hurtienne 2007), given that the retrieval of the prior knowledge through the identification and adoption of image schemas subconsciously recalls and uses stored information with a minimum workload on the cognitive processing capabilities (Mohs *et al.*, 2006). Therefore, in this thesis, the elicitation of image schemas as a starting point for the generation and subsequently evaluation of embodied SMs was required.

The categories identified, linked to the SMs properties by the interpretation of the designers, were adopted by the researcher to design a set of 32 signal/meaning associations composing the 'Designer Model of the Functions Representation', embedded into the prototype of a novel device. A clear focus was dedicated to the design of the set of signals (metaphorical and analogical) embodied by SMs properties and the process that led to their definition. Recalling the schema for physical mapping between source and the target domain (Fig. 2.1, Chapter 2), a clarification about the source domain selected (the abstract concept to be communicated), the target domain intended (the novel device) and the physical mapping of information between the two of them was provided. A Smart Radio

was designed considering the two critical areas identified in Chapter 4, characterising an 'ageing in place' design scenario:

1. *Enhance motivation to foster an independent living;*

2. *Facilitate the communication and social interaction/participation.*

This Chapter starts with a convergent investigation where designers were asked to adopt the dynamic properties of SMs to represent a given abstract concept. The image schemas elicited were clustered under the macro categories identified by previous studies conducted by Hurtienne and colleagues (Hurtienne, 2011, Hurtienne *et al.*, 2015), presented in Chapter 2, section 2.2.

5.2 The elicitation of Image Schemas with SMs workshop

The workshop conducted with designers was structured with the intent to explore opportunities for the SMs properties to serve as physical mapping and therefore represent abstract concepts into physical means. A full list of participants can be viewed in **Appendix I.1**. The process of generation of parallels between the two domains of information involved the intermediate identification of images schemas that will be further adopted to build upon the desired non-linguistic metaphors into a Smart Radio.

All participants completed the workshop and they found the activity informative and inspiring. Due to their interest toward SMs, participants appreciated the opportunity to interact with materials samples and several explanations of the properties of SMs were asked to the researcher. Mood boards produced (Fig. 3.3) to explain the sensorial possibilities of the SMs were constantly circulated within participants as a source of inspiration, along with posters summarising major properties of each family of SMs (**Appendix B**). Since no technical restrictions were demanded, participants were free to interpret the potentialities of SMs as they preferred. Therefore, they found the mood boards more inspiring and effective than posters. Only one participant (participant 9) did not complete the activity, leaving one family of SMs with no interpretation. Figures 5.1 and 5.2 depict participants during the workshop.

Fig. 5.1 Participants during the activity

Fig. 5.2 Two participants interacting with the *Rheological Changing Materials* sample

Designers associated the SMs properties in a diversified set of interpretations. Table 5.1 summarises the materials properties and their representations as interpreted by participants. The table explains the materials properties adopted and how they are interpreted to represent the 'high' and 'low' stimulation' statuses respectively. The nine templates collected can be viewed in **Appendix I.2** with a detailed explanation of each interpretation provided.

Table 5.1 representation of the 'arousal' level through SMs properties as interpreted by participants

	SMs interpretation			
	Light Emitting Materials	Changing Shape Materials	Rheological Changing Materials	Changing Colour Materials
Participant 1	The rhythm of light adopted (steady, blinking, pulsing). All surfaces are blinking: high stimulation); only one surface pulses: low stimulation status.	Changes in the path, direction and permeability (compulsion of the movement) adopted.	Changing volume: high stimulation; The pattern revealed: low stimulation.	Transparency adopted. A dense cube reacting at the user's touch (high stimulation) and a transparent cube showing the changing in the environmental condition (low stimulation).

Participant 2	Controlled light (spots) adopted. The number of dots lights up the cube communicating if it is full or not (more dots = cube full, fewer dots = cube empty).	Path (flat/crinkling) used. When flat, the shape is visible and ready to interact with. When folded, it communicates a sense of intimacy, as the objects needed to be stored.	Texture, spatiality adopted. Rheological Changing Materials dots can shape a Braille language to show information on either one (low stimulation) or more surfaces (high stimulation).	Colour coding.
Participant 3	The rhythm of light (blinking and pulsing) adopted. The uncontrolled variation of 'lights and dark' communicates high stimulation, while the predictable rhythm of lights is interpreted as low stimulation.	Expansion and contraction express high stimulation, dramatic changes. Path properties (pattern/random) show little changes in the shape like the cracking ground (low stimulation).	High spatiality and compulsion of the movement will reflect the high stimulation, while gentle outward movement (like ripples) will communicate low stimulation.	Brightness, lightness, saturation adopted. Alarming colours for high stimulation and shadow colours representing low stimulation.
Participant 4	Human shape and spots adopted. (Transparency, a defined human shape revealed for high stimulation, while a dense cube reflecting an abstract representation of the human body has been interpreted as low stimulation.	Enablement of changing volume through a complex path (high stimulation) and up/down movement (low stimulation).	Not clear	Not clear
Participant 5	Human pattern and spots. Transparency, a defined human shape revealed for high stimulation, while a dense cube with the	Path, pattern creation, nature-inspired shapes adopted that rise to communicate high stimulation.	Volume, adding/subtracting properties adopted. Changing shape can filter out lights and can represent the	Not clear.

	abstract colourful representation of the human body has been interpreted as low stimulation.		passing time through the size of the bubbles.	
Participant 6	Brightness, light intensity adopted. Strong and bright, high illuminance and powerful patterns (high stimulation); soft and less bright – but not dark – (low stimulation).	Permeability, Open/close properties adopted. Relatively closed = high stimulation, open = low stimulation.	Volume properties adopted. Changing the volume based on the level of arousal: high = high volume, low stimulation = lower volume.	Cold/warm on the surface to represent high stimulation and brighter colours to show low stimulation.
Participant 7	Rhythm, intensity adopted. Blinking light going to fade = low stimulation; the pattern revealed (high intensity representing a flow of sound) = high stimulation.	Path (linear/curved) adopted. The whole cube changing = high stimulation, one surface changing = low stimulation.	Form, pattern revealed. Bigger pattern = high stimulation, smaller pattern = low stimulation.	Brightness, high contrast of colours = high stimulation. Changing the hue of colours low stimulation effects can be created.
Participant 8	Intensity, pattern revealed gradually. High stimulation = the pattern is geometrical Low stimulation = floral pattern changing colours.	Direction (contraction/ expansion) Stable = high stimulation Crinkling = low stimulation (closing in intimacy).	Texture, viscosity property adopted. When completed, a pattern on the surface of the cube expresses the high stimulation status.	High contrast colours adopted. Uncomplete colourful patterns = low stimulation Fully coloured = high stimulation.
Participant 9	The rhythm of light adopted. Pulsing dots = low stimulation Blinking edges = high stimulation.	Permeability (open/close) adopted. One surface open = low stimulation All the surfaces open = high stimulation.	Not completed.	Warm/cold contrast adopted. Warm colours on the edges = high stimulation Cold colours in the inner part = low stimulation.

5.2.1 Identified Image Schemas

The interpretation of properties of *Light Emitting Materials* has found a significant application of the *bright/dark* image schema, where three participants out of nine (participant 2, 6 and 7) considered the transition from a bright to a dark status an efficient representation of the level of activity of the human body. Participant 7 described the importance of the variation of the 'on/off' status shaped by a blinking light where the 'off' status represents moments of low stimulation; similarly, participant 2 interpreted the low stimulation status with a lower intensity of the dots covering the outer surface of the cube. Participant 3 has further explored the *bright/dark* image schema, adding a timing sequence to the blinking lights. He represented the low stimulation status with a predictable rhythm of lights while their uncontrolled variation of bright and dark conveys the idea of a high stimulation, producing an example of *predictable/unpredictable* image schema. Two participants (1 and 9) interpreted the lights effect in terms of the spatiality effect they can create. Participants represented the low stimulation status with only one surface of the cube blinking (participant 1) and pulsing dots (participant 9); the higher stimulation status was embodied by the whole cube (participant 1) or just by its edges blinking (participant 9). This spatial interpretation of light can be categorised within the *part/whole* image schema. This image schema has been further interpreted as a 'pattern completion' by participant 8, where a geometrical pattern is gradually revealed to communicate high stimulation, while a floral pattern completion is adopted to convey a sense of low stimulation. Therefore, the *part/whole* image schema can be also interpreted as a *complete/incomplete* image schema, where the shape of the pattern itself helps providing the desired meaning. The cube has also been interpreted as a dense entity that can dynamically reveal its content; two participants (participants 4 and 5) embodied the *Light Emitting Materials* through the adoption of the *full/empty* image schema, where the transparency of the cube plays an important role. When a defined shape is revealed (such as the human body) the high stimulation concept is communicated; when the cube turns into a dense and opaque structure, no more details are shared to the observant conveying the concept of a low stimulation.

Changing Shape Materials were applied by two participants (participant 1 and 4) due to their ability to mimic the up/down movement of the human body. Participant 1 interpreted the *up/down* image schema in combination with the speed of the movement, when a slow/frantic change of height of the cube's faces could either represent a low or

high stimulation; participant 4 adopted the *up/down* image schema as a 'path' to be followed by the cube, that could be chaotic in regard of the high stimulation, and more linear to convey the idea of a low stimulation. Three participants (participant 2, 3 and 8) envisioned the *Changing Shape Materials* as able to embody the *big/small* image schema to communicate the human status selected. Specifically, participant 2 interpreted the transition from a flat to a crinkling shape a shift from a 'being available' status to a more intimate condition, representing a low stimulation. Participant 5 clearly adopted the image schema of *enablement* where the ability of the *Changing Shape Materials* of 'being active' is stressed by the creation of nature-inspired shapes; such as flowers, that repeatedly opened and closed to convey the idea on high and low stimulation. Three participants (participant 6, 7 and 9) interpreted the high/low stimulation through the *part/whole* image schema. For participant 6 the induced permeability of the cube can impede the visibility of communicating a sense of concentration of the connected user (high stimulation) and the possibility to 'see through' the cube delivers a sense of relaxation and 'openness'. Conversely, participant 9 interpreted the low stimulation as only one surface opening, while the high stimulation is created by a dynamic reaction of all the surfaces of the cube that flip up in the state of agitation. Similarly, for participants 7 when one surface bends a low stimulation status is communicated, while a higher sense of activity can be expressed by the whole surfaces changing their shape.

Rheological Changing Materials found multiple interpretations. Participant 1 proposed the *enablement* image schema, where the *Rheological Changing Materials* are adapted to activate different shapes on the cube's surfaces and therefore to communicate diversified information. Participants 8 and 7 embodied the properties of these materials through the *complete/incomplete* image schema, where the completion of a pattern indicates the accomplishment of an activity and, therefore, the high stimulation status. Participant 6 imagined the rheological changing properties as able to represent a dramatic change of volume of the content of the cube, that will visually increase and decrease representing the higher and lower stimulation; the *up/down* image schema seems appropriate to categorise this effect. These properties can also embody the *part/whole* image schema, as represented by Participant 2 where the material shapes a Braille language to show information on either one (low stimulation) or more than one surface (high stimulation). Participant 3 and 5 interpreted the viscosity properties of the materials with the ability to shift between a small, localised representation, to a more scattered and wide

configuration, defined as *small/big* image schema. Specifically, participant 3 interpreted the high spatiality of the patterns designed and the compulsion of the movement as a sense of high stimulation, while the gentle outward waves (like ripples) condensed on one surface of the cube communicate low stimulation.

Three participants out of nine (participant 2, 3 and 7) have adopted the *bright/dark* image schema to embody the properties of *Changing Colours Materials.* The variation of brightness of the surface of the cube has been interpreted to stimulate a clear sensorial reaction that can potentially represent high and low stimulating human activities. Specifically, participant 6 played with the texture of the cube to alternate two sets of intertwined colours that dynamically appear on the surface: cold/warm colours were adopted to communicate the high stimulation status, while brighter colours to convey a sense of low stimulation. Participant 1 adopted the *full/empty* image schema through changing colour properties of the materials to play with transparency effects, where information and details about the environment are shown or hidden. Participant 8 embodied the *complete/incomplete* image schema where colours are adopted to communicate the completion of a specified colourful pattern, resulting in high stimulation sensations. Finally, participant 9 adopted colours to distinguish between 'intimate activities' represented by cold colours depicted in the middle of the cube's surfaces and 'main activities' shaped with warm colours distributed on the edges of the cube; the image scheme adopted is the *centre/periphery*, where the spatial distinction between the two representations conveys the core difference between low and high stimulation. Table 5.2 shows the image schemas identified in association with the interpretation of the SMs properties to represent abstract concepts.

Table 5.2 List of Image-Schemas identified alongside suggestions to apply SMs properties to represent abstract concepts

Smart Materials	Image Schemas identified	Participants	Interpretation of SMs properties
Light Emitting Materials	*Part/whole*	1, 9	Light is adopted to light up one surface or the whole object to quantify the information shared
	Bright/dark	2	Brightness and light intensity are adopted in combination

		6 7	with light effects (blinking, fading light) to modulate the details to be shared
	Predictable/ unpredictable	3	Light effects (blinking and pulsing) can change in a controlled or uncontrolled manner to inform the quality of the message shared
	Full/empty	4 5	Lights confer a spatial dimension to product and they are modulated to make objects appear dense/translucent
	complete/ incomplete	8	Sequence of light is adopted to gradually complete a pattern and convey a sense of 'completeness'
Changing Shape Materials	*Up-down*	1 4	Shapes can 'rise and fall' mimicking the standing up of human behaviour and communicating a sense of excitement/relaxation
	Big/small	2 3 8	Volumes expand and contract communicating a sense of openness for the former and closeness, intimacy for the latter
	Enablement	5	Shapes reproduce nature-inspired mechanism (flowers blossoming) providing the sense of 'action'
	part/whole	6 7 9	Permeability (ability to 'being sought through') of objects is controlled, managing a number of details to be shared: more surfaces opened provide the idea of multiple actions, feelings, activities occurring
Rheological Changing Materials	*Enablement*	1	Changing volume is drastic and reveals a clear 'change of state'
	Part/Whole	2	One or more surfaces of the object are affected by the changing shape surface; more surfaces involved means more details shared and an overall state of activity, excitement communicated
	Big/small	5 3	Adding/subtracting volumes reflects the higher/lower stimulation communicated
	Up/down	6	Shapes can 'rise and fall' mimicking the standing up of human behaviour and communicating a sense of

			excitement/relaxation
	Complete/ incomplete	8	pattern completion to indicate the accomplishment of an activity
		7	Sequence of shapes is adopted to gradually complete a pattern and convey a sense of 'completeness'
Changing Colour Materials	*Full/empty*	1	Colours confer a spatial dimension to product and they are modulated to make objects appear dense/translucent
	Bright/dark	2	Brightness and colour intensity are adopted in combination to colour contrasts (warm/cold) to modulate the emotions to be shared
		3	
		7	
		6	
	Complete/ incomplete	8	Colours are adopted to gradually complete a pattern and convey a sense of 'completeness'
	Centre/ periphery	9	Colours enhance the spatiality of the object and give a sense of intimacy (cold colours in the inner part) and openness, stimulation (warm colours on the edges)

The workshop revealed a plethora of potential image schemas that can serve as a common ground of interpretation for a future embodiment of SMs. Interpretations in the application of SMs properties listed in Table 5.3 highlighted the potentiality of SMs to represent abstract concepts through their properties and unveiled opportunities in adopting those properties upon unconscious prior knowledge of the individual interacting with them. Data were gathered with no a specific application in mind, either context of use; therefore, it is required a contextualization of the findings into an existing device, with a further interpretation of the image schemas in light of the non-linguistic metaphors they help structure.

5.3 Designing the Smart Radio

As discussed in Chapter 2, technological products for the ageing population are dealing with the growing demand for providing motivating, engaging experiences, and allowing for a simplified communication within members of a family and peers, with the intent to enhance an overall sense of 'inclusion'. The two critical areas identified in the

previous Chapter, namely: *enhance motivation to foster an independent living* and *facilitate the communication and social interaction/participation,* are intended as a demand for a device able to shorten the physical and mental distance between older adults. The need for an intimate connection with friends and family has been considered as an incentive for feeling 'part of' a group and, therefore, supported in carrying on with their daily life. The concept of sharing among peers basic information about the activities older adults are doing appeared a promising contextualisation of the insights gained through the activity of observation of the targeted users.

The intention was to design a device that would be able to allow for social connectivity among peers whose crucial feature would be its interface, where the information would be displayed through the adoption of embodied SMs. Before explaining *how* non-metaphorical messages were embodied, it is important to explain *what* information was communicated, to further characterise the source domain of information, the abstract concept that was meant to be physically shaped and embodied into the novel device. Studies on communication appliances to support ageing in place (Riche and Mackay, 2010) suggest that communication appliances designed to share routine-bases information among peers enhance social connectivity alongside raise awareness of the activities performed and help to establish tight relationships among peers. In their investigation, Riche and Mackay (ibid.) demonstrate the need for older adults to establish interpersonal communication based on each other understanding the rhythm of their daily routine: older adults keep a strong sense of awareness of the daily activities performed by whom they are in touch with regularly. This information creates a deep sense of motivation, intimacy, emotional bond, and incentive for an active lifestyle. The adoption of the rhythm of daily activities has been demonstrated to provide benefits in terms of improving the awareness of their peers and act as a conversation trigger when unusual behavioural patterns where shared and observed.

Embracing this concept and extending the idea of a device that shares information about the level of activity of people connected, as seen in the image schema elicitation workshop, the 'source domain' of information selected considered all those everyday activities that older adults may be happy to share. In order to also communicate a sense of protection of personal data, the privacy of the people connected was preserved by sharing only 'lightweight' information about ordinary activities. Moreover, the information shared was kept purposely incomplete, and did not consider a transfer of personal data. Four

daily-based activities were identified to physically represent the rhythms of activities of the older adults. Table 5.3 shows the activities selected and their further categorisation into four corresponding representative statuses.

Table 5.3 list of the four everyday-base activities (first column) and the corresponding four human statuses (fourth column)

Daily activities	Level of stimulation	Level of relaxation	Status
Doing exercises			*Highly stimulated*
Housekeeping/gardening/cooking			*Stimulated, but quiet*
Eating/watching television/reading a book			*Active, but relaxed*
Sleeping			*Highly relaxed*

The four statuses identified were intended as simplified characterisations of the *rhythm* of the daily activities to be shared. Based on the three groups of metaphors, as introduced in Chapter 2, section 2.3, ontological metaphors seemed appropriate to represent the abstract concept of the *rhythm* of human activities with the structures and properties of the SMs. Therefore, the following ontological metaphors were considered:

- *The rhythm of a person (or the level of activity) is a 'changing light';*
- *The rhythm of a person (or the level of activity) is a 'changing shape';*
- *The rhythm of a person (or the level of activity) is a 'touching object';*
- *The rhythm of a person (or the level of activity) is a 'changing colour'.*

The second strand of information was required to confer the device with more credibility and privacy-setting features. Intended to be a communicative appliance, the new device included a feature that allowed each user to define whether he was off-line, receiving information, sending information or both sending and receiving information. The same setting was intended to be shared among peers and enrich the information communicated as 'availability of the user'. The acquisition of this information was considered the primary step when interacting with the device and, therefore, an important way to familiarise with the device itself. The intention of making this strand of information

of immediate interpretation was accomplished through the adoption of a symbolic representation of the four aforementioned statuses of the user using the Smart Radio. Having adopted the ontological metaphors for the representation of the human activities performed, the availability of the user was then embodied by analogical messages, where more immediate correlations were expected with less interpretation effort required by the user using the device. The actions of receiving and sending information were represented by 'ear' and 'lips' symbols; these two symbols were considered as highly descriptive of the actions of 'earing' and 'speaking' and therefore adopted to shape a complete set of functions and allow participants to familiarise themselves with the four families of SMs.

The intended 'target domain' of information, the device on which SMs were embodied, was considered as an interconnected device able to detect and share information about users using it. The intention was to design a radically new device able to share lightweight information between connected users in full respect of their privacy. In order to make participants of the study exclusively focused on the evaluation of the embodied SMs, the device was prototyped taking advantage of the expected familiarity participants already had with conventional products. According to the 'skeuomorphism' theory, objects resembling the design of similar artefacts in another material or technique help users familiarising with novel technologies (Page, T. 2014); as a result, a *radio* appeared to be a device whose components, command, functions were intuitive and familiar enough across generations and still pervasive in everyday lives in all its variations. The novel device designed, from now on called *'Smart Radio'* and depicted in figure 5.3, was an augmented radio-like device intended to support awareness of daily activities and to enhance lightweight communication among peers. The Smart Radio was designed to keep only the aesthetics of an analog radio; instead of broadcasting music, the device would hypothetically be able to share information between people wirelessly connected to each other. As depicted in Fig. 5.4, the Smart Radio would allow each user to

Fig. 5.3 Prototype of the Smart Radio

browse among a selection of friends/relatives (instead of radio stations) and receive information about their 'availability' and 'status updates'. Messages were displayed on the top surface of the Smart Radio and they were shaped by embodied analogical/metaphorical messages based on the four families of SMs identified.

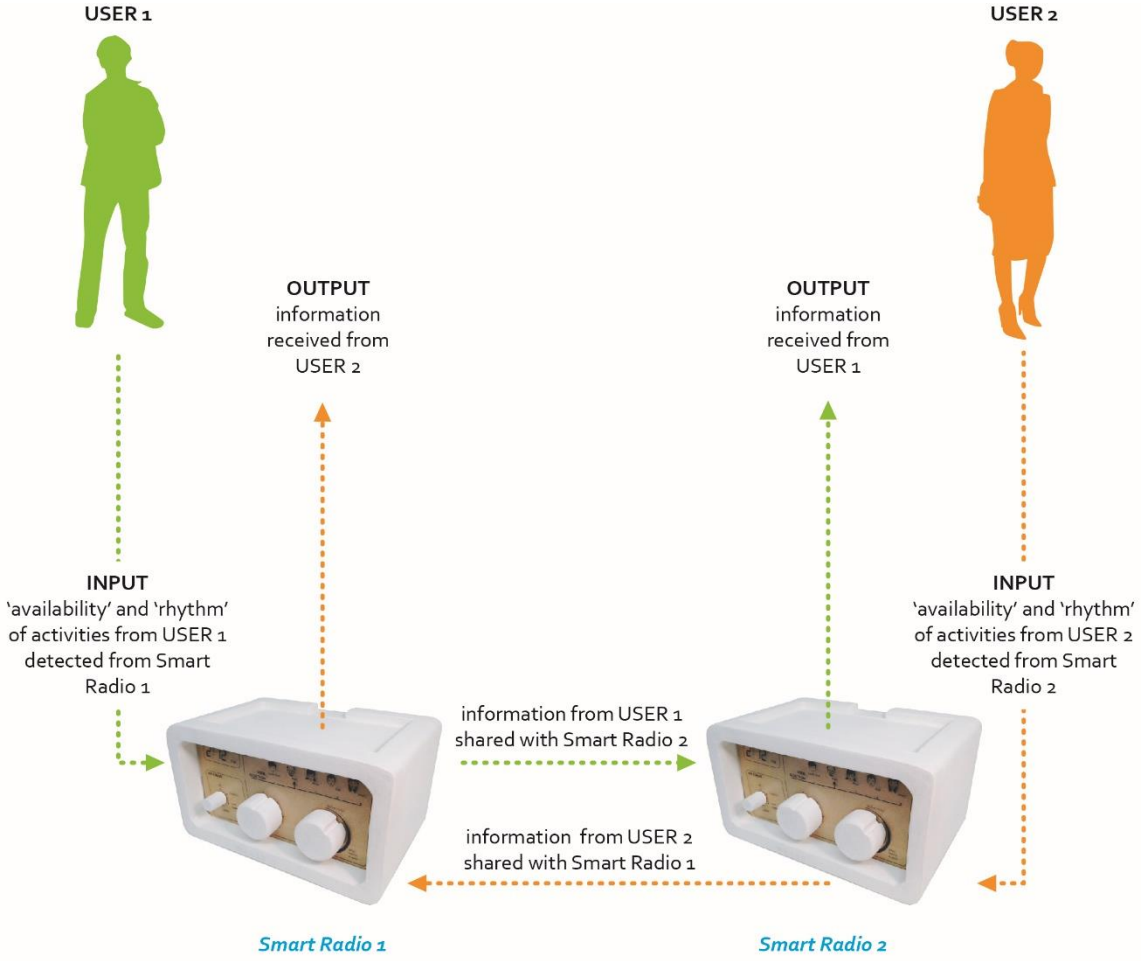


Fig. 5.4 Functionality of the Smart Radio. Each device detects information about the availability and the 'rhythm' of activity of the user using it and broadcast that information to a connected device

The device was intended to be a complementary tool connected to sensors and/or wearable devices able to detect and understand human behavioural patterns and convert the information into visible signals. The device, as used during the study, did not actually broadcast information, but was rather intended as a high-fidelity prototype specifically designed to simulate its functionality. The purpose of the investigation was not the prototype of a fully working device but rather to observe whether participants of the study found its use intuitive and understandable. Therefore, technical issues of the prototyping

were omitted. The use of the device and its functionality were simulated and not real, delegating future studies to the design of a more accurate device. In order to make the product as realistic as possible, privacy concerns were minimised considering the device as able to share only lightweight information, with a minimum amount of details shared.

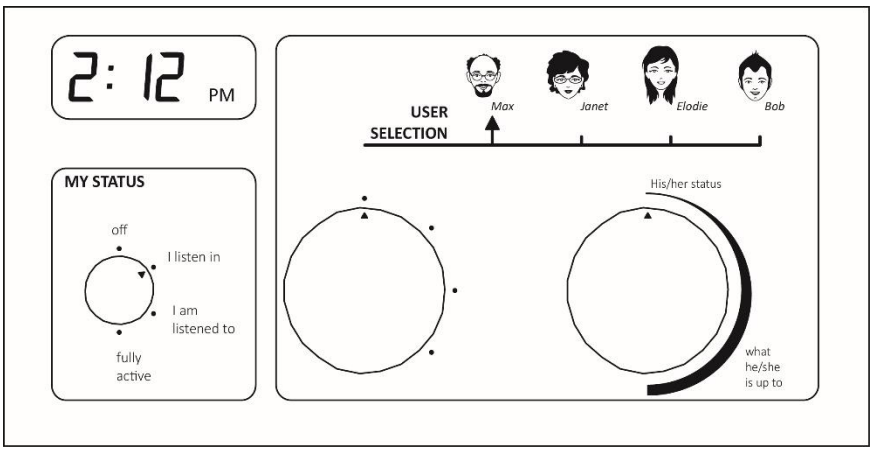


Fig. 5.5 Interface of the Smart Radio with the three knobs designed dedicated to set the status of the device (first knob on the left), the user to receive information from (second knob) and the amount of information to receive (third knob)

Fig. 5.5 shows the three knobs characterising the interface:

1. the first knob, identified by the 'my status' box, allowed the user to activate/deactivate the device (*off-line, I'm listening in, I'm listened to, fully active*);
2. the intermediate knob allowed the user to select among four users who he/she would be receiving information from;
3. the 'volume knob' was intended to allow the user to select the amount of details to receive: the minimum amount of information referred to what status the connected peers set on their device (availability), the maximum amount of information was about the level of activity of the peer connected, identified by the sign '*what he/she is up to*'.

5.3.1 Mapping the domains' attributes

The crucial feature of the Smart Radio was the display of the information broadcasted. Information was intended to be displayed on the top surface of the Smart Radio, in replacement of the conventional radio speakers. The four families of SMs identified were adopted to embody both analogical and metaphorical messages to provide sensorial stimuli. Analogical messages were selected to communicate the 'availability of the

user' from whom information is sought, represented by the dynamic on/off alternation of two symbols by means of 'ear' and 'lips' appearing on the surface of the radio:

- *Off line*: the connected device is off ('ear' and 'lips' symbols are off);
- *The user is listening in*: the connected device is receiving information (only 'ear' symbol is on)
- *The user can be listened to*: the connected device is sending information (only the 'lips' symbol is on)
- *Fully active*: the connected device is both sending and receiving information ('ear' and 'lips' symbols are on)

For example, considering the hypothesis of two connected users (user 1 and user 2) with two connected Smart Radios, if user 1 sets his device on 'I listen in', meaning that he/she wants to get information from user 2, the Smart Radio of user 2 will display the symbol of a 'ear', meaning that user 1 is listening in. For the purpose of ths application, SMs were adopted to enhance the appearance of symbols with the intent to have alternation of lighting symbols (*Light Emitting Materials*), movable flaps revealing underneath symbols (*Shape Changing Materials*), popping up and tangible symbols (*Rheological Changing Materials*) and appearing symbols with a traffic light colour coding (*Changing Colour Materials*).

Metaphorical messages were selected to communicate the four level of activities identified, representing the '*rhythm*' of the user connected. These were:

- *the connected user is highly stimulated* (e.g. doing exercises);
- *the connected user is stimulated but quiet* (e.g. housekeeping, gardening, cooking);
- *the connected user is active but relaxed* (e.g. eating, watching television, reading a book);
- *the connected user is highly relaxed* (e.g. sleeping).

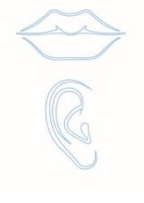
This group of information is supposed to be automatically detected by each Smart Radio. In a real application, the Smart radio will be coupled with a wristband or a wearable device able to detect the necessary information. The level of activity of the user with *Light*

Emitting Materials would be interpreted by the alternation of blinking and pulsing light communicating whether the user is exercising (fast blinking light), walking (slow blinking light), eating (fast pulsing light) or watching television/reading/sleeping (slow pulsing light). *Shape Changing Materials* helped to convey the idea of the actions performed by creating a sharp shape, a smooth shape, slow pace up/down movement and a double curled shape. *Rheological Changing Materials* built a haptic feedback with a series of popping up 'bubbles' each of those simulating the activities performed by the user connected, represented by a high contrast of shapes, high contrast of shape with a spatial gap in between bubbles, small bubbles with no contrast of shape, small bubbles with no contrast of shape with a spatial gap in between them. *Changing Colour Materials* displayed messages shaped by primary colours contrast, warm/cold colours contrast and contrast of saturation, dynamically playing with the hue and brightness of colours.

The resulting matrix of signals to be interpreted consisted of a set of 32 associations where signifiers (the SMs property adopted) and their signified designed by the researcher are based on design suggestions and image schemas emerging from the 'image schema elicitation with SMs' activity with designers, as described in section 5.1.3. The matrix was called '*Designer Model of the Function Representation*' and linked the signifiers (SMs) and signified (the activity of the user) in what the researcher interpreted as the best pair and was therefore used as an initial benchmark for the analysis of participants' interpretations, as further discussed in Chapter 6. A full description of the 32 messages is discussed in the following sections. A high level of interpretation of the image schemas identified in the workshop was required. Selection criteria for the adequate image schema to be used considered the accuracy in the description of each image schema as provided by designers and the number of designers adopting it at the workshop. Image schemas were only adopted as support of the non-linguistic metaphors, given that analogical messages are mere descriptive signals.

The definition of analogical messages with *Light Emitting Materials* communicating the 'availability of the user' connected, was represented by the on/off light effect to maximise the variation of the two symbols selected. A full description of the four analogical signals is presented in Table 5.4.

Table 5.4 Analogical messages embodied by *Light Emitting Materials*. The availability of the user is analogically represented by 'lips' (the user is speaking and can be listened to) and 'ear' (the user is listening in) symbols

	Signifiers	Signified
Signal 1.1		Both ear and lips symbols are on. The connected device is *fully active* and it is able to send (lips) and receive (ear) information.
Signal 1.2		Only the ear symbol is on; The connected device is *listening in*, so it is receiving information and it is not broadcasting his own personal information.
Signal 1.3		Both symbols are off. The connected device is *off line* and is not able to share information.
Signal 1.4		The lips symbol is on. The connected device *can be listened to*, meaning the connected user is sharing their information.

A detailed description of the four metaphorical signals is presented in Table 5.5. The five image-schemas that underpin the applications of *Light Emitting Materials,* as identified in Table 5.2, helped applying light effects to communicate the accomplishment of a given human activity through the completion of patterns (*part/whole, full/empty, complete/incomplete*) and the controlled variation of light and dark effects (*bright/dark, predictable/unpredictable*). Among the potential image schema identified the adoption of the *bright/dark* one, along with a *predictable* use of light, were adopted to embody *Light Emitting Materials*. While the first three (*part/whole, full/empty, complete/incomplete*) were used by designers of the workshop to communicate the completeness of a given activity, the last two (*bright/dark, predictable/unpredictable*) were interpreted to provide qualitative information about the activity performed and they were, therefore, considered worthy of a

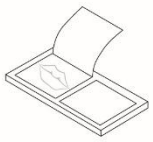
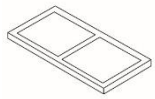
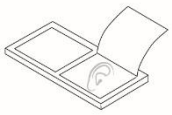
further investigation. In the Smart Radio, a fast sequence of bright and dark effects was adopted to represent the high stimulation status, while a slow pace, fading light was then used to communicate a relaxing status. The *predictability* of each light sequence was used to articulate the variation of bright and dark effects and further differentiate the four activities.

Table 5.5 Metaphorical messages embodied by *Light Emitting Materials*. Exploration of intensity and speed of light through the representation of four human levels of activity. Signals are displayed in the shape of an audio speaker

	Signifiers	Signified	Image Schema adopted
Signal 1.5		The shape of a speaker starts blinking at high rate continuously. The connected device communicates its user is *highly stimulated*.	*Bright/dark effects in a very fast, predictable sequence.*
Signal 1.6		The speaker shows a slow blinking light meaning the user using it is *stimulated but quiet*.	*Bright/dark effects in a fast, predictable sequence.*
Signal 1.7		Fast pulsing light is shown. The connected device communicates its user is *active but relaxed*.	*Bright/dark effects in a fast and smooth, predictable sequence.*
Signal 1.8		The speaker shows a slow pulsing light. The connected user is *highly relaxed*.	*Bright/dark effects in a slow and smooth predictable sequence.*

Table 5.6 shows the analogical messages representing the 'availability of the user' through *Changing Shape Materials*. These messages were represented through movable flaps revealing symbols underneath in sequence and maximising their corresponding meaning.

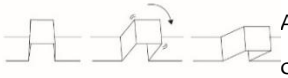
Table 5.6 Analogical messages embodied by *Changing Shape Materials* communicating the 'availability' of the connected user. Two movable flaps reveal underneath symbols and maximise their meaning

	Signifiers	Signified
Signal 2.1		Only the lips symbol is revealed. The connected device is broadcasting information (he *can be listened to*).
Signal 2.2		Both windows are closed. The connected device is *off line*.
Signal 2.3		The ear's flap lifts: the connected device is receiving information (user is *listening in*).
Signal 2.4		Both windows are open, meaning the connected device is both sending and receiving information (*fully active*).

The four signals embodying metaphors with the *Changing Shape Materials* are presented in Table 5.7. Four image schemas where identified for this family of SMs at the workshop: *up/down, big/small, enablement, part-whole*. Emphasis was put on the *big/small* image schema by three participants of the workshop out of nine in terms of expansion and contraction of the shape to alternate a sense of 'openness' and 'closeness' of the human status; likewise, three participants out of nine adopted the *part/whole* image schema as a permeability of the surface, interpreted as the ability of the surface to manage the amount of details to be shared through a total or partial enactment of its parts. All four image

schemas were applied in the prototype of the Smart Radio. Emphasis was put on the *big/small* and *part/whole* image schemas, being used by a relevant number of designers. These two image schemas are simultaneously applied to embody two signals, referring to the 'high stimulation' and 'stimulated, but quite'. Their combination was interpreted as one surface of the radio changing, meaning one activity to be shared, and big/small waves of the surfaced produced to clue about the quality of the information performed. The *up/down* image schema, although more appropriate when underpinning orientational metaphors, was adopted to visually represent the changing behavioural pattern of the user, moving from a status of excitement toward a more relaxed status, through a gentle up and down movement. Finally, the *enablement* image schema, adopted to reproduce nature-inspired mechanism, was adopted to embody the 'curl-up' effect and communicate a deep sense of intimacy of the user.

Table 5.7 Metaphorical messages embodied by *Changing Shape Materials* where four different shape configurations are explored

	Signifiers	Signified	Image Schema adopted
Signal 2.5		The whole upper surface of the Smart Radio starts crumpling to reach a sharp, folded shape communicating the connected user is *highly stimulated*.	*Big/small and part/whole.*
Signal 2.6		The upper surface of the Smart Radio starts to wavy gently, communicating that the connected user is *stimulated, but quiet*.	*Big/small and part/whole.*
Signal 2.7		A square element goes up/down gently. The connected user is *active but relaxed*.	*Up/down.*

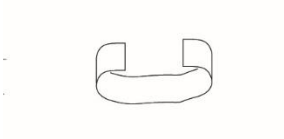
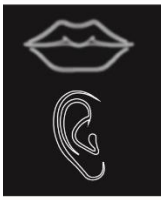
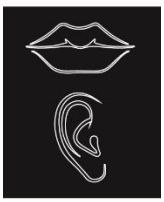
Signal 2.8		A double curled shape, reproducing a hug-style movement, shows an intimate status. The connected user is *highly relaxed*.	*Enablement.*

Table 5.8 shows the analogical messages with *Rheological Changing Materials*. The two symbols were made 'active' through the dynamic properties of the materials and a sequence of alternate haptic symbols created to communicate the availability of the user connected.

Table 5.8 Analogical messages embodied by *Rheological Changing Materials*. The changing viscosity of the material shape the appearance of the 'lips' and 'ear' symbols on the surface of the Smart Radio

	Signifiers	Signified
Signal 3.1		The surface preserves its liquid status without revealing any shape. The connected user is *off line*.
Signal 3.2		The fluid reveals the 'ear' symbol. The connected user is *listening in*.
Signal 3.3		The 'ear' symbol disappears and the 'lips' symbol is disclosed. The connected user can be *listened to*.
Signal 3.4		Both 'lips' and 'ear' symbols are shown, meaning that the connected user is *fully active*, both sending and receiving information.

Five image schemas were identified for this family of SMs at the workshop with designers: *enablement, part/whole, big/small, up/down, and complete/incomplete*. The *big/small* and *complete/incomplete* image schemas were both adopted by two participants respectively with a clear interpretation of the potentiality of the materials. While the *big/small* image schema referred to the adding/subtracting volumes that eventually represent the human behaviour, the *complete/incomplete* image schema suggested the adoption of a sequence of shapes providing the idea of a set of activities performed. The remaining three image schemas did not present a clear interpretation and insufficient clues were provided to further apply them. Therefore, the first two image schemas were applied in the Smart Radio. A sequence of 'popping up bubbles' was considered as an effective way to embody these two image schemas, where the size of each bubbles represented the intensity of the activity performed and the distance between bubbles represented the moment of 'rest' between activities. The four metaphorical messages, designed through the embodiment of the *big/small* and *complete/incomplete* image schemas, are presented in Table 5.9.

Table 5.9 Metaphorical messages embodied by *Rheological Changing Materials*. A set of four bubbles appear on the surface. Each bubble may have two different sizes, representing the activity the user is doing: small bubbles mean calming activity while big bubbles high effort actions. The distance between them represent a pause in the activity

	Signifiers	Signified	Image Schema adopted
Signal 3.5		Two groups of big/small bubbles are shown, with a space in between meaning a moment of rest between activities. The connected user is *stimulated but quiet*.	*Big/small* and *complete/incomplete.*
Signal 3.6		Four small bubbles of the same size appear on the surface of the Smart Radio. They are close to each other, with no difference in shape. The connected user is *active, but relaxed*.	*Big/small* and *complete/incomplete*

Signal 3.7		The appearing pattern has four bubbles of two different sizes and same distance in between each other. Each bubble represents the activity the user is doing and their variation means the connected user is *highly stimulated*.	*Big/small* and *complete/incomplete.*
Signal 3.8		Four small distant bubbles appear on the surface of the Smart Radio. The rhythm of the activity performed by the connected user is *highly relaxed.*	*Big/small* and *complete/incomplete.*

Table 5.10 shows the adoption of *Changing Colour Materials* as a colour coding scheme is applied to the 'ear' and 'lips' symbols. These symbols represent the 'availability of the user' connected in relation of the last family of SMs.

Table 5.10 Analogical messages embodied by *Changing Colour Materials* through the association of the colour coding to the 'lips' and the 'ear' symbols on the surface of the Smart Radio. Following the 'traffic light' code, green is used to signify the availability of the user, while red signifies that the user not being available

	Signifiers	Signified
Signal 4.1		Red 'lips' and green 'ear' symbols are shown, meaning the connected user is *listening in.*
Signal 4.2		Both 'lips' and 'ear' symbols are green. The connected user is *fully active*.

Signal 4.3		Green 'lips' symbol means the user *can be listened to* but the red 'ear' symbol states he is not available to receive any messages.
Signal 4.4		Both 'lips' and 'ear' symbols are red. The connected device is *off line*.

Table 5.11 shows the four metaphorical messages embodied by *Changing Colour Materials*. Findings of the 'image-schema elicitation with SMs' activity revealed the prevalence of *bright/dark* image schema in the embodiment of *Changing Colour Materials* (five participants out of nine) where variations of brightness and colour hues were adopted to represent different human activities. This image-schema was explored mainly in regards to adopting colour intensity changes and colour contrast pattern to modulate the sensorial stimuli desired to be evoked. In adoption of the solution proposed by the designers, the four metaphorical messages embodied with the *Changing Colour Materials* were designed adopting three colour contrasts, as shown in Table 5.11, intended as the closest solutions to the *bright/dark* image schema suggested, among the colour studies investigated by Itten (1975):

- *primary colour contrast*: formed by the juxtaposition of primary hues;
- *warm/cold colour contrast*: formed by the juxtaposition of hues considered 'warm' or 'cold';
- *contrast of saturation*: contrast between pure, intense colours and dull, diluted colours.

The contrast of saturation, involving the quality or hue of the colour, was adopted to shape two signals in order to understand whether participants could discriminate among patterns with different colour dilution. The remaining image schemas identified (*full/empty, complete/incomplete, centre/periphery*) did not appear strong enough to build any messages upon them.

Table 5.11 Metaphorical messages embodied by *Changing Colour Materials*. Colourful patterns are displayed adopting three different colour contrasts: primary colours, warm and cold and saturation contrast

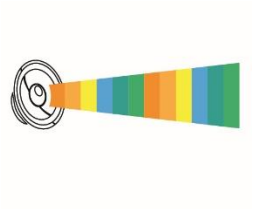
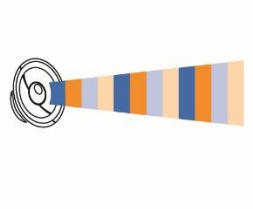
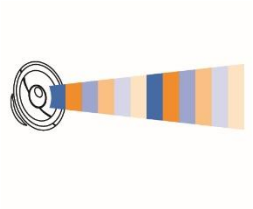
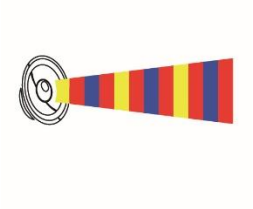
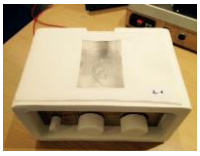
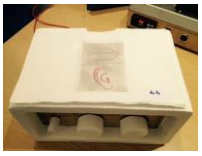
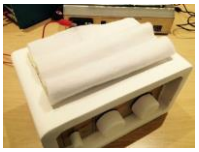
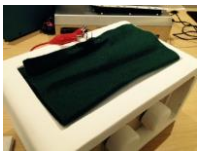
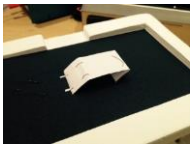
	Signifiers	Signified	Image Schema adopted
Signal 4.5		A harmonious sequence of colours creates a pattern where the contrast of warm and cold shades represents the activity of the connected user. He is stimulated but quiet.	*Bright/dark.*
Signal 4.6		Colours are displayed while their hue gradually fades away. This gradual loss of brightness is interpreted as a passage from a high level of activity to a calm and relaxed status. The sequence is divided into three parts, all with the same colour pattern and quality contrast, meaning the connected user is active, but relaxed.	*Bright/dark.*
Signal 4.7		In this pattern two colourful segments based on quality contrast are displayed. Compared to the previous message, the 4.7 shows the connected user is doing less actions and their general level of activity is highly relaxed.	*Bright/dark.*
Signal 4.8		Primary colours are drawn close at their highest level of brilliance. This contrast is extremely vivid and there are no intermediate hues from a colour to another. The connected user is highly stimulated.	*Bright/dark.*

Table 5.12 shows the way each signal was prototyped.

Table 5.12 List of pictures revealing how each signal was prototyped to be displayed on the top surface of the Smart Radio

Light Emitting Materials	Changing Shape Materials	Rheological Changing Materials	Changing Colour Materials
 Signal 1.1	 Signal 2.1	 Signal 3.1	 Signal 4.1
 Signal 1.2	 Signal 2.2	 Signal 3.2	 Signal 4.2
 Signal 1.3	 Signal 2.3	 Signal 3.3	 Signal 4.3
 Signal 1.4	 Signal 2.4	 Signal 3.4	 Signal 4.4
 Signal 1.5	 Signal 2.5	 Signal 3.5	 Signal 4.5
 Signal 1.6	 Signal 2.6	 Signal 3.6	 Signal 4.6
 Signal 1.7	 Signal 2.7	 Signal 3.7	 Signal 4.7

Signal 1.8

Signal 2.8

Signal 3.8

Signal 4.8

Signals embodying *Rheological Changing Materials* were prototyped through the adoption of a static maquette, as shown in the third column of table 5.12. In order to also provide a 'visual' representation of the changing haptic surface, signals were prototyped through a Ferrofluid liquid, a mineral oil with iron particles, manually activated by a series of magnets. The different effects produced were video recorded and shown during the evaluation phase of the Smart Radio to participants. The prototype using Ferrofluid as *Rheological Changing Material* was not directly shown to participants for health and safety concern. Ferrofluid is an oil-base material that causes indelible stains. Table 5.13 shows screenshots from the video recording the *Rheological Changing Materials* prototyped with Ferrofluid.

Table 5.13 Signals embodying the *Rheological Changing Materials* prototyped through the adoption of Ferrofluid liquid and magnets

Analogical messages				
	Signal 3.1	Signal 3.2	Signal 3.3	Signal 3.4
Metaphorical messages				
	Signal 3.5	Signal 3.6	Signal 3.7	Signal 3.8

5.4 Summary of the Chapter

In the 'image schema elicitation with SMs' activity a group of nine designers where asked to physically represent abstract concepts through the adoption of SMs properties as a first step toward the generation of embodying metaphors into a novel technological, communicative device. Findings of the activity are summarised as follows:

- Five image schemas where identified regarding *Light Emitting Materials*, namely: *part/whole, bright/dark, predictable/unpredictable, full/empty, complete/uncomplete* with a specific interest given to the *bright/dark* image schema;

- For the *Changing Shape Materials*, four image schemas where identified: *up/down, big/small, enablement, part-whole*;
- For the *Rheological Changing Materials*, five image schemas where adopted: *enablement, part/whole, big/small, up/down,* and *complete/incomplete*;
- A majority of *bright/dark* image schema in the embodiment of *Changing Colour Materials* are observed where variations of brightness and colour hues where adopted to represent different human activities.

The knowledge gained through the 'image schema elicitation with SMs' was adopted to demonstrate that SMs can easily embody non-linguistic metaphors when contextualised into a novel device. Among the plethora of potential dynamic effects achievable with SMs properties, this study demonstrated that the identification and adoption of image schemas helps bridging abstract concepts into a physical tangible domain in more systematic way. Designers interpreted the SMs properties in the way they made sense to them, based on their experiences and expertise on product design development. Although this could be seen as a limitation of the multitude of possibilities achievable though the embodiment of metaphors, the activity attempted an original interpretation of the SMs properties. A preliminary list of image schemas and SMs properties interpretation was delivered (Table 5.2). The guidelines identified were subsequently adopted to prioritise the available properties of SMs, understand their representative potentialities and design a novel communicative device. The target domain selected, by means of a Smart Radio, was designed in elaboration of the criteria identified in Chapter 4, where a design scenario for the ageing population was outlined.

Image schemas and SMs properties were further interpreted to provide a complete view of the design possibilities achievable and to shape a set of diversified messages. The process of interpretation led towards the definition of the 'Designer Model of the Function representation' by means of a set of 32 SMs output and their corresponding meanings, associating the embodied SMs (signifiers) to a specific activity of the user connected (signified) that is intended to be shared. The model was not considered as a set of 'right' associations, but rather an initial benchmark to evaluate responses of participants of the assessment study, as explained in the next chapter. Messages composing the model were divided into two categories, analogical messages and metaphorical messages, both embodied by the four families of SMs.

Chapter 6

Findings on the evaluation of the Smart Radio

6.1 Introduction

The study presented in this Chapter aims to describe the similarities and differences across generations in the evaluation of the Smart Radio with embodied SMs in accomplishment of the third objective of this thesis. Two age groups were considered in the main evaluation study: under-60-year-old and over-60-year-old participants; based on the assumption that older adults have a lower prior exposure to technology than younger adults, who typically show higher familiarity with technological products, as explained in Chapter 2 section 2.1. These two groups were considered as highly representative of two relevant extremes that need to be investigated. Based on the original version designed by Blackler *et al.* (2010), a Technology Familiarity (TF) questionnaire was adapted to radio related technologies and was used to confirm the appropriateness of samples adopted and test their level of prior exposure to such technologies. The TF questionnaire has been adopted in literature to select participants based on their familiarity with the technology (ibid.); given that the strategy adopted in this thesis does not consider a random participant sample selection, the TF questionnaire confirmed that the two groups selected had a different prior exposure to radio related technologies and their assessment of the Smart Radio was relevant to be considered. The TF questionnaire was a self-rating questionnaire asking participants how often they used certain technologies, and how much of the functionality of those products they used. The questionnaire was designed considering how often participants use a digital radio fully equipped, a standard portable digital radio, a radio embedded in other products (like in a smartphone) and a car radio. As conducted in the model of Blackler *et al.* (ibid.), prior exposure to conventional communication tools, such as smartphones, tablets, social networks, telecommunication applications (Skype, twitter) and personal computer was also probed. Participants were asked to estimate how often they use the listed products/technologies based on the following options: *every day,*

several times a week, once or twice a week, every few weeks, every few months, only ever used it once or twice, never. They were also asked how many features of the aforementioned products they commonly used. The optional answers are those present in the model of Blackler *et al.* (ibid.): *all the features, as many features you can figure out without manual, just enough features to get by with, your limited knowledge of the features limits your use of the product, none of the features – you don't use the product.* In the TF questionnaire, more exposure to, and knowledge of certain products specifically selected, produced a higher technology familiarity score. The maximum possible score on this questionnaire was 100 while the minimum was 0. The TF questionnaire can be viewed in **Appendix C**.

The questionnaire for the Smart Radio evaluation (**Appendix D**) included four evaluation sections, each of those referring to one of the family embodied SMs to be assessed, was amended upon observation emerged in the pilot study. In both studies, two independent variables were considered: the age of participants and their familiarity with the product category selected. The dependent variable referred to the ability of each participant to understand the Smart Radio and was supposed to be influenced by the independent variables. A pilot study served as an assessment of the protocol adopted and amendments were provided prior to the main study.

In order to fulfil the third objective of this thesis (*describe how older and younger adults understand and evaluate the novel smart object*), the following exploratory steps have been undertaken:

1. Verified the inverse correlation age/Technology Familiarity of each participant to validate the samples adopted;
2. Counted how many times the given answers 'matched' the 'Designer Model of the function representation' in both samples for each SMs family (shown through a percentage value);
3. Counted how many times the given answers 'matched' the 'Designer Model of the function representation' in both samples for each signal (shown through a percentage value);
4. As findings from the pilot study suggested, in the main study participants were asked to 'weight' their answers; the score recorded in each signal by both groups of participants was compared and discussed;

5. Described the overall understanding and evaluation of the Smart Radio from both samples;
6. Designed a comparison chart where differences and similarities in the evaluation of the embodied SMs are summarised (main study).

6.2 Pilot study

The pilot study was performed with the scope to evaluate the appropriateness of the protocol adopted, the response of the users and the completeness of data gathered.

A controlled environment was adopted to allow participants to be focused exclusively on the signals shown and prevent distractions or external stimuli. Each participant completed a consent form where they accepted to perform the test and to share their data for research purposes. Participants were assured no personal information would be used and that their names would be carefully replaced to protect their privacy. After a detailed explanation of the test and after the TF questionnaire was completed, participants received a full explanation of the Smart Radio with the possibility to ask questions to the researcher. In order to recreate a realistic situation, the prototype of the Smart Radio was used as it is a fully working device by turning the knobs simulating a realistic setting of its functionalities. Each participant found the Radio set on '*I listen in*' in the box '*My Status*' that hypothetically allowed them to get information from one of the users selected through the intermediate knob (Fig. 5.5, Chapter 5). Participants were individually asked to use the Smart Radio to select one of the four hypothetically connected users and receive messages from them in order to 'browse' the four families of SMs and their corresponding signals. The 32 signals were individually shown simulating the interaction with the Smart Radio and participants were invited to complete the Main Questionnaire matching each message with a potential meaning.

Once the questionnaire was completed, a brief qualitative evaluation by means of a semi-structured interview was conducted. Participants were encouraged to freely discuss the relevance of the study, their own concerns, and the strengths of the device. The following three questions were asked:

1) In your opinion, which of the signals you have identified better represent the availability of the user? Why?

2) In your opinion, which of the signals you have identified better represent what the user is up to? Why?

3) Finally, how do you think the Digital Radio should be improved in the future? Should it share different information? Should be the signals combined for a more meaningful signal to you?

The Pilot Study was performed as one-to-one test and participants were welcomed in a dedicated room at Brunel University London premises. Older adults were difficult to be recruited; they showed reluctance to come to Brunel University London and they were not comfortable with the idea of a one-to-one test. Although the researcher gave them a full explanation of the study and created an appropriate situation to welcome them, a low response from older adult's participants was recorded. Pictures 6.1 and 6.2, show respectively one younger adult and an older adult during the test.

Fig. 6.1 One of the younger adults' participant doing the test

Fig. 6.2 One of the older adults' participant doing the test

A full list of participants of the Pilot Study and the individual score recorded for the Technology Familiarity questionnaire can be seen in **Appendix L.1**.

Differences in the Technology Familiarity among age groups were conducted by comparing the means of the recorded values in both samples. Means values reported in Table 6.1 reveal a decreasing familiarity with digital radio-related products as the age of participants increases. By comparing the median value of the Technology Familiarity recorded in both age groups, an inverse correlation between age and the technology familiarity was observed: younger adults scored 63.4, while older adults scored 32.2.

Data collected have been subsequently analysed seeking for convergences and differences in the interpretation of the Smart Radio between the two age groups; the analysis of matches between the participants' answers collected and the 'Designer Model of the Functions Representation' was conducted. The aim of such analysis was not the identification of 'right' or 'wrong' answers, but rather a consistency among the

interpretation given. The analysis was conducted by comparing the percentage of the participants matching the 'Design Model of the Function Representation' with those who reported different associations, defined as 'scattered answers', and of those who reported other answers, as shown in **Appendix L.2**.

Table 6.1 Descriptive Statistics of the Technology Familiarity score for both samples of the Pilot Study

	N	Minimum Score	Maximum Score	**Mean**	Std. Deviation
Familiarity with the Product Category younger adults	13	42	78	**63.4**	11.2
Familiarity with the Product Category older adults	4	17	46	**32.2**	15.3

Each percentage was calculated by multiplying the sum of the recorded answers in each sub-group ('matches', 'scattered' and 'other' answers for both analogical and metaphorical messages) for 100, and dividing the resulting value for the maximum amount of answers potentially given by each group of participants in each SMs family. The following formula was adopted:

$$\%\ value = \frac{[(number\ of\ recorded\ answers\ in\ each\ sub\ group) * 100]}{maximum\ number\ of\ answers\ achievable\ for\ each\ SMs\ family}$$

The maximum score achievable for each SMs family was calculated by multiplying the number of participants for the maximum number of matches achievable in each SMs family. For example, in the younger adults group 13 participants are counted, meaning that they could potentially match 13 x 8 answers with a total of 104 achievable matches in each family of materials; the older adults group counted 4 participants, meaning a number of 32 (4 x 8) potential matches. Based on percentages observed, Table 6.2 highlights the first preliminary differences among samples.

Table 6.2 Preliminary similarities and differences among samples of the pilot study

Younger adults	Older adults
• Analogical messages count the highest scores in the *Changing Shape Materials* (44.2%) and a considerable higher score than metaphors in the remaining families of materials. *Light Emitting Materials* show a similar percentage of matches for both analogies and metaphors revealing the effectiveness of this means to convey messages for this group of participants.	• Analogical messages present higher scores than the metaphor in three families of materials (*Changing Shape, Rheological Changing* and *Changing Colour Materials*); *Changing Shape Materials* present the highest score of the analogical messages of the group (40.6%).
• Metaphorical messages undergo multiple interpretations; *Changing Shape* and *Rheological Changing materials* show the lowest number of matches with a wide gap of interpretation from the analogical messages of the same families of SMs. The family of SMs that efficiently shapes metaphorical messages with the highest percentage of matches recorded is the *Light Emitting Materials* (42.3%).	• Metaphorical messages have relatively low percentages in all families of SMs but *Changing Colour Materials* have the highest data scattered recorded and the lowest score of matches in both analogical and metaphorical messages. *Light Emitting Materials* and *Rheological Changing Materials* have the highest percentage of people matching the 'Designer Model of the Function Representation' (25% and 21.5% respectively).

Overall, it is observed that younger adults have better understood materials involving visual stimuli (*Light Emitting Materials* with 83.7% of matches and *Changing Colours Materials* with 68.3% of matches) while a different preference is observed for the older adults, where tangible and haptic stimuli were better understood (*Changing Shape Materials* with 59.4% matches and *Rheological Changing Materials* with 56.3 matches).

The third step of this analysis considered individual interpretations of each association signal/meaning. For each association signal/meaning, the percentage of matches, 'scattered data', and 'other' answers recorded were calculated. Each percentage has been calculated by dividing the sum of the recorded answers for each association signal/meaning listed in the 'Designer Model of the Function Representation' for the number of participants in each sample. The following formula was adopted:

$$\%\ value = \frac{[(number\ of\ recorded\ answers\ in\ each\ association) * 100]}{number\ of\ participants}$$

The complete list of percentages can be seen in **Appendix L.3.** The comparison of percentages of matches with the sum of 'scattered' and 'other' answers provided a further understanding of the interpretational patterns adopted by the two age groups. Table 6.3 lists the differences found.

Table 6.3 Main differences recorded between the two groups of participants of the Pilot Study regarding each association signal/meaning

Younger adults	Older adults
• The percentage of younger adults that matched the 'Designer Model of the Function Representation' is higher than the scattered answers in 26 out of 32 signals.	• The percentage of people matching the 'Designer Model of the Function Representation' was higher than the percentage of people recording scattered answers for 20 signals out of 32, highlighting a lower understandability of the Smart Radio from the older adults, compared to younger adults.
• Six metaphorical messages (2.7, 2.8 of the *Changing Shape Materials,* 3.5, 3.7 of the *Rheological Changing Materials* and 4.5, 4.7 of the *Changing Colour Materials*) were associated with different meanings, not matching the initial benchmark of associations (highlighted with green colour in **Annex L.3**).	• Twelve signals were not aligned with the interpretation of the initial benchmark of the 'Designer Model of the Function Representation', reporting a higher percentage of 'scattered' and 'other' answers. These signals were both analogical (signal 1.1 of the *Light Emitting Materials* and 4.1, 4.2, 4.3 of the *Changing Colour Materials*) and metaphorical (1.6, 1.7 of the *Light Emitting Materials*, 2.7, 2.8 of the *Changing Shape Materials,* 3.8 of the *Rheological Changing Materials* and *4.5, 4.6, 4.7 of the Changing Colours Materials*).

- *Light Emitting Materials* is the only SMs family that whose assessment matched the 'Designer Model of the Function Representation' on all 8 associations, with a low percentage of scattered answers.
- *Rheological Changing Materials* presented only one misunderstood signal, while the *Changing Colour Materials* presented the highest percentage of scattered answers.

In order to provide a clarification of the data collected, feedback from participants, collected through the open questions at the end of each questionnaire, were analysed and clustered into heuristics that facilitate the understanding of preferences of each sample. An extended version of the comments recorded from the participants can be found in **Appendix L.4**.

Younger adults showed a better understanding of the analogical above the metaphorical messages, matching the 'Designer Model of the Function Representation' in all the four SMs families presented. Metaphorical messages have four misunderstood signals in three families out of four (*Changing Shape Materials*, *Rheological Changing Materials, and Changing Colour Materials*). The highest score of matches was recorded for two families of SMs, *Light Emitting* and *Changing Colour Materials*, demonstrating how younger adults prefer visual means of interaction due to the familiarity they have with those signals, as declared by James (male, 22-year-old) and Andrea (male, 24-year-old). However, they clearly appreciated the *"surprise and decorative effects"* (Liu, female, 26-year-old) shaped by the *Rheological Changing Materials* and their ability to recreate an appealing and entertaining movement (Bilal, male, 29-year-old). Nonetheless, these signals also created ambiguity and confusion, leading the participants to a not intuitive, nor immediate, interpretation of the signals. In order to improve the metaphorical application of SMs, participants asked for a simplified application of each material (Richard, male, 22-year-old and Andrea, male, 24-year-old,) where only one code of interpretation is adopted in association with a single SMs property (Victor, male, 22-year-old). Moreover, an interesting point emerged regarding the potential combination of multiple means to help the user building a clear idea of the information provided. While Merzad (male, 25 -year-old) asked for a combination of two signals he found intuitive, such as *Light Emitting* and *Changing Colours Materials*, Victor proposed a combination of a well-established means, like the *Light Emitting Materials*, with a novel one, like the *Rheological Changing Materials* to cover both visual and tangible effects. For this purpose, Bilal (male, 29-year-old), Priya

(female, 27-year-old) and Liu (female, 26-year-old), wished for the combination of decorative and appealing means like *Rheological Changing Materials*, with clear and effective signals like *Light Emitting Materials*, will enrich the device of the entertainment factors resulting in a rich interaction.

Older adults provided a different interpretation of the signals shown. Analogical messages were better understood than metaphorical messages in three out of four families of SMs (*Changing Shape, Rheological Changing* and *Changing Colour Materials*), while metaphorical messages for the *Light Emitting Materials* showed a high percentage of people who matched the 'Designer Model of the Function Representation' (see **Appendix L.2**). The family of *Changing Shape Materials* is the group that recorded the higher percentage of people matching the 'Designer Model of the Function Representation' highlighting a preference for movable means of interaction. Hanna (female, 76-year-old) explained that *Changing Shape Materials* can convey an immediate message because of the simplicity of their actions. Cheryl (female, 76-year-old) appreciated the immediateness of the *Light Emitting Materials* but she appeared confused by the *Rheological Changing Materials*. Hanna appreciated the effects created by the *Changing Shape Materials* and invited the researcher to further implement the signal to build a "*robust meaning of each signal*", potentially playing with the heights of the changing surfaces. For these participants, *Changing Colours* had a very disappointing result. Hanna said that *Colour Changing Materials* appear really confusing in their changing patterns, especially signals 4.6 and 4.7 where differences between them are not perceived. Cheryl claimed that *Changing Colours* alone are not intuitive and their combination with *Light Emitting Materials* will enhance their strength. The following heuristics summarise the differences and similarities in the interpretation of the Smart Radio as highlighted in the pilot study.

1. Analogical messages were perceived to be more immediate and intuitive than metaphorical messages for both age groups investigated;

2. Younger adults found 'visual' means such as *Light Emitting* and *Changing Colour Materials* more intuitive;

3. Older adults expressed curiosity towards the *Rheological Changing Materials* and an overall good understanding of both analogical/metaphorical messages when shaped with *Changing Shape Materials;*

4. Simplicity should be always fostered through the adoption of materials properties and one code of interpretation (e.g. only different sizes for the *Rheological Changing Materials* and warm/cold colours for the *Colour Changing Materials* signifying the activity/relaxation status of the connected user);

5. Opportunities in combining multiple means together must be explored with the intent to enhance signals and simultaneously shape pleasant effects.

In addition, the following points emerged in regards to the functionality of the Smart Radio:

1. The adoption of 'symbols' is based on the cultural background of each user and they must be carefully designed to be understood;

2. Metaphorical messages are more effective when they stimulate the human senses;

3. The introduction of health and safety parameters would be appreciated, especially in consideration of the opportunity of SMs to mimic human behaviour (such as heart rate with *Light Emitting Materials* and human movement with *Rheological Changing Materials* and *Changing Shape Materials*).

The overall procedure of the Pilot Study presented some aspects that needed to be amended, in order to promote an efficient data collection. The changes in the evaluation protocol are explained in the next paragraph.

6.3 Amendments to the pilot study evaluation protocol

Although preliminary results are promising, data analysis of the older adults group revealed difficulties in interpretation due to the low number of participants. Neither clear differences nor similarities in the interpretation were observed, but rather a trend of interpretation that can be hardly generalised for further studies. Hence, amendments in the procedure were provided to further investigate the topic.

1. A representative sample of younger and older adults was considered for a preliminary interpretation, where younger adults have people aged less than 30 years old and older adults were participants aged over 70 years old. Being aware of the limitation occurring with a strict selection of participants, the main study considered a broader number of participants embracing multiple age brackets, divided by the age threshold of 60 years old. Although the definition of 'elderly' is arbitrary and mainly refers to the age at

which pension benefits are received, it is a common belief that in western countries, 60+ years is the cut-off referring to older population (World Health Organization WHO, 2012) and justifies the selection of two sample having the 60 years old as a divide between the two. Furthermore, the low number of participants and their inconsistent distribution between the two age brackets investigated in the pilot study (n=13 and n=4) posed the question of the reliability of the study conducted. Two equally distributed groups were therefore considered in the main evaluation study with the intent to provide robust data and acquire comparable scores.

2. Secondly, the pilot study revealed that embodied SMs were not equally perceived as 'intuitive' by all participants and the matching with the 'Designer Model of the Function Representation' alone does not offer any qualitative value of these differences. Several pitfalls in the interpretation of metaphors can threaten the understandability of the Smart Radio; users might miss the intended metaphor, the inferences designed by the designer might not be the ones intended, users can build an 'unintended' metaphor. It was, therefore, necessary to further investigate how the interpretation of the proposed signals varies among individuals. Each SMs family must also be individually analysed,understanding how participants metaphorically depicted the signals in their minds and the strength perceived by each association. The main evaluation study was therefore conducted considering a 1-to-3 ratio for each association signal-meaning. Participants were asked to identify where the association meaning/signal was:
    - 'Strong, intuitive and immediate' (represented by a score of 3);
    - 'Average' (represented by a score of 2), meaning that the participant sees the meaning of the signals but its intuitiveness is not clear;
    - 'Weak, non-intuitive perception of the association' (represented by a score of 1).
3. Lastly, another relevant amended aspect of the protocol of the pilot study was that each signal was shown individually asking the participants to assess it at a glance. Participants reported how difficult the interpretation of each signal was without a clear overview of all the signals together; the main study was therefore conducted giving the opportunity to browse all the analogical and metaphorical signals for each family of SMs at first and then attempt their assessment.

6.4 Main evaluation study

Participants of the main evaluation study were conveniently selected to fill two age groups: under-60-year-old and over-60-year-old participants. A heterogeneous sample of

population was investigated to infer commonalities and differences through the analysis of the given answers. In order to reach a relevant number of over-60-year-old participants the test was also performed at a nursing house in Uxbridge (London), at the Open School East in Hackney (London) and at the Uxbridge Library. In these occasions, the same lab setting was reproduced and participants were briefed all together. To guarantee the full respect of the study protocol and rigour, each participant was asked to independently complete the study, with no opportunity to talk with other members of the group. Participants were further asked to individually answer the three open questions at the end of each questionnaire. This different procedure was necessary due to the reluctance shown by over-60-year-old people to leave their home premises. Their lack of motivation to participate in the study was due to their limited amount of time they were willing to dedicate to the study as they preferred to engage in social activities instead. A £5 amazon voucher was given to each participant to thank them for their time and input. Pictures 6.3 and 6.4 show two over-60-year-old participant doing the study respectively in a Nursing Home in Uxbridge (London) and at the Uxbridge Library (London).

Fig. 6.3 One of the over-60 years old participant doing the test at the Nursing Home in Uxbridge (London)

Fig. 6.4 One of the over-60 years old participant doing the test at the Uxbridge Library (London)

Over-60-year-old participants responded positively to the study and an equal number of participants was reached in both samples. All participants completed the study; although their interest and dedication, older adults appeared to be shyer and less talkative than younger adults when discussing their feedback. Fewer information were recorded than under-60-year-old participants. The final list of the 62 participants can be viewed in **Appendix M.1** along with their age and their self-recorded Technology Familiarity score.

Descriptive statistics of the Technology Familiarity differences among the two samples is shown in Table 6.4.

Table 6.4 Descriptive statistics of the Age and the Technology Familiarity scores for both samples of the Main Study

	N	Minimum	Maximum	**Mean**	Std. Deviation	Skewness		Kurtosis	
	Statistic	*Statistic*	*Statistic*	***Statistic***	*Statistic*	*Statistic*	*Std. Error*	*Statistic*	*Std. Error*
Age	62	21	84	**53.6**	20.380	-.237	.304	-1.544	.599
Technology Familiarity	62	0	92	**49.9**	21.718	-.529	.304	-.454	.599
Valid N (listwise)	62								

Negative values of Kurtosis for both variables (age and Technology Familiarity score) suggest that data do not follow a normal distribution. Therefore, a non-parametric test was chosen to further describe the inverse correlation between the two variables. A Spearman's correlation was run to determine the relationship between the 62 participants of the main study and their Technology Familiarity score. As shown in Table 6.5, there is a negative correlation between age and Technology Familiairty value, which was statistically significant (r = - .610, p = .0) explaining the inverse correlation between the age and the TF score also for the samples selected for the main evaluation study and related to the product category of the Smart Radio.

The evaluation of the results from the Main Questionnaire has been primarily conducted with non-parametric statistical methods, considering the variables of the study (matches with the 'Designer Model of the Function Representation', 'scattered' answers, 'other' answers and 1-3 ratio) as categorical data.

Table 6.5 Spearman's rho correlation test between the age of the 62 participants of the main study and their Technology Familiarity score recorded

			Age	Technology Familiarity
Spearman's rho	Age	Correlation Coefficient	1.000	**-.610****
		Sig. (1-tailed)	.	.000
		N	62	62
	Technology Familiarity	Correlation Coefficient	**-.610****	1.000
		Sig. (1-tailed)	.000	.
		N	62	62

**. Correlation is significant at the 0.01 level (1-tailed).

Before embarking on the qualitative interpretation of the findings, the Mann-Whitney U test is conducted to define whether the distribution of matches with the 'Designer Model of the Function Representation', 'scattered' and 'other' answers recorded in each family of SMs are different across samples. The test was conducted in order to understand how the independent variable (the age of participants) has an influence on the dependent variable (answers recorded in each SMs family). The null hypothesys claims that the two distributions, those provided by the two age groups, are equal, at p = .05. The Mann-Whitney U test conducted on the answers given by the both samples in each family of SMs, reveals that the null hypothesis cannot be rejected therefore, there is no evidence to support a statistical difference between the two distributions in all the families of SMs investigated:

- **Light Emitting Materials**: matches ($U = 436.5$, $N_1 = 31$, $N_2 = 31$, $p = .522$, two tailed), 'scattered' ($U = 375$, $N_1 = 31$, $N_2 = 31$, $p = .116$, two tailed) and 'other' answers ($U = 435$, $N_1 = 31$, $N_2 = 31$, $p = .365$, two tailed);
- **Changing Shape Materials**: matches ($U = 417.5$, $N_1 = 31$, $N_2 = 31$, $p = .366$, two tailed), 'scattered' ($U = 399$, $N_1 = 31$, $N_2 = 31$, $p = .241$, two tailed) and 'others' answers ($U = 476.6$, $N_1 = 31$, $N_2 = 31$, $p = .913$, two tailed);

- **Rheological Changing Materials**: matches ($U = 480.5$, $N1 = 31$, $N2 = 31$, $p = 1.0$, two tailed), 'scattered' ($U = 454.5$, $N1 = 31$, $N2 = 31$, $p = .710$, two tailed) and 'others' answers ($U = 465.$, $N1 = 31$, $N2 = 31$, $p = .743$, two tailed);
- **Changing Colour Materials**: matches ($U = 396.0$, $N1 = 31$, $N2 = 31$, $p = .227$, two tailed), 'scattered' ($U = 439$, $N1 = 31$, $N2 = 31$, $p = .553$, two tailed) and 'others' answers ($U = 432.5$, $N1 = 31$, $N2 = 31$, $p = .219$, two tailed).

Detailed results from the Mann-Whitney U test can be observed in **Appendix M.2**.

As conducted for the pilot evaluation study, the answers recorded were converted into percentage values, as shown in **Appendix M.3**, to qualitatively observe subtle differences in the interpretation among age groups. Similarly to the pilot study, each percentage was calculated by multiplying the sum of the recorded answers in each subgroup ('matches', 'scattered' and 'other' answers in both analogical and metaphorical sub-groups) for 100, and by dividing the resulting value for the maximum amount of answers potentially given by each group of participants in each SMs family. Both age groups count 31 participants, meaning that they could potentially match 31 x 8 answers with a total of 248 achievable matches in each family of SMs. Table 6.6 shows the preliminary similarities and differences in the interpretation of the Smart Radio among the sample observed through the analysis of percentages of the given answers.

Table 6.6 Similarities and differences in the interpretation of each family of SMs by both age groups of the main study

Under-60-year-old participants	Over-60-year-old participants
• Analogical messages were always better understood than metaphorical messages.	• Analogical messages are better understood than metaphorical messages in three SMs families out of four (*Changing Shape Materials*, *Rheological Changing Materials*, and *Changing Colour Materials*).
• *Changing Shape Materials* count the highest percentage of people matching analogical messages (44.8%); *Changing Colour Materials* show the lowest percentage of matches for	• *Rheological Changing Materials* count the highest percentage of people matching analogical messages (40.3%), whilst the lowest is recorded for the *Changing Colour*

the analogical messages (37.5%).

- Metaphorical messages have the highest number of matches recorded for the *Light Emitting Materials* (40.3%), while the lowest number is observed for the *Rheological Changing Materials* (18.1%).

Materials (34.7%).

- *Light Emitting Materials* have the highest percentage recorded in the metaphorical messages (42.3%) and *Rheological Changing Materials* the lowest (19.4%).

Overall, it is possible to observe that:

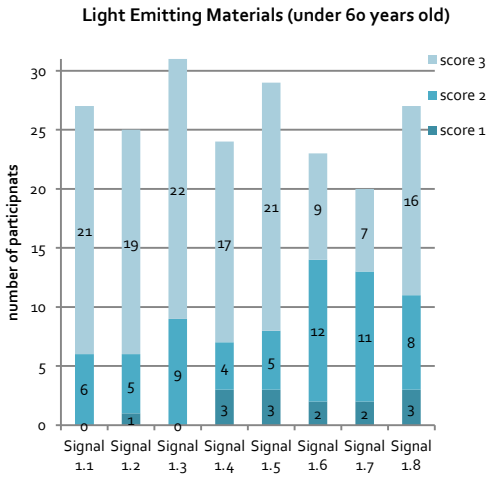
- The percentage of the participants who matched the 'Designer Model of the Function Representation' is always higher than both 'scattered' and 'other' answers;
- Analogical messages are better understood when shaped with tangible and 'moving' means (*Changing Shape Materials* and *Rheological Changing Materials*) in both age groups;
- Metaphorical messages appear to be difficult to be interpreted by participants when shaped by *Rheological Changing Materials* in both age groups.

The percentages of 'matches' with the 'Designer Model of the Function Representation', 'scattered', 'other' answers as provided for each signal shown are analysed to further highlight differences and similarities in the interpretation of the Smart Radio among the two age groups. Each percentage was calculated by multiplying the unit value of recorded answers in each signal by 100 and dividing the resulting value by the maximum amount of answers potentially given by each group of participants in that specific association. Both samples count 31 participants, meaning that they could potentially match 31 answers in each association signal/meaning. Matches were compared to the total amount of 'scattered' and 'other' answers. A detailed list of percentages can be observed in **Appendix M.3**. This analysis reveals that a higher number of both 'scattered' and 'other' answers than matches is reported, in relation to seven metaphorical messages for the under-60-year-old and five metaphorical messages for the over-60-years-old. The under-60-year-old participants experienced some difficulties while interpreting two signals of the *Shape Changing Materials* (signals 2.7 and 2.8), three signals of the *Rheological Changing Materials* (signals 3.5, 3.6 and 3.7), two messages of the *Changing Colour Materials* (signals 4.5 and 4.6). Over-60-year-old participants could not understand at full two signals of the *Changing Shape Materials* (signals 2.7 and 2.8), three signals of the *Rheological Changing Materials* (signals 3.5, 3.6 and 3.7). Interestingly, all the five misinterpreted

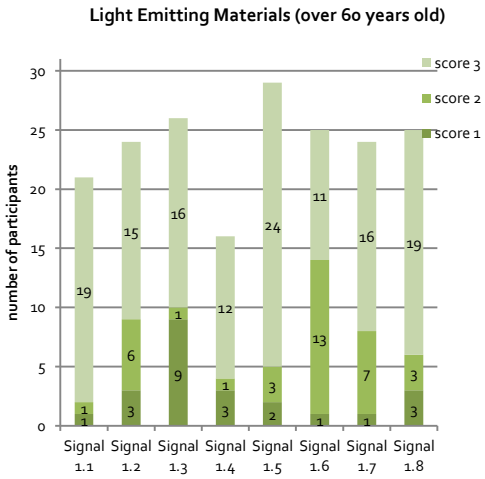
messages recorded among the over-60-year-old group are the same of those counted in the under-60-year-old group.

In order to further understand how differences in age affect the intuitiveness of each signal of the Smart Radio, as informed by the Pilot Study, participants were asked to 'score' their signal/meaning preferences, on a scale of 1 to 3, where 1 is 'not intuitive, and 3 is 'very powerful and intuitive'. Answers were separately recorded in a dedicated table, shown in **Appendix M.5**. With the intent of understanding whether the ratings of under-60-year-old participants are significantly different than the ratings of the over-60-year-old participant group, a second Mann-Whitney U test is conducted. The age of each sample was used as an independent variable while scores recorded in each signal as dependent variables. The null hypothesis considered in this test expresses that the two distributions compared are equal, at p = .05. The Mann-Whitney U test revealed that the null hypothesis cannot be rejected for 25 signals out of 32, where the Sig. (2-tailed) found is bigger than 0.05. Conversely, evidence to support a different distribution of ratings between the two samples is observed in seven signals out of 32: Signal 1.3 (U = 324.5, N1 = 31, N2 = 31, p = 0.012, two-tailed); Signal 1.7 (U = 341, N1 = 31, N2 = 31, p = 0.038, two-tailed); Signal 2.2 (U = 327.5, N1 = 31, N2 = 31, p = 0.008, two-tailed); Signal 4.5 (U = 314.5, N1 = 31, N2 = 31, p = 0.009, two-tailed); Signal 4.6 (U = 328, N1 = 31, N2 = 31, p = 0.023, two-tailed); Signal 4.7 (U = 334.5, N1 = 31, N2 = 31, p = 0.031, two-tailed); Signal 4.8 (U = 229, N1 = 31, N2 = 31, p = .00, two tailed). A detailed table with the findings from the Mann-Whitney U test is shown in **Appendix M.6**.

In order to qualitatively display and analyse the ratings attributed to each signal/meaning association as provided, a set of eight graphs is produced. Each graph displays the distributions of the ratings in each SMs family, for the two groups respectively. The following four descriptions are provided:

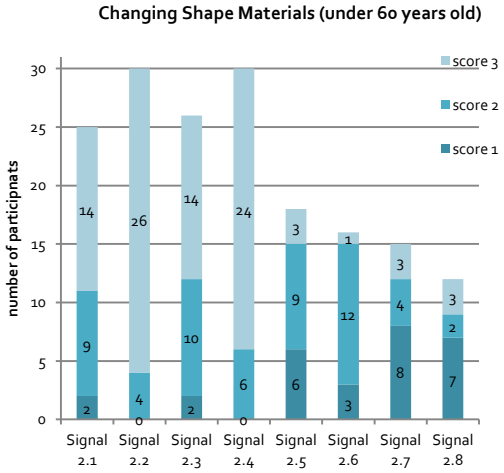


Graph 6.1 Number of under-60 years old participants attributing the score '1', '2' and '3' in each signal of *Light Emitting Materials*

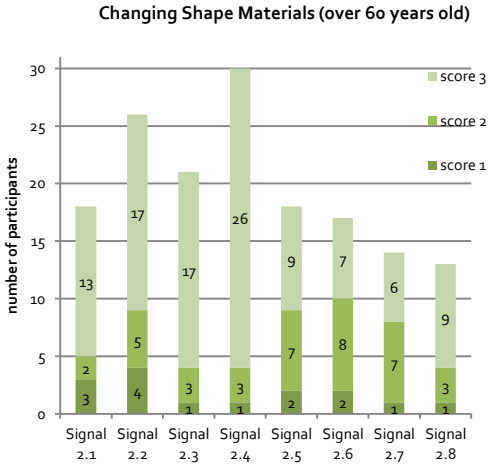


Graph 6.2 Number of over-60 years old participants attributing the score '1', '2' and '3' in each signal of *Light Emitting Materials*

1. As shown in Graph 6.1, *Light Emitting Materials* for the under-60-year-old group present a significant amount of '3' score in six associations out of eight. Signals 1.6 and 1.7, both referring to metaphorical messages, have been scored respectively by 12 and 11 participants with a score of '2', meaning that the intuitiveness of the message showed was not as intuitive as the other messages. Nonetheless, the lower amount of '1' scores recorded highlights the potential of this means to embodied metaphorical/analogical messages among the under-60-year-old user group. This category of materials has been unanimously interpreted with a dominant score '3' in seven signals out of eight by over-60-year-old participants (Graph 6.2). Signals 1.5, 1.7 and 1.8 have been scored respectively by 24, 16 and 19 participants with '3' value, while signal 1.6 has been scored with '2' by 13 participants and with '3' by only 11 participants.



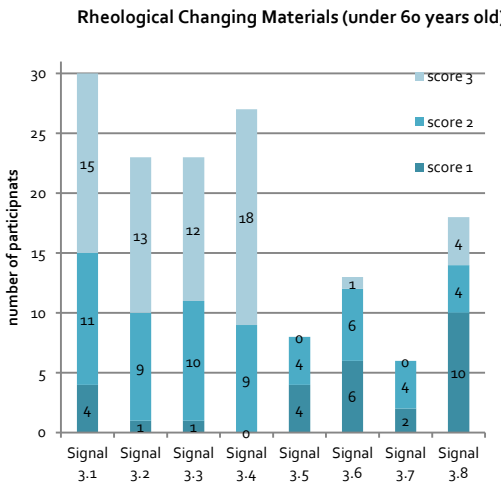
Graph 6.3 Number of under-60 years old participants attributing the score '1', '2' and '3' in each signal of *Changing Shape Materials*



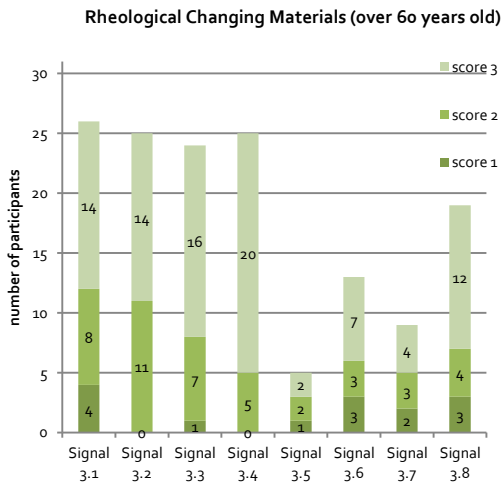
Graph 6.4 Number of over-60 years old participants attributing the score '1', '2' and '3' in each signal of *Changing Shape Materials*

2. Under-60-year-old participants interpreted *Changing Shape Materials* with a relevant amount of '3' scores for all four analogical signals, as shown in Graph 6.3. The two signals that recorded the highest amount of '3' scores (signal 2.2 – Grandma is off line – both flaps down, and signal 2.4 – Grandma is fully active – both flaps up) were the two messages composed by a simultaneous and unambiguous change of shapes, where the two flaps animated by SMs showed similar behaviour (both up, both down). The high number of people scoring the two remaining analogical signals (signal 2.1 – Grandma can be listened to – lips up and signal 2.3 – Grandma is listening in – ear up) with a score of '3' reveals how the alternate moving flaps associated with these symbols helps under-60-year-old people to acquire the expected information. Within the metaphorical messages, only two signals were scored with a significant amount of a score value of '2' (signal 2.5 – Grandma is highly stimulated – sharp shape and signal 2.6 – Grandma is stimulated but quiet – smooth shape). The remaining two signals, 2.7 and 2.8, were all scored as 'poorly understandable' with the highest amount of score value of '1', revealing how the application of *Changing Shape Materials* in terms of their kinetic properties has to be further improved. Graph 6.4 shows how the over-60-year-old group interpreted this family of SMs. Analogical messages were scored with a high number of '3' score, confirming the effectiveness of *Changing Shape Materials* to fortify the meaning of symbols embodied. The four metaphorical messages received a lower score than the analogical messages; specifically, only two signals (Signal

2.5 - Grandma is highly stimulated – sharp shape and Signal 2.8 – Grandma is highly relaxed – curling up shape) have a relevant number of participants scoring the value of '3'. Although the remaining two signals (2.6 and 2.7) have not been scored with higher amounts of '3' score values, the low number of participants scoring '1' reveals the potential of the *Changing Shape Materials* to embody abstract concepts and in improving the perception of smart objects as intuitive by the over-60-year-old participant group.



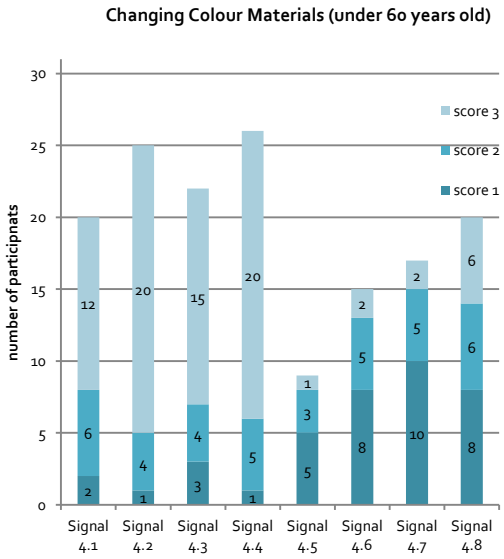
Graph 6.5 Number of under-60 years old participants attributing the score '1', '2' and '3' in each signal of the *Rheological Changing Materials*



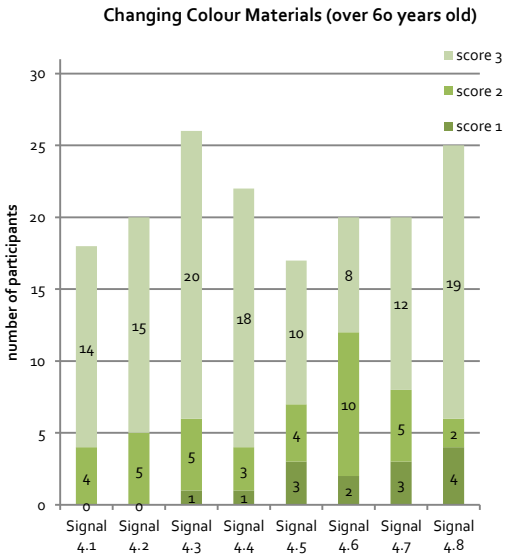
Graph 6.6 Number of over-60 years old participants attributing the score '1', '2' and '3' in each signal of the *Rheological Changing Materials*

3. Ratings recorded by the under-60-year-old participant group show a clear distinction of interpretation of *Rheological Changing Materials* among analogical and metaphorical messages, as shown in Graph 6.5. Data show an intuitive pattern of interpretation of the associations 3.1-3.4 with a relevant amount of '3' scores. The interpretation of metaphorical messages appeared not intuitively perceived. Signal 3.8 (Aunt Elodie is highly relaxed - four small shapes with a spatial divide between them) counted the highest number of people scoring it a value of '3'. The remaining signals were scored mainly with '1' and '2' score value. These associations involve the understanding of differences in shape and size, apparently too difficult to be perceived. Furthermore, the over-60-year-old participant group scored the analogical messages of *Rheological Changing Materials* with an intuitive pattern of interpretation. These signals were fully understood,

demonstrated by a higher number of participants scoring values of '3' above the '1' and '2' scores; metaphorical messages were found to be perceived as difficult to be interpreted by participants.



Graph 6.7 Number of under-60 years old participants attributing the scores of '1', '2' and '3' for each signal of *Changing Colour Materials*



Graph 6.8 Number of over-60 years old participants attributing the scores of '1', '2' and '3' for each signal of *Changing Colour Materials*

4. The number of under-60-year-old participant attributing values of '3' for the analogical messages embodied with the *Changing Colour Materials* properties reveals how the colour coding has been intuitively interpreted (green = go, red = not go), as demonstrated in Graph 6.7. The highest number of values of '3' was attributed to two signals (signal 4.2 - Bob is fully active, both symbols green, and signal 4.4 - Bob is off-line, both symbols red). Difficulties in the interpretation of *Changing Colour Materials* appeared clearer when metaphorical messages were used. Participants found the colourful patterns presented less intuitive; none of the metaphorical messages presented was scored with a relevant value of '3'. Over-60-year-old participants interpreted messages embodied with the *Changing Colour Materials* with a different level of intuition (Graph 6.8). Signals adopting analogical messages show an undisputed majority of scores of '3' above others, confirming how the enhancement of colour coding through SMs was efficient for the sample investigated. An intuitive pattern of interpretation is recorded also for the signals adopting

metaphorical messages, with a relevant number of participants scoring values of '3' for all the signals.

The analysis conducted, supported by the adoption of two Mann-Whitney U Tests, suggests that age does not affect the understanding of embodied SMs, but rather their intuitiveness, as suggested by the differences in ratings expressed by graphs 6.1 – 6.8. Therefore, feedback from participants is presented to provide further evidence in support of the similarities and differences in the interpretation of both analogical and metaphorical messages by the two age groups and to further clarify why embodied SMs were not understood as equally intuitive. A set of eight heuristics is produced to explain age-related differences in the interpretation of embodied SMs. Excerpts from the open ended questions are provided to support each heuristic. An extended version of the feedback recorded is shown in **Appendix M.6**.

1. **Analogical messages with *Light Emitting Materials* are perceived as familiar and intuitive by the under-60-year-old participant group, while the over-60-year-old participant groups are mainly concerned by their visual impairments that may lead to a misleading perception of these messages.**

Participants acknowledged the effectiveness of the lights but they prefer them combined with stronger means of communication, like some touch stimuli (Betty, female, 56-year-old, and Sophia, female, 60-year-old) to compensate for the growing visual impairments of people and loss of perception. Sophia said: "*lights are straightforward but are better to add the touching stimuli (like Rheological Changing Materials) in order to compensate any loss of perception due to ageing factors. The sense of touch is not going to faint*". Ivan (male, 67-year-old) said: "*half lights and half touch. A combination is good and maybe adding a vibrating signal to enhance the message*".

2. **Metaphorical messages with *Light Emitting Materials* attracted both age groups, but a clear distinction between messages is required.**

Gianpaolo (male, 27-year-old) stressed how the meaning of each signal was not fully clear to him. He said the changing speed and intensity of lights gave him the idea of danger and did not help him understand the quality of the message, whether it was positive or negative. Antonio (male, 28-year-old) highlighted how he could interpret these light signals thanks to his past experiences with interactive objects that adopt a similar interface Chul (32 years old, Male) stressed how working with lights reduces the number of mental errors

because the user does not have to spend the time to think. Diana (female, 60-year-old) appeared positively impressed by the light effects, so she suggested redesigning the radio display where each face lights up when you are listening to the connected user with the volume knob becoming brighter once is turned on. Susan (female, 72-year-old) found it difficult to interpret the metaphorical messages with *Light Emitting Materials*. She reported how the signals required a proper understanding of the codes associated.

3. Analogical messages embodied with *Changing Shape Materials* minimise errors in the interpretation and provide an amusing visual clue for both age groups.

William, (male, 21-year-old) said that: *"movable flaps are efficient enough to convey the message and the meaning of symbols appear reinforced by the movement"*; Antonio said that *Shape Changing Materials* work better in communicating the availability of the user because: *"the immediateness of the movable flaps reduces the possibility of misleading interpretations"*. Stella (female, 71-years-old) appreciated how the moving flaps give a visual contribution to the device while Sasha (female, 71-year-old) considers them *"really amusing"*.

4. A general sense of confusion is experienced by both samples when interpreting metaphorical messages embodied with *Changing Shape Materials*. The addition of extra sensorial stimuli should be considered (such as a 'time' parameter).

Samantha (female, 24-year-old), Johnny (male, 25-year-old) and Mary (female, 28-year-old) commented how the changes in frequencies and shapes (sharp vs smooth) are effective but it is important to carefully discriminate between them to prevent confusion. Marta (female, 28-year-old) and Mario (male, 27-year-old) explained how people are not familiar with these kind of interfaces, therefore, a further level of detail should be added to further characterise them. Mario suggested the addition of the 'time-related' parameter, such as frequency, speed of reaction, continuous movement that will eventually help to properly interpret the activity of the user with the *Changing Shape Materials* properties. The emerging issue is to allow the material be dynamic and show the transition from two different statuses (Mario, male, 27-year-old, and Bobby, male, 30-year-old) to adequately recall the human behaviour, as 'reaching out' arms (Mary, female, 28-year-old). Chul (male, 32-year-old) explained how the 'speed of changing' would eventually make the difference for the interpretations of each message. An ideal and powerful interaction could also involve the combination of the crinkling shape with lights (Alexandra, female, 34-year-old).

The principle is that in a combination of signals if the user does not understand the first one, they will probably understand the second.

5. **The use of tangible symbols (analogical messages of *Rheological Changing Materials*) stimulates the interest of both age groups.**

Mark (male, 59-year-old) found the adoption of tangible symbols an excellent way of communicating information, but he suggested speeding up their response time to make them clearer to understand. LyLy (female, 28-year-old) appreciated the touching surface as a new experience and she suggested that it might be enhanced with a physical reproduction of sound. The movement of the surface is considered a good way to show a changing situation (Gianpaolo, male, 27-year-old) but the popping up symbols must be shaped with more definition, clearly indicating when they are active. Sharon (female, 66-year-old) described the symbols appearing on the surface as: *"easy and intuitive, you can't get wrong".* Justin (male, 79-year-old) commented how the tangible symbols were effective and he envisioned a number of possible applications for visually impaired people.

6. **Metaphorical messages embodied with *Rheological Changing Materials* appear to be perceived as confusing, although eye-catching, and materials properties must be exploited to further mimic the sense of 'action'.**

The appearance of changing and movable bubbles shaped by *Rheological Changing Materials* was considered by William (male, 21-years-old) as an interesting way to provide direct messages but he explained how it was important to further explore the parameters characterising the rheological changing fluids to better shape the abstract concepts to be intentionally conveyed. For example, he suggested considering to re-design the size of each bubble in order to communicate the activity of the user (bigger size = more activity) while Samantha (female, 24-year-old) suggested further experimenting with the movement of the liquid in combination with lighting signals to enhance the message. Anita (female, 26-year-old) said that the 'touching features' helped her to acquire more information but this sensation could be further improved. She suggested considering the movement of the shapes: *"If they had moved, I would have understood the message!".* Mary (female, 28-year-old) suggested further experimenting with the growing and decreasing shapes to recall the human activity of the user who is broadcasting the information. LyLy (female, 28-year-old) proposed the addition of vibration and rhythm to recall the activity of the user. The addition of the 'time' parameter that will eventually provide clues on the abstract information to be

communicated was considered as a fundamental step in improving the understandability of the messages, as suggested by Mario (male, 27-year-old). Both Gabriele (male, 29-year-old) and Nastaran (female, 30-year-old) reported how the haptic shapes have a code of interpretation that is not fully understood. She explained that she tried to understand widely different signals at first to catch the essential differences and the others.

7. **Colour coding might not be cross-culturally accepted and the ageing process could affect the perception of colours that need to be enhanced with lights and dynamic effects.**

Samantha (female, 24-year-old) commented that colours have different meanings in different cultures, therefore, it could be counter-productive to work with them. Gianpaolo claimed that: *"Working with colours, such as red and green is confusing. You don't really understand the meaning of the colour unless you see the whole interactions. Lips are red, so if you see the signal 4.1 you don't see a message but a representation of the reality".* Elizabeth (female, 76-year-old), was concerned with the effectiveness of the application of colours given that the ageing process affects their perception of colours. Deborah (female, 64-year-old) claimed that with colours it is easy to fall in a personal interpretation and you are never fully sure about their actual meaning. Whitney (female, 71-year-old) suggested a combination of colours and light signals to improve the visibility of the interface and enhance the understandability of signals.

8. **Metaphorical messages embodied with *Changing Colour Materials* appear to be difficult to be interpreted by both age groups. Brightness and intensity of colours must be dynamically combined to clearly resemble certain sensorial information.**

Johnny (male, 25-year-old) suggested how colours can be improved by dynamically activating them and *"letting them move to actually see them changing".* Anita (female, 26-year-old) thought that messages adopting changes of colour intensity are efficient because: *"they can show hard/slow beat of the activity performed as in signals 4.6-4.7, resulting really powerful".* She also stressed how colours must have a proper coding and that working with only one colour could be more effective that with a combination of lights and changing intensities. Janet (female, 28-year-old) claimed that *"Tempo is a good indicator that must be used to enhance the signals".* Alexandra (female, 34-year-old): *"Colourful patterns are really hard to be understood. This results in a really demanding interaction because you have to play with the device just to understand the signals and get confident with colours".* The brightness

of colours as a way to convey different user statuses was really appreciated by Ivan (male, 67-year-old). He suggested clarifying the colour coding by displaying the spectrum on different bars and experiment with colour intensity. The brightness of colours can shape the activity of the user: the brighter the colour, the more active the user is. The representation of the activity of the user through brightness and intensity of colours was reported as clear to understand by Mary (female, 70-year-old), saying that the colours come up more when bright: *"I thought how the body would react if I was relaxed… and I imagined clear colours".* Whitney (female, 71-year-old) appreciated the idea of colour brightness to express the activity of the user (bright colours standing for high activity versus pale colours to express a status of relaxation). These new interfaces allow the representation of what we cannot share verbally by re-creating the same emotions. Whitney said: *"colours give me an emotion that is potentially the same emotion felt by the connected user".* In this regard, Sharon (female, 66-year-old) commented that colourful patterns are easier because *"you can attach meaning such as relaxation and stress to the brightness of the colours".* Sasha (female, 71-year-old) defined changing colours as "*thought provoking*" and very intuitive. She considered signal 4.8 (primary colour contrast – Bob is highly stimulated) as the best because of its power to stand out. For Deborah (female, 64-year-old), colourful patterns did not express any meaning and she suggested a combination of colours and lights in order to increase the perception of the meaning.

6.4.1 Feedback on the Smart Radio design and functionality

Participants appeared interested in the functionality of the Smart Radio and they provided a suggestion for its implementation. Full transcripts supporting the following three statements are shown in **Appendix M.8**.

- **Participant preference for the sharing of health parameters, emotions and information that cannot be expressed with conventional communication tools.**

Participants would like the device to support them in monitoring their peers, with a non-verbal, engaging communication. Gianpaolo (male, 27-year-old), said that: *"it would be great to get health related information. It is interesting to play with the breath of the user and simulate it. At the same time, it is important to understand what 'being active' means: for a young user is a positive sign, for an old lady maybe not! Would it be interesting to communicate emotions".* Marta (female, 28-year-old) believed that the device should show unconscious information (feelings) that cannot be communicated by traditional device like

a mobile phone; therefore, the device should share the mood of the connected peers: *"it is like the baby monitor: you can also use it to monitor your baby".* Paola (female, 36-year-old) stressed how the Smart Radio should create an emotional support for the user: *"For example when one user send a sad message (sad face), you can send a message to support him".* Sophia (60 years old, Female) suggested that the device shows when two users are in contact with the intent to enhance the emotional bond between the two of them. Susan (female, 72-year-old) said that older adults prefer to know if their peers and family are alright: *"my son and daughter will be happy to check if I'm alright".* Likewise, Nick (male, 68-year-old), who explained that the quality of the information shared is imperative to improve the overall functionality of the device. Therefore, he suggested improving the device by allowing the sharing of information that is usually not shared with conventional devices, such as emotions. He explained that this information should be detected automatically, to avoid the device being invasive.

- **Preference for less details but redundant signals for an intuitive interface.**

Participants appreciated the concept of the Smart Radio, but they found certain signals difficult to interpret. A simplified interface for the Smart Radio was suggested, to allow users to intuitively understand its meaning. Details in the design of the smart product are advocated to be as simple as possible but redundant at the same time, to communicate a clear message. Matthew (male, 50-year-old) commented that interacting with a visual and haptic interface is powerful, especially considering elderly and blind people. He suggested to *"add some vibration would help too, just to give the idea of the activity of the user. It is important to simplify the concept and give the user fewer things to do. Instead of knobs, would be preferable to have a 'turn and touch' device...no more complex devices! The user should turn on the device and select the user by touching an icon, symbol. It is important to enhance what the user is doing through visual tools and working on vibration: one vibration of the lips = the user is busy, two vibrations = the user is available, etc...)".* Gabriele (male, 29-year-old) reported how signals like 'listening in' and 'listening to' appeared confusing: *"The two symbols give me a general idea but the description of the meaning doesn't really match.".* Horacio (male, 24-year-old) suggested experimenting exclusively with a 'switch between shapes' enhanced with lighting signals: he imagined the device to be like a transparent ball that can change shape based on what the user is doing: the bigger the shape, the more active the user is. The simplicity of the interaction was an important issue for Janet (female,

28-year-old) saying that "*The amount of information shared is correct. More information shared could be confusing, most of all if we consider that our tech devices are full of features embedded we don't really use. Elderly wise, an ideal device should have only one knob".* Nick (male, 68-year-old) explained how symbols could be confusing and it is important to get all the users understanding them. He suggested the use of dynamic text messages in combination with symbols to ensure the messages are being properly conveyed regardless of the cultural background of the listeners.

- **Concerns for the privacy of the connected users**

Participants expressed their concerns regarding the privacy of the connected users. For Mary (female, 28-year-old) an added value of the Smart Radio would be to understand whether the privacy of the user listened to is invaded or not: *"I'd like to know what the user is doing and eventually avoid bothering him with a phone call".* Billy (male, 72-year-old) said that users must be free to select the amount of information to be shared. The activity to be shared must be categorised such as personal time (such as bath, cleaning teeth), social time (meeting friends) etc. plus a set of environmental factors, explaining what is happening around the user. Ivan (male, 67-year-old) discussed the need to avoid the 'big brother' effect and to find ways to support and monitor people without invading their privacy. Finally, Allison (female, 69-year-old) expressed her reluctance in sharing information although she recognised the importance of allowing depressed or sick people to share their feelings and be constantly monitored.

6.5 Summary of findings

Three points emerged that informed how embodied SMs enhance the understandability of smart objects by the ageing population:

1. The high understandability of analogical messages and the minor differences in their interpretation among age groups reveal the potential of SMs properties to maximise the use of 'symbols' in product designs.

2. Embodied SMs help to recall past sensorial memories, which eventually lead to a common pattern of interpretation among age groups. Even when signals were not completely understood, such as in the case of the metaphorical messages of the *Rheological Changing Materials*, no statistical difference was observed (**Appendix M.6**), meaning that even for complex signals, a similarity in the interpretation is observed among samples of a population with different familiarity with the technology considered.

3. Feedback from participants revealed relevant information about how each signal was perceived as 'intuitive' or not. The interpretations recorded reinforce the need to support embodied SMs within a defined context of use and targeted users. A recurring theme emerging from the feedback of participants of both age groups is to augment signals with 'time' and 'speed' parameters. Participants interpreted the potential of SMs to change over time as an opportunity to see a 'story' being built and displayed when dynamic and changeable messages take the place of static and often meaningless signals. Embodied SMs are therefore envisioned to be able to build a narrative, where their combined properties stimulate a continuous sensorial reaction of the user. These possibilities have been described as a potential solution to the difficulties of discerning between similar items of a signal, expressed by Elfman, Parks, & Yonelinas (2008), as they may help encode further elements to be used for discriminating among these similar items.

Findings suggest that that embodied SMs mitigate age-related differences when understanding a new smart object, but its intuitiveness may be differently perceived. Design recommendations on how each SMs family can contribute to a better understanding of novel technologies were identified. These conclusions are summarised in the following section.

6.5.1 Embodied SMs and design recommendations

Findings have shown that the understandability of *Light Emitting Materials* with the use of the analogies present a light decreasing percentage of matches with the growing age (**Appendix M.2**). This suggests that older adults find it more difficult to interpret the lighting symbols, while the under-60-year group found these more intuitive and familiar. The under-60-year-old participant group reported a connection between the lighting symbols and the existing technological devices whose displays adopt a similar interface. The design of analogical messages for the over-60-year-old group seems to imply that a clear distinction of meaning should be considered and that misleading signals should be avoided to not confuse the end users. The on/off effect of the lights was positively perceived as a way to enhance the corresponding symbol, although symbols were asked to be carefully designed: the 'off' status could allow the user to understand the device itself is not working. The interpretation of embodied metaphors with *Light Emitting Materials* shows a surprising high peak of matches for the over-60-year-old participants. Under-60-year-old participants reported how they found it easier to discern very different signals

among the four proposed (blinking lights – highly stimulated and pulsing light – highly relaxed) while sublte differences among signals were barely perceived. A recurrent concern was observed : the changing speed and intensity of light can potentially convey the general sense of 'action' of the connected users, but the quality of the messages was not always clear. What the under 60-years-old participant group reported explains the confusion also perceived by the over-60-year-old group while interpreting these signals. They found the signals to not be universally clear and they required a 'code of messages' to better understand their meaning. Although there was a high number of participants matching the 'Designer Model of the Function Representation', participants struggled to understand whether the 'activity' perceived was positive or negative; the metaphors shaped with speed and intensity of light required the support of subsidiary means to clarify their message. Signals representing intermediate human status (such as: active but relaxed, stimulated but quiet) were difficult to be distinguished, becoming redundant and inefficient. This feedback supported what was highlighted in Chapter 1 as one of the main age-related cognitive differences: older adults find difficult to discern between similar items and they encode contextual details to identify differences between items which are too similar (Elfman, Parks, & Yonelinas, 2008 in O'Brien, 2010). Although embodied SMs seem not to fully solve this concern, a promising solution is presented in the combination of signals embodied by different materials. The adoption of lights combined with touch and/or colour coding will eventually clarify the message conveyed and will help the over 60-years-old user group to intuitively obtain the metaphorical application of speed and intensity of lights. It is relevant to notice how, despite those differences, both groups had a similar pattern of interpretation of these embodied SMs (see Graph 6.1 and 6.2).

Analogical messages embedded with *Changing Shape Materials* showed a light decreasing percentage of matches as the age of participants increased (**Appendix M.2**). Under-60-year-old participants appreciated the 'immediateness' of the movable flaps and the consequent reduction of potential mistakes, due to the high visibility of the interface. The 'off' status was the signal that required the most time to be understood because participants were struggling to understand whether the device was working or not. This insight suggests that *Changing Shape Materials* should be applied for the high visibility of their changing properties. These results demonstrate that it is important not to expect the user understand subtle shape changes or underlying meanings embedded in the interactive surface. Similarly, the interpretation of metaphorical messages with *Changing Shape*

Materials led to a drastic reduction of understandability compared to the analogical messages in both age groups. These materials are perceived as an excellent way to mimic human behaviour and therefore depict a plethora of human statuses, but the changing shapes as they were presented for the study were found to be static and inexpressive. Participants encouraged the application of more dynamic parameters such as the 'time' and 'speed' of the changing shape to deduce differences among signals. A continuous changing shape with different speeds of movement will help build strong metaphors recalling anthropomorphic behaviour. Sharp shapes can be associated with high speed and dramatic change of shapes, while gentle movements can accompany smooth outlines. These insights clarify that the way the shape is obtained could create a sensorial perception that builds cognitive connections in the user observing them. Moreover, the combination with an already known means of interaction will support over-60-year-old people to immediately recognise the signals and acquire the new information. The qualitative interpretation of the signals, shown in Graphs 6.3 and 6.4, highlights similarities in the interpretation of both analogical and metaphorical messages among the two age groups with a higher number of '3' scores given by the over-60-year-old participants.

Rheological Changing Materials intrigued the participants but the novelty of their application prevented the identification of an intuitive interpretation. Participants found the adoption of tactile interfaces interesting and therefore suggested to implement the efficacy of the 'popping up' symbols. An interesting way to enrich the adoption of the *Rheological Changing Materials* was identified in the addition of further parameters such as the 'rhythm' of the pulsing symbols and the tangible reproduction of sound waves. Participants explicitly required the enhancement of these signals. Interestingly, the addition of the 'time' parameter was suggested to reinforce the way *Rheological Changing Materials* can mimic specific human behaviours. 'Bubbles', rather than reaching a static position, can grow and decrease to describe the user activity and the vibration could provide further qualitative information. The distance between bubbles was not perceived as an important parameter to be improved. The interpretation of metaphorical messages was considered to be time-consuming for both groups of participants. They preferred to go through each signal several times before attempting any interpretation. What is clear is an underestimation of the 'space' parameter between popping up bubbles, which was not considered as a vehicle for the communication of a meaningful message. The percentage of participants matching the 'Designer Model of the Function Representation' was higher

that the sum of both 'other' and 'scattered' answers only for the signal 3.8 (**Appendix M.3**) for both under-60-year-old and over-60-year-old participants. This signal was composed of four small bubbles at a distance that conveyed a general sense of 'relaxation and peace'. The static nature of the prototype did not help the over-60-year-old user group to be aware of the messages, and it is reasonable to understand why participants required the addition of 'vibration' and 'speed' parameters to better convey the desired meaning.

The combination of colour coding adopted to embody analogical messages with *Changing Colour Material,* and symbols was not considered an effective way to display messages and participants reported how it was time-consuming to understand both symbols and colour coding associated. The adoption of two symbols simultaneously was considered as redundant and the colours adopted were described as a confusing way to enhance the message. An interesting insight emerges in this interpretation: participants required simple, clear and immediate interactions and SMs should facilitate this process. Moreover, the interpretation of colours differs among cultures and their interpretation might not be caught by a wide audience. As observed for the previous family of materials, participants suggested the addition of the 'tempo' parameter to shape powerful metaphors with colour contrasts. The colourful patterns shaping the metaphorical messages with *Changing Colour Materials* were not fully appreciated due to the static nature of the prototype. Participants understood the power of this means but they suggested enhancing the contrast of colours by showing them in different time segments depicting a specific activity of the peer connected. The over-60-year-old participant group stressed the importance of comparing signals before attempting a proper evaluation and they suggested improving the application of the changing colours by working with the 'brightness' of colours rather than the colour coding. For the sake of clarity, one single pattern can be designed and the changing parameters such as brightness, speed and variation of changing colour can emotionally recreate what the user is doing and convey a pleasant and enjoyable signal.

In order to provide an answer to the research question, Figure 6.5 summarises the possibilities of embodied SMs to enhance the understandability of smart objects by the ageing population.

Figure 6.5 Flow chart explaining how embodied SMs enhance the understandability of smart objects by the ageing population and suggestions for future applications of the four SMs' families

6.6 Summary of the Chapter

This Chapter provided insights about the role of embodied SMs to shorten the gap of understandability among under-60-year-old and over-60-year-old people. What was demonstrated is that embodied SMs can effectively convey information that leads to a similar understanding of a novel smart object with minor age related differences. The intuitiveness of the signals shown is still affected by age and by cultural factors not considered in this study. However, the analysis of the matches with the 'Designer Model of the Function Representation' provide an optimistic way to design smart objects that mitigate differences in ages and make technologies more familiar even when prior exposure is limited. For instance, only six out of 32 signals were not fully understood by the under-60-year-old group and five our of 32 by the over-60-year-old group (**Appendix M.3**). Interestingly, all five messages whose percentage of matches was lower than the sum of 'other' and 'scattered' answers, as reported by the over-60-year-old group, were the same that the under-60-year-old group found difficult to interpret. Nevertheless, the way embodied SMs are perceived as 'intuitive' may vary across ages and different signals were asked to be combined together to help older adults discriminate between similar items. Both age groups explained the importance of enhancing the embodied SMs with 'tempo' parameter, making them more dynamic and active and able to exploit their narrative abilities. Findings can be summarised into three criteria that explain how embodied SMs enhance the understandability of smart objects by the ageing population:

1) *when SMs maximise the use of 'symbols' in product designs through their sensorial properties;*
2) *when SMs properties help the user evoking his/her past experiences and sensorial memories;*
3) *when SMs exert their 'narrative' abilities.*

This study did not attempt to determine a one-to-one association between a certain material property and a specific user response but rather it moves towards the exploration of the possibilities of embodied SMs to activate cognitive abilities and volitional actions of the human agent. The study has highlighted a relevant thread of commonalities in the interpretation between the two age groups and suggestions for future designs of embodied SMs that further justify their adoption to shorten the digital divide between generations. Interestingly, the study reveals how the combination of SMs and analogies/metaphors has benefits in the way lack of prior exposure to technologies could

be minimised and the gap in understanding among ages could be effectively bridged. Opportunities are observed in the design of smart objects: the interaction with the Smart Radio has been proved to potentially lead toward a simplification of the human/human communication and a common interpretation of the changeable actions and situations emerging from the environment. Finally, the influence that embodied SMs have on the human agent has been proven to effectively reactivate the ability of older adults to choose between options and attribute a meaning to their preferences.

Chapter 7

Conclusions and future research

7.1 Addressing the research question

This Chapter concludes the research study by highlighting the contributions and impact of this thesis on future research. The Chapter highlights how the three research objectives were achieved, aimed at defining how the adoption of smart objects for the ageing population could be improved, specifically by investigating how embodied Smart Materials may improve the understandability of smart objects for the ageing population. A series of activities has been carried out for this purpose and is described below:

OBJECTIVE 1: 'Identify a set of critical areas in promotion of an 'ageing in place' scenario'.

ACTIVITY CONDUCTED: The Cultural Probe and Focus Group activities

Primary needs, wishes and life priorities of older adults were categorised in two critical areas, which are: *enhance motivation to foster an independent living* and *facilitate communication and social interaction/participation*. The Cultural Probe technique was adopted to acquire a preliminary set of data on everyday experiences of older adults and their relationship with conventional and smart objects and to familiarise with the targeted users. A subsequent exhaustive prioritisation of older adults' everyday wishes and concern was conducted through a Focus Group discussion. The Cultural Probe produced eight recurrent themes, experienced by older adults on a daily base, that were further discussed during the Focus Group in the form of eight daily-life situations. The Cultural Probe sustained that older adults are interested in the adoption of new technologies; however, this is undermined by several barriers. From a practical point of view, their limited technology literacy hinders their ability to understand how to use and explore new products, while a low self-esteem and self-confidence affect the interaction with novel devices from an emotional point of view. Their rigid daily routine is based on simple, ordinary actions often interrupted by social activities and family time. These activities are

not ephemeral distractions, but rather pillars of their social life and a source of motivation in carrying on in their life, entertainment, and emotional support. Participants of the Focus Group discussions further explained how their daily activities were intended to maintain a high level of personal independence and to fight loneliness, reported as one of the main issues experienced on a daily basis. Social activities emerged as a relevant source of elders' self-actualisation, whereas smart objects are not fully considered as an incentive for their motivation and independent living. Based on these findings, the need for improving the communication between peers with an intuitive and entertaining smart object that stimulates the social exchange of information for self-monitoring purposes was considered as a starting point for further exploration.

OBJECTIVE 2: 'Design a smart object with embodied Smart Materials'

ACTIVITY CONDUCTED: Image Schema elicitation with SMs workshop

Nine designers have been engaged in a workshop aimed at designing embodied SMs into a novel smart object. Participants were asked to characterise the interface of a hypothetical new smart object intended for sharing certain behavioural patterns of peers connected through this device. The aim was to make information exchange more intuitive, engaging and pleasant. Specifically, the information to be exchanged was about two human statuses (high and low stimulation). Designers were asked to address this by reinterpreting the sensorial stimuli that SMs create.

The researcher categorised each interpretation of the SMs properties provided by designers into a list of potential image schemas; subsequently, a second interpretation established the expected 'embodied SMs', by means of 32 signals constituting the 'Designer Model of the Function Representation'. These signals were embedded into the shape of a Smart Radio, a novel device for communicative purposes. The final outline of the Smart Radio was designed by the researcher following a three steps approach for metaphor generation:

1. understanding the source domain of information, interpreted as the 'rhythm' of the activity performed and intended to be shared;
2. understanding the target domain of information, constituting the shape of the Smart Radio and its functionality;
3. mapping of attributes, intended as the way the information is embodied and communicated.

OBJECTIVE 3: 'Describe and evaluate how older adults and younger users understand and evaluate the novel smart object'

ACTIVITY CONDUCTED: Questionnaire-based study for Smart Radio evaluation

The two assumptions emerged in Chapter two were considered:

1. the age of the users affects the familiarity with the technology;
2. non-linguistic metaphors contribute to better understanding of new technologies.

An inverse correlation between age and prior exposure to products related to the Smart Radio for the two samples engaged in this research was identified (Table 6.7). This is consistent with findings from previous studies on Technology Familiarity (cf. Chapter 2 section 2.2) thus sustaining the validity of the analysis upon the circumstances of a quasi-experiment, where participants were not selected randomly. Furthermore, the identification of the Technology Familiarity score was considered fundamental to probe the domain knowledge of participants within Smart Radio related products, as demanded in studies conducted by Blackler *et al.* (2003b). Although data collected revealed a diversified prior exposure to technology within participant samples, the observed trend of familiarity advocates that regardless of the cultural background and geographical location of the user, overall older adults have less prior exposure to the product domain identified compared to the younger adult sample. Building upon the results of a pilot study, a main evaluation study for the Smart Radio was conducted comparing its interpretation by two equal participant samples (n=31 under-60 years old and n=31 over-60 years old participants). Participants were asked to identify an association between each Smart Radio signal shown to them, assign each signal with a potential meaning and score each association with a 1-3 ratio, to qualitatively 'weigh' their preferences and explain how intuitively signals were perceived. Indeed, the 1-3 ratio was introduced to identify whether each association found by participants was weakly intuitive (score 1), averagely clear (score 2) or clearly intuitive (score 3). A frequency analysis was conducted comparing the number of matches recorded by the samples with the 'designer Model of the Function Representation', that was used as an initial benchmark for the participants' responses evaluation. Further non-parametric tests were conducted to reinforce the data collected. Findings demonstrated a common trend of understanding for each family of SMs between samples; the high percentage of signals/meaning matched by both age groups provides evidence of the opportunity of embodied SMs as a promising solution for the 'digital divide' in the promotion of a greater technology adoption by the ageing population. Furthermore, the scores attributed to each

signal provided information on the preferred means by each participant sample and how they were intuitively perceived, as a reference for future designs. According to the results, differences in the understanding of technologies are mitigated when embodied SMs bridge the users' prior knowledge to the new information that ought to be acquired and when a technical agent, the smart object, aids and supports those functions that human agents may be less capable/more error prone to perform. The maximisation of sensorial stimuli that SMs properties promote in a non-linguistic metaphor scenario has shown promising improvements in the older adult's ability to take informed decisions, as further highlighted by the comments provided by participants.

7.2 Research contributions

The results of this thesis are hoped to have advanced several frontiers, explained in the following sections.

7.2.1 Non-linguistic metaphors for new product development

This thesis highlights the limited understandability of smart objects (Bradley, Barnard *et al.* 2010, Barnard, Bradley *et al.* 2013) and benefits occurring with their adoption (Jensen 2008, Mitzner *et al.* 2010, Melenhorst, Rogers *et al.* 2006) as main factors hindering a widespread diffusion of technological products by the ageing population. The application of non-linguistic metaphors into smart objects, called in the thesis embodied SMs, was investigated for their potentiality to be more equally and widely understood by people of different ages. Their application will eventually contribute to solve the digital divide concern. Findings reveal opportunities in the adoption of embodied SMs in the mitigation of cognitive age differences, due to their intrinsic ability to create enhanced sensorial stimuli that recall the stored past knowledge of the user, less affected by the ageing process. When embedded into a novel smart object, the Smart Radio, the embodied SMs have facilitated the understanding of unknown product functions with limited differences observed in both age groups, with promising feedback also from users who self-declared themselves less familiar with the digital radio category of products. The rigorous process of design of embodied SMs upon a selection of image schemas has also provided an example of a potential resolution of the tension between innovation, inclusion and the intuitive use of a product, as auspicated by scholars in previous studies (Hurtienne *et al.* 2015). Embodied SMs did not simply mimic existing interfaces to make them more familiar and intuitive; they were designed to unconsciously retrieve the prior knowledge of the user and results

demonstrate that it is a promising practice to simplify the acquisition of new information. Therefore, the research contributes to the 'Theory of Metaphors' by showing the first case of embodied SMs, where non-linguistic metaphors are combined with Smart Materials to facilitate how older adults capitalise their past knowledge to understand novel technologies.

7.2.2 Material Experience

This research also contributes to the 'Materials Experience' theory by identifying routes for future human-centred applications and development of SMs. The contribution of the adoption of SMs to embody non-linguistic metaphors is identified in their potentiality to enhance the sensorial perception of the user with intuitive prompts that do not deflect the attention from the product. In this perspective, SMs are explored for their ability to simplify the way older adults understand a series of messages shaped upon SMs changing properties and so acquire new information. The 'smartness' of the material is, therefore, a function of its application instead of an intrinsic property. What is suggested in this thesis is that embodied SMs can help in reducing the cognitive distance between the evaluation and the execution of an action, which unfamiliar and not intuitive smart objects can create at times. Specifically, the study conducted on the evaluation of the Smart radio suggests that the combination SMs and metaphors/analogies have a promising effect in the understanding of a novel smart objects: while embodied SMs create a maximised effect of analogical messages (such as 'symbols'), opportunity are observed in their ability to build a 'story' and a 'narrative' in the message created that will eventually result in a 'intuitive' and 'immediate' interaction. SMs are, therefore, endowed with a meaning in the continuous interaction with the user and with a combination and design of their properties upon the mental model of the targeted user.

7.2.3 Design implications

This thesis also contributes to current design practice. A human-centred approach was adopted to foster new product development and to minimise the effects of trial-and-error when designing smart objects for the ageing population. The primary investigation on critical areas affecting the ageing population was a necessary contextualisation of the novel device to be tested. Therefore, embodied SMs were defined and tested through a convergent methodology that involved the identification of a new product scenario, a 'Designer Model of the Function Representation' based on a selection of image-schemas

and the prototype design and evaluation. The process of SMs embodiment was conducted through the adoption of the conventional metaphor generation process – understanding the source domain, the target domain of information, and the mapping between the two. The image schema elicitation activity was adopted as an intermediate step where SMs properties were interpreted and categorised by the most commonly identified image schema that scholars have previously selected (Chapter 2) allowing a 'physical mapping' of attributes between an abstract and a physical domain, that constitutes the novelty of this approach. The practical implications of the results lie directly into this practice, as the research investigation invites design practitioners to adopt this three-step process as a roadmap to design novel technological products for the ageing population.

7.3 Limitations of the study and future research

Four limitations are acknowledged in the studies conducted and are further discussed in the following sections:

1. The promotion of the adoption of technology by older adults has been investigated by shortening the gap of understanding of novel technologies between generations. As Chapter 1 and 2 discussed, technology adoption may be hindered or promoted by multiple factors, such as cost, cultural background, the personal motivation of the user, etc. Those factors were not the focus of the investigations of this study but they are considered as relevant as they increase the understandability of a technology, explored in this thesis. Future research may consider a complete observation of the phenomenon where multiple factors concur to technology adoption. Moreover, as addressed in Chapter 1, there is a clear distinction between 'acceptance' and 'adoption' of a technology. In this study, 'acceptance' was not considered, as it is related to a personal and objective predisposition of the user towards technologies.
2. The design scenario identified has been framed within the participant samples selected and the two activities conducted. A general investigation was required to understand how older adults relate to technology, identify design requirements, and highlight the relevance of a human-centred approach when adopting novel technologies. Being aware of the limitations occurring when observing a small sample of the population and the weaknesses in the adoption of only two consequent activities, a broader sample of the population is suggested in future studies. Furthermore, a detailed analysis of targeted users is advocated in future studies where they are involvement in co-design activities at different research stages. Specifically, in the workshop for the image

schema elicitation with SMs, the set of image schemas selected were not identified with the targeted users; moreover, the non-linguistic metaphors designed by the researcher have not being directly assesed by targeted users. These gap results in relevant limitation of the thesis that a co-design activity with older adults would have been compensated. In this thesis, a high level of interpretation was demanded when designing the embodied SMs and the quality of the evaluation carried by the researcher may have affected the final design of signals and the overall understanding of them by the targeted user. Therefore, in a future research, a dedicated study with the targeted users is advocated after the workshop with designers with the intent to evaluate the appropriateness of the image schemas identified and simplify the process of generation of the embodied SMs. Furthermore, image schemas were categorised within the categories found in the literature. The identification of new categories of image schemas could also be the objective of future studies.

3. The identification of the level of familiarity with radio related technology was based on the prior exposure participants had with the 'product category' selected. The definition of such product category resulted in a further limitation: it is likely that people not familiar with either a car radio or a smart phone would find it difficult to interpret the Smart Radio prototype, but the interplay of multiple factors may promote/hinder such interpretation. As expressed in the literature review (Chapter 2), technological products are now produced at a high-speed rate and it is, therefore, difficult to categorise them and define whether users have had a prior exposure to them or not. The high dispersion of data recorded with the Technology Familiarity questionnaire lies in the qualitative nature of the quasi-experiment whose small sample examined may have hindered the definition of a linear correlation. Furthermore, multiple geographical and sociological factors affect the Technology Familiarity score have not been considered in this study. Nonetheless, the approximation conducted (comparison of means value) informed the study with a qualitative trend that justifies the selection of the two participant samples and further studies are recommended to better characterise the inverse correlation identified.
4. Aware that human action is distributed between many concurrent socio-technical agents that contribute in the execution of an activity (Rammert 2008), this research has highlighted opportunities in the cooperation between the human agent and a smart object, where the latter aids those functions that human agents may be less

capable/more error prone to perform. However, we need further studies to demonstrate how the influence that the embodied SMs has on the human agent can recall past sensorial memories, reactivate the ability of older adults to choose between options and attribute a meaning to their preferences. What is still lacking to be fully defined and demonstrated is that stimuli created by embodied SMs at the sensorial level will eventually help older adults re-establishing their innate ability to act, decide and understand.

7.4 Concluding remarks

This thesis paves the way to explore the role of embodied SMs to promote the adoption of products for the ageing population. The research not only enriches extant literature on metaphorical learning but provides a human-centred perspective on the development of new technologies. Opportunities in the embodiment of SMs into smart objects for the ageing population in support of their learnability are found in the ability that SMs have in maximising sensorial stimuli that smart objects produce and systematically stimulate the prior knowledge and memories of older adults. The adoption of SMs in a non-linguistic metaphors setting has demonstrated that the application of embodied SMs may significantly facilitate older adults to link the past and new knowledge with the intent to intuitively interact with products they had limited prior exposure with.

The study conducted complement the 'materials experience' theory, where a human-centred applications and development of SMs approach is presented. Furthermore, the work presented in this thesis in regards to the resolution of the digital divide concern, provides the important groundwork for exploring the benefit in the application of non-linguistic metaphors and embodied SMs at the product design level for new interaction possibilities that future studies might benefit from.

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Appendix A - Cultural Probes Kit

For any information, please contact:

Massimo Micocci

PhD Student
Brunel University London
School of Engineering & Design
Uxbridge

contact: Massimo.Micocci@brunel.ac.uk

Index

We guess you might be wondering what is this all about...

This test is a part of a comprehensive ongoing research at **Brunel University London** relates to the promotion of care and well-being by understanding people needs, meanings and experiences in daily life.

The purpose of this test is to investigate feelings, thoughts, habits of people in different daily life activities and their relationship with common life products. Our aim is to research possible ways to improve people`s lives with new product designs.
In doing so, we need to observe your life and collect meaningful suggestions for our work.

You will have a period of 7 days to perform the activities in the booklet. The days should or should not be consecutive; you are free to choose and descrive those days that mainly represent your "usual" life.

Please respond to each statement as truthfully as you can, and also please remember that there are no right or wrong answers. All information will be used for statistical analyses only and will remain strictly confidential.

Your details:

Nationality: _____
Age (years):_____

Sex: Male [ ] Female [ ]

How to use the booklet

We ask you to reflect on the main aspects of your life, your relationship, emotions and feelings for the next days and to perform the activities described in this booklet.

You should complete as much or as little as you like.

We suggest you to read all the activities at carefully at first before pick up those of your interest.

For each activity we ask you to fill the empty space with your own thoughts. Feel free to express yourself in all the ways you prefer (sketches, collages...). We provide you the following logos as tips that help you to understand how to performe the activities:

write down!

sketch it!

stick it!

Thank you for your time!

Introduce yourself: This is my body...

We would like you to use the outline of a human body below to indicate areas where you usually experience pain, discomfort, decline, or positive feelings within the following days.

How do you usually behave to alleviate pain?
Positive feelings: how do you improve them?
Please give us some quick information about.

...and this is my house!

We ask you to draw down a map of your home, indicating any objects you use and activities you perform that are relevant to you.

Feel free to use collages, stickers, pictures to better express the way you live.

A postcard to a friend...

Imagine to send a postcard to a friend and to answer, in few words, each of these questions:

What is your favorite object?

What is the last object that you have bought?

What would you like to buy for yourself?

Diary description

In the next pages, you will found a “Diary-like” sheets, where we ask you to record chosen activities, routines and events during the next 7 days.

Each page has three sections for:

- **morning;**
- **afternoon;**
- **evening.**

We invite you to reflect upon different aspects of each of the following day and think about what event affected you both positively and negatively.

Diary_Day 1

Morning

Afternoon

Evening

Diary_Day 1

What was “meaningful” for you today?

How could today have been better?

Diary_Day 2

Morning

Afternoon

Evening

Diary_Day 2

What was “meaningful” for you today?

How could today have been better?

Diary_Day 3

Morning

Afternoon

Evening

Diary_Day 3

What was “meaningful” for you today?

How could today have been better?

Diary_Day 4

Morning

Afternoon

Evening

Diary_Day 4

What was “meaningful” for you today?

How could today have been better?

Diary_Day 5

Morning

Afternoon

Evening

Diary_Day 5

What was “meaningful” for you today?

How could today have been better?

Diary_Day 6

Morning

Afternoon

Evening

Diary_Day 6

What was “meaningful” for you today?

How could today have been better?

Diary_Day 7

Morning

Afternoon

Evening

Diary_Day 7

What was “meaningful” for you today?

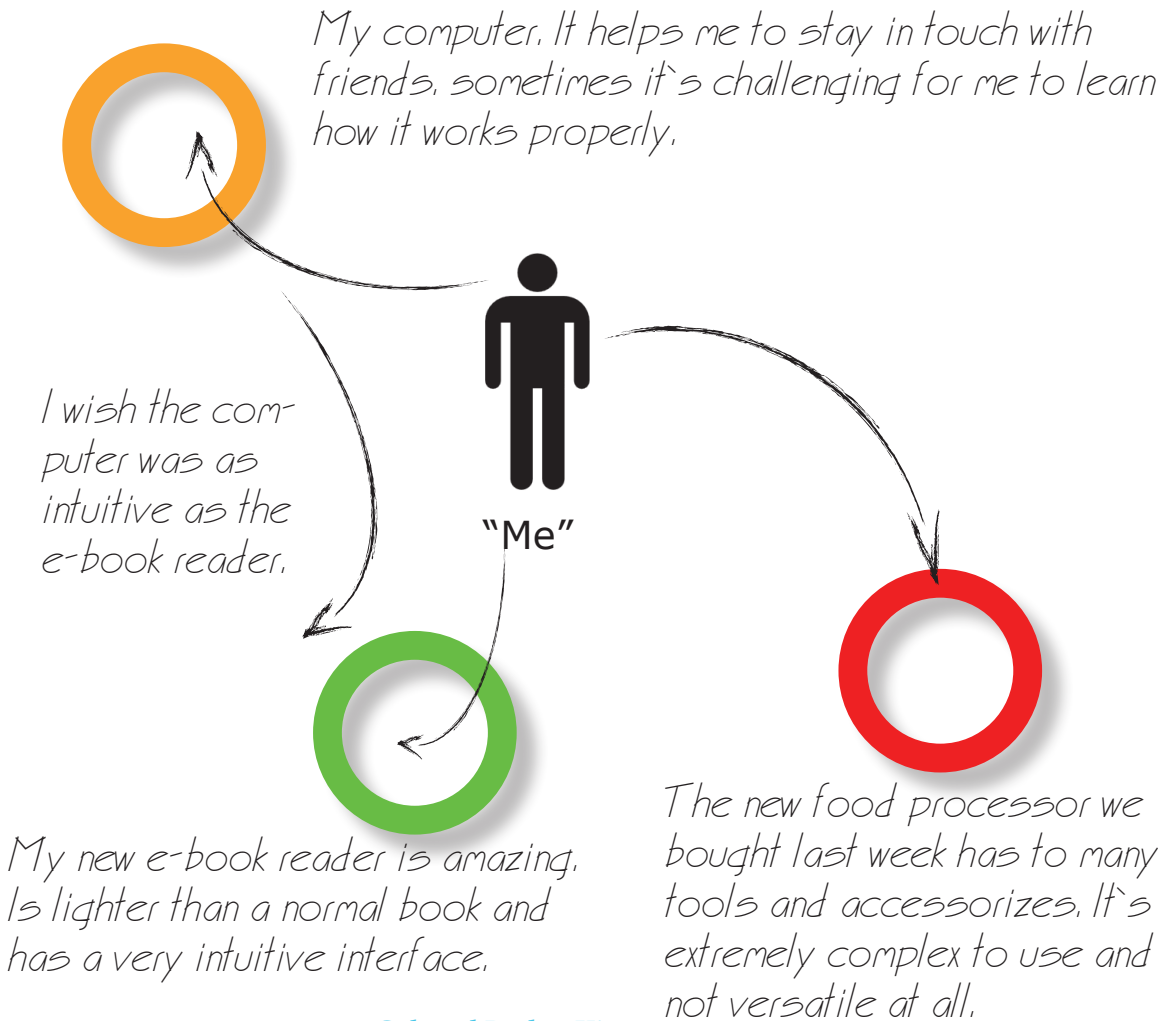
How could today have been better?

Map of objects

In the following page we ask you to draw a "**mind map**" to indicate your relationship with objects. The page include a shadow silhouette representing you.

Think about the main relations that occur in the **next days** and write down a possible connection between them.
In the kit, you will find some stickers, representing general positive (green), neutral (orange), negative (red) mood; feel free to use them in the maps to better express your feelings.
Please add stickers as much as you need.

Example:

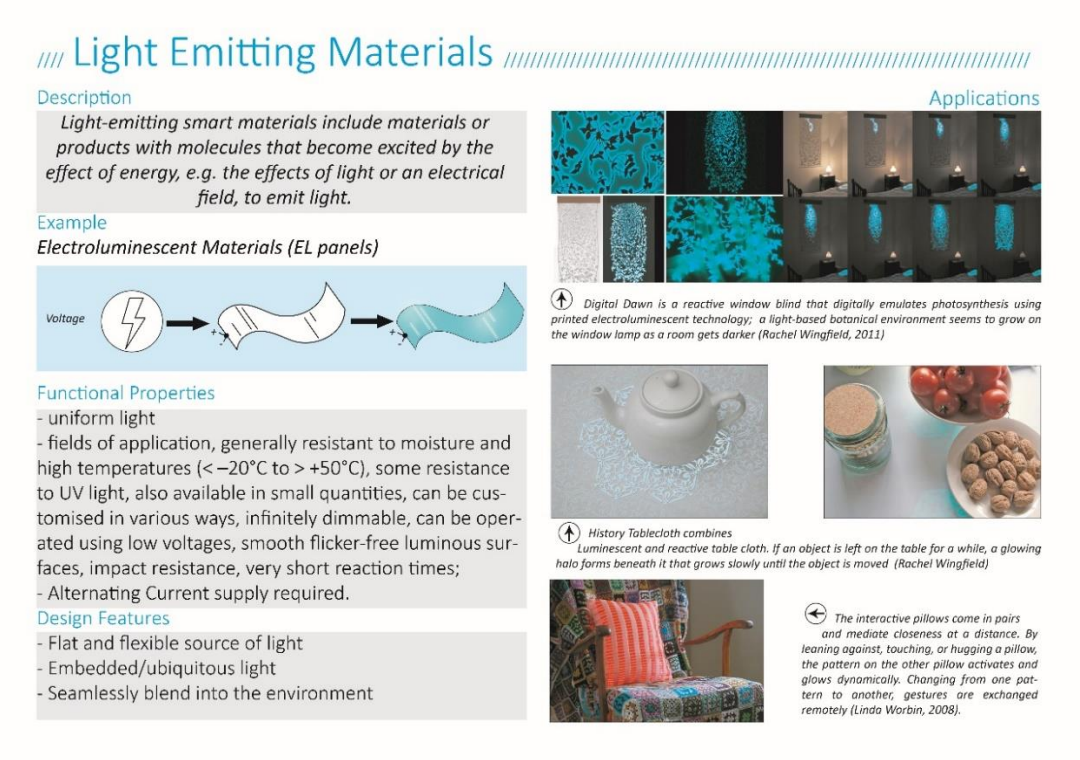


This is my map!

“Me”

Appendix B
Posters for the image schema elicitation with SMs workshop

Posters summarising major properties of each family of SMs as presented during the Image Schema elicitation with Smart Materials workshop.



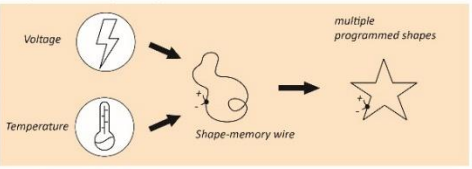
//// Changing Shape Materials //

Description

Shape Changing Materials have properties that enable them to independently react to one or more stimuli by reversibly changing their shape and/or dimensions.

Example

Shape Memory Alloy



Functional Properties

- Metal wires can be designed to react at environmental condition (- 40°C to >120°C);
- Only one shape per time programmable;
- **Active effect**: direct heating through environment temperature;
- **Indirect effect**: using electricity through the wire (3 ≤ 9 V).

Design Features

- Recover the designed original shape;
- Dynamically change shape;
- Generate shrinkage/elongation actions.

Applications

The shirt Oricalco is composed by Shape Memory Alloy wires. The fabric forms itself into different shapes in response to the ambient temperature (Corpo Nove and Grado Zero Espace).

Shape-changing materials are used as a responsive surface that creates ventilation when outdoor temperature increases (Doris Kim Sung, 2012).

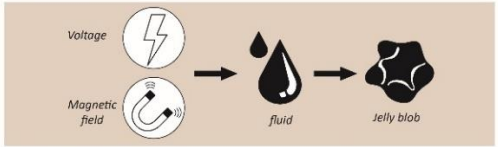
//// Rheological Changing Materials //

Description

Rheological Property Changing Materials change their viscosity in response to electric or magnetic fields. Accompanying the phase change is a change in the properties of the fluid that can eventually result in a new sensorial and tactile perception of the material.

Example

Ferrofluid



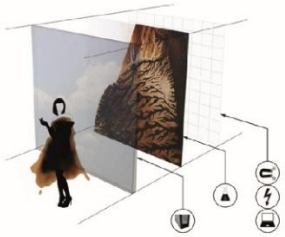
Functional Properties

- Magnetic field can be induced electrically;
- not possible to touch them directly;
- real time change of properties.

Design Features

- Create dynamic patterns on walls and façades;
- Communicate information through haptic signals;
- change haptic (touch) perception;
- basic (black and white) colours availabe.

Applications



Magnetism is used to allow façades to change translucency, colours and more. The idea behind Magnetic Architecture is to explore the possibility of producing a façade cladding that changes properties such as transparency, reflectivity, colour and even shape (Space Group Architects).

This Audio Player adopts the ferrofluid acting as a visualization of the selected modality. By rotating the glass knob, the product switches on, dimly illuminating the four sides and their respective symbols. When selecting tracks, the ferrofluid diminishes in size when reaching the end of a album or artist (Jan Van Der Asdonk, 2008)

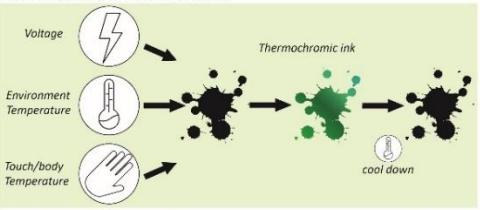
//// Changing Colour Materials //

Description

Colour- and optically changing smart materials include materials that are able to reversibly change their colour and/or optical properties in response to one or more stimuli through external influences.

Example

Thermochromic Materials



Functional Properties

- The liquid crystals can change temperature from-25 to +250 °F (-30 to 120 °C);
- Changing colour from black through red, orange, yellow, green, blue to violet and back again to black or they can achieve a translucent/transparent transformation.

Design Features

- Evolve over time;
- Communicate body/environmental information through interactive colour changing.

Applications

The Fabrication Bag applies thermochromic ink with different colours on cotton textiles combined with conductive yarn.
When an incoming call is detected, different areas of the heat patches are activated in order to cause localised heating of the thermochromic print.
Aim: connect different kinds of data, calls etc. with different visual design expressions. (Linda Worbin, 2010).

Radiate Athletics is a sport garment that uses changing colours materials to monitor the athlete's exertion levels and to change color in the exact location at which the athlete is exerting themselves the most (Radiate Athletics)

Appendix C
Technology Familiarity (TF) questionnaire

Name: _____ Age (years): _____

Profession: _____

Highest academic qualification:_____

Sex: Male ☐ Female ☐

How often do you use the following products? (If you have never used any of the following products, please tick never)

Product	Every day	Several times a week	Once or twice a week	Every few weeks	Every few months	Only ever used it once or twice	Never
Digital Radio fully equipped	☐	☐	☐	☐	☐	☐	☐
Standard, portable digital radio	☐	☐	☐	☐	☐	☐	☐
Radio embedded in other products (app in a smart phone)	☐	☐	☐	☐	☐	☐	☐
Car radio	☐	☐	☐	☐	☐	☐	☐
Other music appliances (Mp3 reader…)	☐	☐	☐	☐	☐	☐	☐
Smart phone	☐	☐	☐	☐	☐	☐	☐
Tablet	☐	☐	☐	☐	☐	☐	☐
Social network	☐	☐	☐	☐	☐	☐	☐
Telecommunication applications (Skype, Whatsapp…)	☐	☐	☐	☐	☐	☐	☐
Personal Computer	☐	☐	☐	☐	☐	☐	☐

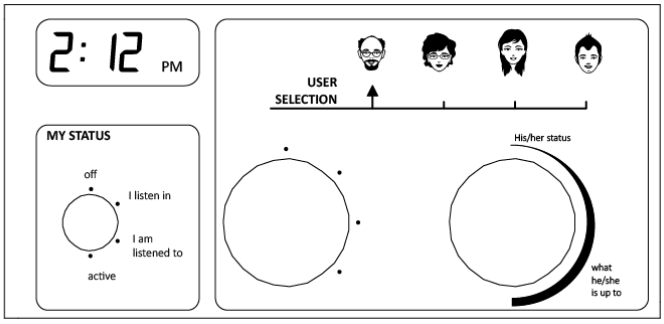
When using versions of these products (below), how many of the features on the products do you use? (if you do not use a product of the following please thick none)

Product	All of the features (you read the manual to check them)	As many features as you can figure out without manual	Just enough features to get by with	Your limited knowledge of the features limits your use of the products	None of the features – you do not use this product
Digital Radio fully equipped	□	□	□	□	□
Standard, portable digital radio	□	□	□	□	□
Radio embedded in other products (e.g. app in a smart phone)	□	□	□	□	□
Car radio	□	□	□	□	□
Other music appliances (Mp3 reader…)	□	□	□	□	□
Smart phone	□	□	□	□	□
Tablet	□	□	□	□	□
Social network	□	□	□	□	□
Telecommunication applications (Skype, Whatsapp…)	□	□	□	□	□
Personal Computer	□	□	□	□	□

Appendix D
Smart Radio evaluation questionnaire

During the test I ask you to imagine that you are using the Smart Radio to "listen" what your friends and peers are doing. Specifically, you will find the Smart Radio with your status set on "I listen in", that allow you to get information from one of the users selected through the intermediate knob.

The questionnaire is divided into four parts; in each part you will get information from 4 different users. Each user is correlated to a set of different signals that you can freely explore during the test.



While "listening" the selected user, you will receive information through multiple signals that will inform you about your peer's availability to broadcast information:

- *he/she is off;*
- *he/she is listening in;*
- *he/she is listened to;*
- *he/she is active to listen and be listened;*

and what he/she is up to:

- *he/she is highly stimulated (he is exercising, running, etc..);*
- *he/she is stimulated, but calm (he is walking, cooking, housekeeping, etc..);*
- *he/she is active, but relaxed (he is eating, watching television, reading a book, etc..);*
- *he/she is highly relaxed (sleeping, etc..).*

You are asked to go through the four sets of interactions and attempt an association between each signal received and its potential meaning and rate the power of each association using a 1 to 3 scale.

SCORE 1: the association is weak and not strong enough to be understood;
SCORE 2: the association is clear, but not really strong;
SCORE 3: the association is really clear you are strongly sure about its meaning.

You will have supporting video and pictures on the Support Board to understand each interaction. If you can't see any association, please tick "other" on the table. Please, feel free to interpret each interaction in the way that makes sense to you.

Once the correlation is clear to you, ***rate the power of the correlation using a 1 to 3 scale*** *where 1 means the correlation is weak and not strong enough to be understood, 2 means the correlation is clear, but not really strong and 3 states that the correlation is really clear you are strongly sure about its meaning. Please use the table below to assess the interactions.*

Consider that you want to listen in your friend Max. You set the device on "***I listen in***" and browse the list of your peers unless you find Max on the display. Firstly, you want to understand your friend's ***availability***. Please go through the signals 1.1, 1.2, 1.3, 1.4 and attempt a correlation between them and the potential meaning perceived. More than one correlation is possible.

Control set 1: user's availability					
"Listening" Max 	**Max is "off line"**	**Max is listening in**	**Max can be listened to**	**Max is fully active**	**other**
Signal 1.1					
Signal 1.2					
Signal 1.3					
Signal 1.4					

Now, you set the third knob of the device on "***what the user is up to***". You now receive a set of signals that give you clues about wha*t* Matt *i*s up to. Please go through the signals 1.5, 1.6, 1.7, 1.8 and assess the potential meaning you perceive. Use the table below to assess the interactions.

Control set 2: what he/she is up to					
"Listening" Max 	**Max is highly stimulated**	**Max is stimulated, but quiet**	**Max is active, but relaxed**	**Max is highly relaxed**	**other**
Signal 1.5					
Signal 1.6					
Signal 1.7					
Signal 1.8					

USER 2

Control set 1: user's availability					
"Listening" Janet 	**Janet is "off line"**	**Janet is listening in**	**Janet can be listened to**	**Janet is fully active**	**other**
Signal 2.1					
Signal 2.2					
Signal 2.3					
Signal 2.4					

Control set 2: what he/she is up to					
"Listening" Janet 	**Janet is highly stimulated**	**Janet is stimulated, but quiet**	**Janet is active, but relaxed**	**Janet is highly relaxed**	**other**
Signal 2.5					
Signal 2.6					
Signal 2.7					
Signal 2.8					

USER 3

Control set 1: user's availability					
"Listening" Elodie 	**Elodie is "off line"**	**Elodie is listening in**	**Elodie can be listened to**	**Elodie is fully active**	**other**
Signal 3.1					
Signal 3.2					
Signal 3.3					
Signal 3.4					

Control set 2: what he/she is up to					
"Listening" Elodie 	**Elodie is highly stimulated**	**Elodie is stimulated, but quiet**	**Elodie is active, but relaxed**	**Elodie is highly relaxed**	**other**
Signal 3.5					
Signal 3.6					
Signal 3.7					
Signal 3.8					

USER 4

Control set 1: user's availability					
"Listening" Bob 	**Bob is "off line"**	**Bob is listening in**	**Bob can be listened to**	**Bob is fully active**	**other**
Signal 4.1					
Signal 4.2					
Signal 4.3					
Signal 4.4					

Control set 2: what he/she is up to					
"Listening" Bob 	**Bob is highly stimulated**	**Bob is stimulated, but quiet**	**Bob is active, but relaxed**	**Bob is highly relaxed**	**other**
Signal 4.5					
Signal 4.6					
Signal 4.7					
Signal 4.8					

Final Evaluation

In your opinion, which of the signals you have identified better represent:

1) The availability of the user? Why?

_____
_____
_____
_____
_____
_____
_____

2) What the user is up to? Why?

_____
_____
_____
_____
_____

Finally, do you think the Digital Radio should share different information?

_____
_____
_____
_____
_____

Name of the participant:

_____

Appendix E
Participant Information Sheet

College of Engineering, Design and Physical Sciences
Department of Design

When our research students conduct their studies, they often need to carry out some initial research with the target market and later with stakeholder groups to evaluate the proposed design solutions or engineering innovation ideas.

• This is an invitation to you to join the study, and to let you know what this would involve.

• This project is being supervised by the supervisors, *Marco Ajovalasit* and *Gabriella Spinelli*.

• When the project is completed, results will be added to appropriate document (e.g. Word, Excel, PowerPoint, still photo, short videos). No personal information will be identified but images of participants may be used within the final presentation if you have explicitly given your permission.

• If you want to find out more about the project, or if you need more information to help you make a decision about joining in, please contact the project supervisor (Marco Ajovalasit, Marco.Ajovalasit@brunel.ac.uk).

Your participation in the Research/Project

Why you have been asked?
You have been asked because we think you are a target user or a relevant stakeholder of the proposed project. The participation in the study is entirely voluntary; there is absolutely no obligation of any kind to join the study.

What happens if you want to change your mind?
If you decide to join the study you can change your mind and withdraw at any time.

What would happen if you join the study?
If you agree to join the study, then we will ask you to be part of a workshop based on multiple creative activities.

Are there any risks?

We shall try to minimise any possible risks. If you did feel that there was any stress involved you can stop at any time. Just tell the researcher that you want to stop.

What happens to the research results?

The students conducting the research are responsible for putting all the information from the study (except names and addresses, and personal identification information) into a computer programme such as Excel, Word or PowerPoint. The student then analyses the information via graphs and images presented in a research report (often these reports are not public documents). The objective is to prove and evaluate the design for a new product or service. For presentation purposes, digital imagery and video may be used at public presentations. If this is the case then prior permission will be sought from participants.

What will I gain from taking part?

You may find the project interesting, and your opinions may inspire the researcher to innovate, but you will not receive any particular direct benefit otherwise.

How we protect your privacy

All information that is collected about you during the course of the research will be kept strictly confidential. Any information recorded about you will have your name and address removed so that you cannot be recognised from it.

If I have more questions, who can I ask?

Please feel free to ask us any question you would like about the study.

Thank you very much for taking the time to read this sheet.

Researcher's name and contact details:

Massimo Micocci
Massimo.Micocci@brunel.ac.uk

Supervisors` name and contact details:

Marco Ajovalasit
Marco.Ajovalasit@brunel.ac.uk

Gabriella Spinelli
Gabriella.Spinelli@brunel.ac.uk

Appendix F
Participant Consent Form

Name of Researchers: Massimo Micocci

This project has been approved by the ethics committee of the College of Engineering, Design and Physical Sciences, Brunel University London.

The participant should complete the whole of this sheet him/herself

Please tick appropriate box

	YES	NO
I have read and understood the Participant Information Sheet		
I have had an opportunity to ask questions and discuss this study		
I understand that I am free to withdraw from the study:		
- at any time		
- without having to give a reason for withdrawing		
I give permission to the researchers for recording the interview		
I give permission to the researchers for taking photos and videos during the study		
I agree to take part in this study		

Signature of Participant…….. Date……..

Name in capitals……

Appendix G

Report from the Cultural Probes Kit activity

1) Findings from the daily dairy activity of the Cultural Probes Kit

- Participant 1 reported how her daily routine was based on exercises to help arthritis (stretching exercises) in the morning, just before breakfast. The first day, she called the maintenance service to fix the kitchen light and she felt satisfied having solved this problem. During the evening, she went to play Bingo but she was expecting to socialise more. The second day, she found meaningful to attend a 'social group' where she could meet friends. Normal routine activities were recorded, such as shopping, housekeeping and word search/crossword to kill the time at evening. On the third day, she felt happy when she went to the church in the morning and when she picked up her new glasses from an optician. Activities were almost similar in the remaining days, with a high level of satisfaction for the good weather on both day 4 and 5.

- Participant 2 reported an ordinary set of constant activities such as washing up, housework, take the dog for a walk in the morning, shopping, gardening and dinner cooking in the afternoon, and computer, television and bath every night. Within her activities, she found *"therapeutic calming"* doing gardening (day 2) and volunteering (day 4), while she considered as a boring activity, watching the same programs on television (day 2).

- Participant 3 described a well-organized weekly routine, starting every morning at 7:30 with an asthma inhaler, 15 minutes of armchair pedalling, medications and breakfast waiting for the carer for the washing up and dressing activities. The morning routine further included the hairdresser in the sheltered housing when participant 3 resides (day 2), shopping downtown (day 2), socialising activities in the communal lounge (day 3 and 5) also with tapestry working (day 3) and going to the local shop with the electric scooter to meet friends (day 6). On day 7, she reported how she was looking for to attend church service but she was not able to go. Afternoon activities were based on lunch, working on the tapestry, watch the news on TV and game shows, do crosswords, basic housekeeping and house management like post-office (day 3), craft work (day 4), spend time with offspring (day 6) and relatives (day

7). At evening time, she reported similar activities within the seven days: watching television, playing bingo (day 1 and 4), doing the crossword and some reading. From her description, there is a deep sense of 'separation' between herself and the world outside. When there is the visit of her son, she is happy and satisfied with her day, as long as going in town enjoying the multiple places where she could eat. Being entertained by Age UK caregivers for one morning was so meaningful that she wished the activity to be extended to the whole day. It was important for her to meet people from outside and have more opportunity to *"go out and about"* (day 6).

- Participant 4 reported a strong parishioner activity. She started every day at 6:30 am with an hour Bible reading and prayer time, before starting the ordinary activities. In day 1 she attended the MacMillan Coffee Morning where she happily met family and friends. On day 5 she visited her son-in-law elderly parents, she picked up some grocery to be delivered at Age UK group members and she helped one of those to reach the Age UK venue. She spent two mornings with her daughter and her dog (day 3 and 6), an activity that she considered very special. During the afternoons, she often took her husband to a local hospital to Parkinson group (day 1, 2 and 4), a group that she considered very informative and clarifying. Shopping with her husband (day 3), crosswords and Sudoku (day 3), knit group at local library (day 4), help organizing Alpha group (evangelistic course) at church (day 4), hairdresser (day 5) and reading (day 7) were further activities performed in her afternoons. Evenings were described as relaxing and peaceful, watching television, doing the crossword, going to the prayer meeting (day 3, 5 and 7). What she found meaningful in her days was the prayer time and her volunteering work in the local community, fellowship with church friends, knitting with other ladies in the village, meeting friends on Friday night (day 5). Interestingly, she said: *"even though I can no longer do a lot of things, it is good to be useful and help family"*.

- Participant 5 described an ordinary daily routine based on housekeeping and shopping in the morning, gardening and television in the afternoon, having a shower and relaxation in the evening. She found meaningful the time spent for herself (hairdresser), gardening and with family. No relevant differences among days where recorded

- Participant 6 reported a busy routine based on her morning working activities as a library assistant. On day 4, she went to the Church in the morning. She described her faith as meaningful. Her afternoons are filled with working activities and

learning task that sometimes made her feel tired (day 1); nonetheless, she always enjoyed her garden and the good weather. As reported on day 2, shopping activities could be a challenge due to her weak arms. She also reported a phobia of storms that during one rainy night (day 3) stopped her from doing any activity. In the pursuit of security and control during the thunderstorm, she used listening music to keep her thoughts away from the storm. Time with family and friends was always considered as meaningful (day 6) especially when unexpected. On day 1 she explained the need to take care of her body as a 'healing' therapy against the daily working problems and the need to better manage her free time with something more productive like playing the piano, instead of watching Facebook.

- Finally, participant 7 reported as main highlights of her week the visit of her daughter and a skype call with her son (day 1), the self-organized book group at a friend's house (day 2) where they discussed the latest books read; gardening and vegetables cropping (day 3); barbequing with very old friends (day 6) and dog walk every day. Housekeeping is considered a very boring activity and the need of socialising has made clear on day 3 and 5.

2) List of descriptive codes, categories, analytic codes and the eight themes identified among data collected with the Cultural Probes Kit activity.

DESCRIPTIVE CODES	CATEGORIES	ANALYTIC CODES	THEME
Bed	conventional home setting	feeling reassured and sheltered at home	CONVENTIONAL PRODUCTS VS NOVEL TECHNOLOGIES
Wardrobe	conventional home setting	feeling reassured and sheltered at home	
Bedside lamp	conventional home setting	feeling reassured and sheltered at home	
Chair	conventional home setting	feeling reassured and sheltered at home	
Sofa	conventional home setting	feeling reassured and sheltered at home	
Cupboard	conventional home setting	feeling reassured and sheltered at home	
Toaster	conventional home setting	feeling reassured and sheltered at home	
Cooker (pot)	conventional home setting	feeling reassured and sheltered at home	

Sink	conventional home setting	feeling reassured and sheltered at home	
Crossword	conventional pastime objects	being entertained at home	
walk-in shower, toilet	conventional home setting	feeling reassured and sheltered at home	
radiator	conventional home setting	feeling reassured and sheltered at home	
electric stoves	conventional home setting	feeling reassured and sheltered at home	
microwave	conventional home setting	feeling reassured and sheltered at home	
fridge	conventional home setting	feeling reassured and sheltered at home	
electric relax chair	conventional home setting	feeling reassured and sheltered at home	
automatic bed	conventional home setting	feeling reassured and sheltered at home	
coffee table (easily reaching objects on it)	conventional home setting	feeling reassured and sheltered at home	
desk	conventional home setting	feeling reassured and sheltered at home	
hook	conventional home setting	feeling reassured and sheltered at home	
dressing table with mirror	conventional home setting	feeling reassured and sheltered at home	
Knit needles and wool	conventional pastime objects	being entertained at home	
Book	conventional pastime objects	being entertained at home	
Kitchen equipment	conventional home setting	feeling reassured and sheltered at home	
Television	conventional pastime appliance	being entertained at home	
Sewing machine	conventional pastime objects	being entertained at home	
EBook reader	tech pastime appliance	being entertained at home	
Laptop computer	tech pastime appliance	being entertained at home	
Bible	conventional pastime objects	being emotionally fulfilled at home	
Feet massager	tech pastime appliance	being physically supported at home	
Tablet	tech pastime appliance	feeling empowered	

Mobile phone	tech pastime appliance	feeling empowered	
Electric scooter	daily support appliance	feeling empowered	
photo album	conventional pastime objects	being emotionally fulfilled at home	

Volunteering	"me" and society	self-actualization within society	SOCIAL INVOLVEMENT
Parishioner activities	"me" and society	self-actualization within society	
Mac Millan Coffee Morning	"me" and society	being supported within society	
help Age UK members to attend social events and to do shopping	"me" and society	self-actualization within society	
attend Age UK events	"me" and society	being entertained within society	
Spend time with family	"me" and my family	enhance the sense of belonging	
Knit group	"me" and society	being entertained within society	
Prayer meeting	"me" and society	self-actualization within society	
Self-organized books group	"me" and society	being entertained within society	
Play Bingo	"me" and society	being entertained within society	

Shoulder pain	physical concerns	being challenged in ordinary activities	KEEP THE BODY ACTIVE
Knee pain	physical concerns	being challenged in ordinary activities	
Back pain	physical concerns	being challenged in ordinary activities	
neck pain	physical concerns	being challenged in ordinary activities	
forearm pain	physical concerns	being challenged in ordinary activities	
feet pain	physical concerns	being challenged in ordinary activities	
wrist pain	physical concerns	being challenged in ordinary activities	
Positive feelings	purposeful behaviour	carrying on in ordinary activities	
Legs pain	physical concerns	being challenged in ordinary activities	

Exercises	purposeful behaviour	carrying on in ordinary activities	
Keep moving	purposeful behaviour	carrying on in ordinary activities	
Stay positive	purposeful behaviour	carrying on in ordinary activities	
Praying	purposeful behaviour	carrying on in ordinary activities	
Looking for the good	purposeful behaviour	carrying on in ordinary activities	
Painkiller	physical concerns	carrying on in ordinary activities	
Armchair pedaling	purposeful behaviour	carrying on in ordinary activities	
weak arms	physical concerns	being challenged in ordinary activities	
deal with a phobia of storms	purposeful behaviour	being challenged in ordinary activities	
deal with generalised fear	purposeful behaviour	being challenged in ordinary activities	

Not able to attend church service	Be always at home	feeling isolated	ENHANCE MOBILITY
Opportunity to go out and about	Going out	freedom of movement	
being able to meet friends thanks to the electric scooter	Going out	freedom of movement	
going to the local shop with an electric scooter	Going out	freedom of movement	
Waiting for offspring	Be always at home	need of integration	
Being house bound	Be always at home	feeling isolated	

eBook is easy to handle	Recreational activities	accomplishment of an ordinary task	BE INDIPENDENT
Maintenance service to replace a light bulb	external support	help to accomplish an ordinary task	
Ordinary housekeeping	ordinary activities	accomplishment of an ordinary task	
Walking	ordinary activities	accomplishment of an ordinary task	
gardening	recreational activities	accomplishment of an ordinary task	

Cooking	ordinary activities	accomplishment of an ordinary task	
Craft work	recreational activities	accomplishment of an ordinary task	
Visit from son	external support	help to accomplish an ordinary task	
sense of 'Separation'	external support	help to accomplish an ordinary task	
Shopping	ordinary activities	accomplishment of an ordinary task	
Hairdresser	ordinary activities	accomplishment of an ordinary task	
shopping activity hindered by weak arms	ordinary activities	help to accomplish an ordinary task	
Vegetables crop	ordinary activities	accomplishment of an ordinary task	
gardening as "therapeutic calming"	ordinary activities	accomplishment of a fulfilling activity	
going to the Church regularly	ordinary activities	accomplishment of a fulfilling activity	
take dog for a walk with daughter	ordinary activities	accomplishment of a fulfilling activity	
waiting for the carer	external support	help to accomplish an ordinary task	
tapestry working	recreational activities	accomplishment of a fulfilling activity	
"spend time for myself"	ordinary activities	accomplishment of a fulfilling activity	
faith	ordinary activities	accomplishment of a fulfilling activity	

Stretching	body care	ageing-prevent practices	HEALTH-CARE and WELLEBEING PRACTICES
Exercising	body care	ageing-prevent practices	
Think positive	mind care	ageing-prevent practices	
Socialize	mind care	ageing-prevent practices	
Exercising	health care	ageing-prevent practices	
regular blood pressure monitoring	health care	ageing-prevent practices	
Spine curvature exercises	health care	ageing-prevent practices	
Paracetamol for pain	health care	ageing-prevent practices	
Parkinson support group	health care	ageing-prevent practices	

Social group where to find friends	“me" and society	communication opportunities	BEING IN TOUCH

A mobile phone to keep in touch with friends and family	tech pastime appliance	communication opportunities	

Being entertained	leisure	being able to manage my wishes	NEW CHALLENGES
Extend the social activities	leisure	being able to manage my wishes	
Fill the free time with more productive activities	leisure	being able to manage my wishes	

Appendix H

Report from the Focus Group discussion

1) Extended reports from the Focus Group

Scenario 1. Mary (Female, 70-year-old) explained that when she purchases a new device, she generally looks for somebody who teaches her how to use it. At the question, if she tries at first to use the device and rely more on her abilities, she exclaimed: *"yes, but when you press (the button) you do not know what you are pressing!"* This statement explained her need of external support. Anne (Female) said when she bought a new smartphone, she tried to use the instruction leaflet at first but she did not understand how to go further and what to do. Janet (Female, 66-year-old) supported the idea to preferably using the instruction leaflet and, in the case of a complete misunderstanding of product functionality, to give the product back to the seller. In order to further explore this behaviour, participants were asked if they have ever returned any device back because they could not manage how to work it, and they all confirmed that it happens often, but mainly to ask the seller for an explanation. Mary (Female, 70-year-old) explained how accidentally locked the tablet and she asked for help at the retailer while Janet (Female, 66-year-old) returned her tablet back to the shop saying that: *"there is no point for me!"* stressing how the product was not perceived as useful. Mary explained when she tried to use the laptop received for Christmas, she was scared to even touch it, especially the mouse: *"That arrow drove me crazy and I did not know where to click and what it wanted from me."* She further explained how she could finally master emails and basic functionalities of the laptop because of her daughter, really committed helping her mum. When a further question asked them how they learnt to use their mobile phone, participants confirmed that practice and dedication are important attitudes to acquire expertise alongside motivation from their children. Rob explained that although he did not know how to use his new smartphone recently purchased, he was confident that after some practice he would become expert enough to master it; however, he wanted to stress how the initial impact with the new device was highly demotivating. Patty (Female, 58-year-old) explained her fear to *"push the wrong button"* and Jack (Male, 64-year-old) explained he was also cautious handling a new product, because of his fear of doing irreversible actions. Another emerging issue for Patty,

Jack and Rob, was about the fear of losing phone credit by doing the wrong action on the phone with internet connection. Rob expresses his willingness to find anyone to help him in coping with new technologies and, if not, he explained how alternative options could work as well, such as courses at Age UK and independent practice on the device. He further expressed his frustration in the ever-changing technology: *"I manage to use windows 7 when windows 8 came out; I know how to use a computer but not windows 8 and this confused me… it is not a new technology but it is difficult for me when things are continuously changing."* Patty confirmed that she was not able to easily switch from an old device to new one that she had to carry with her three mobile phones; difficulties in understanding the new device forced her to keep her contact details on multiple phones and use them when necessary. Anne expressed her satisfaction when she could finally send text messages with her phone, stressing the idea that: *"when you practice, you get it!"* In order to get the dimension of her satisfaction, Anne was further asked if she finally perceived the whole benefits in the use of the new device, but she showed a clear reluctance, mainly referred to all the apps and paid services available: *"A mobile phone does not solve problems; it makes you do what you do not want to do. I do not buy phone products; I always prefer phoning my family."* Alongside this comment, participants stressed how they prefer a traditional phone call instead of messaging, and how the continuous purchase of new phones is a waste of money when the aim is to accomplish such a simple and basic task. When a further point was showed regarding the possibility of these technologies to be of any support, Melanie (65-year-old), said that: *"If anything happens to you, like an emergency, you phone your children straightaway. Also, if you miss a place and need an indication, you can always call them. I also have a map on my phone; I don't know how to use it but I think that would improve my life."* She also stressed how the phone helps her to be independent; going out feeling safe anyone could be contacted at any time. The safety concern emerges at the end of this scenario conversation; Anne said she does not give her number to anyone and how she feels worried to unexpectedly pay for apps that charge all her credit. Participants debated how were important to keep sometimes the phone off and prevent unpleasant calls and the credit to be stolen. Melanie (65-year-old) said her phone is always on, in order to avoid missing important messages and calls but she never answered to unknown numbers. She explained the perceived danger in picking the phone to strangers is that sometimes they want to sell products and she is scared to be swindled.

Scenario 2. Melanie (Female, 65-year-old) expressed her dedication for children in hospital by giving money at the local hospital; Mary (Female, 70-year-old) explained she is part of

the Antigua and Barbuda National Association where she mainly contributed with fund raising activities and organizing once per year the celebration of the independence of Antigua with a celebrating ceremony. She explained how the event is really important to sensitise younger generation to the topic as only older adults are currently involved. Anne found in her faith in the church a way to be active in her society. She explained how every fourth Sunday of the month she goes to a church in a suburb of London where she can meet friends and sing altogether. She further reported how she attends with great pleasure, every Wednesday, the dancing group organised at the same church; she explained how the group is of about 25 people and they usually keep in touch with email and phones. Jack (Male, 64-year-old) said he had just retired from his job and having being spent his life travelling, he never had the chance for any volunteering; nonetheless, he happily reported his commitment in a suburb of London where he supports socially isolated people with the company and spending time with. Rob reported his activity in a refuge charity that provides free food, advice guidance for bureaucracy issues and helps people to be more integrated into the society; he said that this activity makes he feel like a *"hero"* because of this helpful and meaningful commitment in the society. Patty (Female, 58 years old) explained that she had worked helping and support people in need for her whole life and now she would prefer to get some rest and spend some time with her. She reported her working activity as very demanding, because of the different needs of her assisted; although her tiredness, she acknowledged how helping people was really satisfying and made her feel 'alive', having the mind always occupied. Her commitment to guide people to carry on in her life was a valuable incentive to increase her self-esteem and energy and her life was eventually positively affected.

Scenario 3. Melanie (Female, 65-year-old) was excited telling how much she enjoyed the dance class and that she exercised every day; Katy (Female, 81-year-old) reported a severe discomfort: she appeared terrified of water because of an early childhood trauma. She explained how she has been trying to swim for the last 25 years without succeeding and she was currently taking lessons to challenge herself and overcome her fears. In her explanation, she told how lately was scared by the behaviour of the instructor who was not there to rescue her in a moment of emergency. Although the frustration of this problem, she looked determined to challenge herself and repress her fears. Participants further explained they prefer activities that can empower the full body, like practising a Caribbean dance that involves the whole body because, as explained by Janet (Female, 66-year-old) while dancing they never feel tired and being with other people is a good stimulus.

Furthermore, they looked so dedicated to keeping an active lifestyle that in case no dancing class is available, simple activities at home can be performed, such as going up and down from the home stairs for Melanie (65-year-old). Patty (Female, 58-year-old), said her best way to keep active was swimming and always staying with motivating people. She could manage to swim at least three times per week as she considered an important incentive for her self-confidence. She reported of a dedicated trainer at the local swimming pool that gave her the right motivation to complete exercises. Jack (Male, 64-year-old) said he walks almost 30 minutes a day every morning as he used to play table tennis but his knees do not allow him to play anymore. Paul (Male, 80-year-old), reported the desire to be more active, but his lack of motivation refrained him to do any specific activity. Also, Patty agreed how a growing lack of motivation is a recurrent feeling to cope with; both Patty and Rob, described engaging and stimulating activities, such as dancing, as potential solutions that alleviate the lack of motivation toward a more active life.

Scenario 4. Participants agreed that the bus is a comfortable way to move around the city, as none of them drives. They appeared always aware of the journey and they never had the need to change their plan. In case they need information, Janet (Female, 66-year-old) said she calls the information service of the bus company. She further said being aware that people driving use the satnav, but in her case, asking information at the ticket desk of the station sufficed. They all claimed to be happy sometimes to move out London with the train, usually buying the ticket in advance. They did not experience difficulties in reading a timetable, although Katy (Female, 81-year-old) reported some problems in map reading that forced her to constantly ask for help. Jack (Male, 64-year-old) was the only one that showed an interest in using browser engines like Google to get unknown information. Jenny (Female, 76-year-old), stressed how was easy for her to read maps and ask for information at the nearest train station for information. Both Jack and Rob reported that was easy for them to use apps for 'talk' with mobile phones and tablet and ask for information while Patty reported how she tried to use the voice command of her phone but she was really confused when the device could not understand her voice input.

Scenario 5. Housekeeping is getting slightly hard to everyone, especially due to decreasing body performances such as pain caused by stretching arms; they reported difficulties in replacing bed sheets and move mattresses. Anne said her husband passed away 17 years before and she could manage to perfectly live on her own. None of the participants had pets in their home for hygiene reasons. Rob happily said he had the chance to share his

ordinary life with his family composed of his mum and children and he would never move to live on his own. Jack found the daily management of loneliness more challenging than normal everyday issues and Rob stressed the importance to be part of a group and share life with others, as we are that we are *"social animals"*, but Patty (Female, 58-year-old) expressed the importance to be, sometimes, on her own. Jenny (Female, 76-year-old) said her husband passed away few years before but she well accepted and managed her life, also with the constant help of her daughter when necessary. Rob expressed the need to find someone to share intimate aspects of life and everyday activities.

Scenario 6. Melanie (Female, 65-year-old) said she checks blood pressure and takes some dedicated pills on a daily base; she remembers to accomplish these daily tasks by writing down notes and the correct dosage of medicines on pill boxes. Janet (Female, 66-year-old) had the same memory issue that she reduced by taking medicine every day after breakfast in order know exactly when a dose is missing. Mary (70-year-old) said she did want to constantly control her blood pressure because her mum died because of a stroke. She reported that she often checks her blood pressure at night. All of them relied on general practitioners to check their health status. Josephine said she goes to the doctor two/three times a year. They all agreed that nobody reminds them to take pills and check the blood pressure and they can manage their health requirements independently. Rob said how difficult was, especially for her mum, to deal every day with medicine intake, to avoid mistakes and save money too and a device for self-monitoring activities would simplify her life.

Scenario 7. Ellie and Jenny (Female, 76-year-old) explained they preferred to call their friends or relatives instead of email, in order to keep an intimate level of communication, while Patty explained how the free social events are a good way for socialising, meet people and have a deal about future events.

Scenario 8. Anne stressed how she was *"scared of technology"* and how she asked for support within the Age UK local branch to understand how to use the tablet. Melanie and Katy agreed that the social group organised at Age UK were really helpful and they will keep attending them in the future. They reported how attending social groups was extremely important to feed their motivation and find all the answers they were looking for, as emphasised by Rob. All participants considered social groups organised at Age UK and local Churches as a source of motivation, socialisation, and information; therefore, Rob stressed the importance to keep those places accessible to everyone: *"access is the key"*.

2) List of descriptive codes, categories, analytic codes and the two critical areas that technology for the ageing population should cope with, as identified through the Focus Group activity

DESCRIPTIVE CODES	CATEGORIES	ANALYTIC CODES	CRICTICAL AREAS
need of someone else who teaches how to use the new device	"me" and technology	demotivation	ENHANCE MOTIVATION TO FOSTER AN INDEPENDENT LIVING
instruction leaflet	"me" and technology	being always in control	
ask for information at the seller	"me" and technology	being always in control	
"there is no point for me"	"me" and technology	demotivation	
scared of touch the mouse	"me" and technology	demotivation	
not able to go at the same speed with technology	"me" and technology	demotivation	
need upgradable product	"me" and technology	demotivation	
mobile phone as address book	"me" and technology	demotivation	
mobile phone does not solve problems	"me" and technology	demotivation	
scared of technology	"me" and technology	demotivation	
practise and dedication to understand a new product	"me" and technology	keep an independent lifestyle	
"when you practice, you get it"	"me" and technology	keep an independent lifestyle	
I feel safe going out aware that I can call anyone at any time	"me" and technology	being always in control	
I keep the phone off to save money	"me" and technology	being always in control	
scared to be swindled	ordinary activities	being always in control	
everyday walking	purposeful behaviour	keep an independent lifestyle	
repress fears	purposeful behaviour	being always in control	
going up and down from home stairs	purposeful behaviour	keep an independent lifestyle	
being aware of the journey	ordinary activities	being always in control	
information service of the bus company	ordinary activities	being always in control	
reading problems	ordinary activities	keep an independent lifestyle	
minor problems in house keeping	health care	being always in control	
blood pressure monitoring	health care	being always in control	
taking pills	health care	being always in control	

I need something to make me feel *"stronger, healthier and independent again."*	purposeful behaviour	keep an independent lifestyle	
memory aid	health care	being always in control	
self-monitoring	health care	being always in control	
writing notes to remind information	health care	being always in control	
keep the body active	health care	keep an independent lifestyle	
fear to do something wrong when using a new device	"me" and technology	demotivation	
spend time for me	purposeful behaviour	keep an independent lifestyle	
information at the bus station	ordinary activities	being always in control	
browse information on google	"me" and technology	being always in control	
everyday loneliness	ordinary activities	demotivation	
"crystalized purposes or interests that grip me"	ordinary activities	demotivation	

I prefer phone my family	"me" and my family	communication opportunities	FACILITATE COMMUNICATION AND SOCIAL INTERACTIONS/PARTICIPATION
I can phone my children in the case of emergency	"me" and technology	communication opportunities	
email and phone to arrange social event	"me" and technology	communication opportunities	
being with other people is a stimulus to challenge mind and body	"me" and society	self-actualization within society	
meet friends in person to talk	"me" and society	communication opportunities	
social group at Age UK to learn how to use a tablet	"me" and technology	being supported within society	
need of a companion to go out with	"me" and society	being supported within society	
I would like to go to the cinema	"me" and society	being entertained within society	
support socially isolated people with company	"me" and society	self-actualization within society	
feeling heroic when helping people	"me" and society	self-actualization within society	
satisfaction in helping people	"me" and society	self-actualization within society	
mentoring people in carrying on in their life	"me" and society	self-actualization within society	

stay always with motivating people	"me" and society	being supported within society	
swimming with trainer	"me" and society	being supported within society	
engaging activities	"me" and society	being entertained within society	
share intimate everyday aspects with someone	"me" and society	self-actualization within society	
mobile phone for an intimate level of communication	"me" and technology	communication opportunities	
accessibility of social events	"me" and society	self-actualization within society	
keen to help friends with technology	"me" and society	being supported within society	
giving money to charity	"me" and society	self-actualization within society	
involve younger generation in charity activities	"me" and society	self-actualization within society	
Faith in the Church	"me" and society	self-actualization within society	
singing group	"me" and society	being entertained within society	
dancing group	"me" and society	being entertained within society	

Appendix I

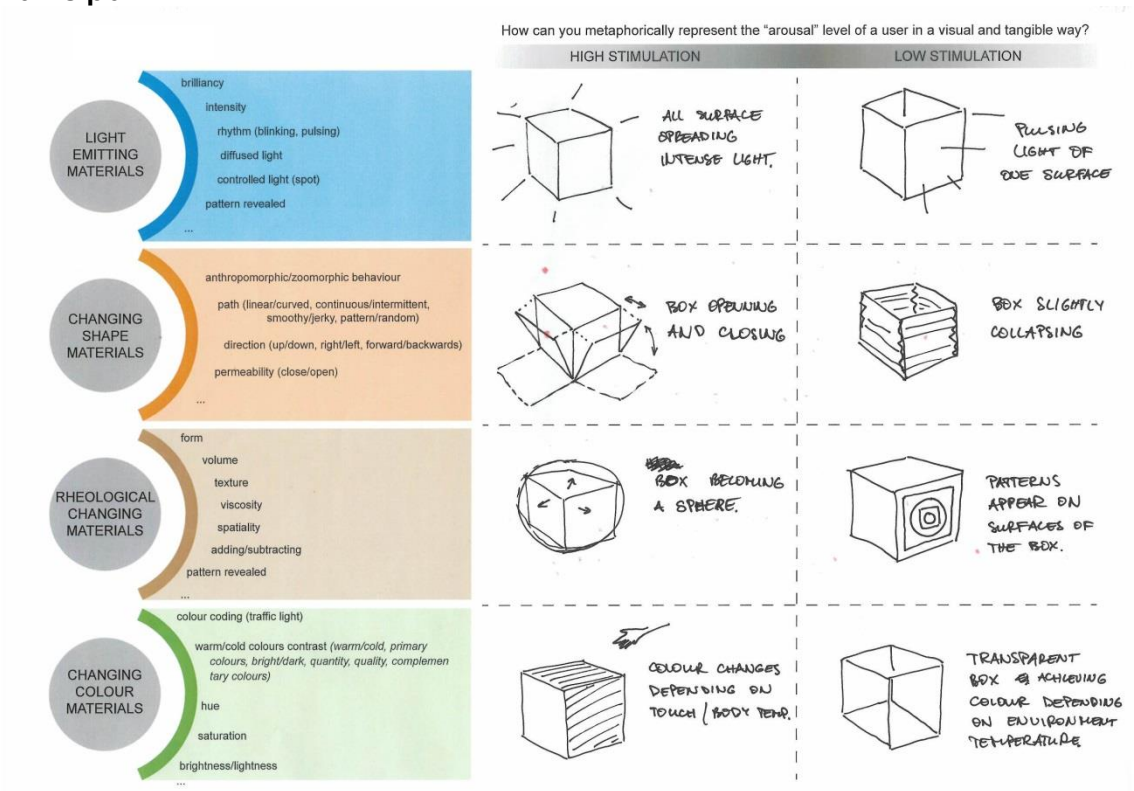
Findings from the image schema elicitation with SMs workshop

1) Participants of the Image-schema elicitation with SMs' workshop

participants	fictional name	age	gender	nationality
1	Mary	26	F	Lithuanian
2	Bob	32	M	Korean
3	Ning	24	F	Chinese
4	Lang	22	M	Chinese
5	Liu	24	F	Chinese
6	Yin Jang	25	F	Chinese
7	Jisun	24	F	Korean
8	Kate	24	F	Chinese
9	Liu Park	24	M	Chinese

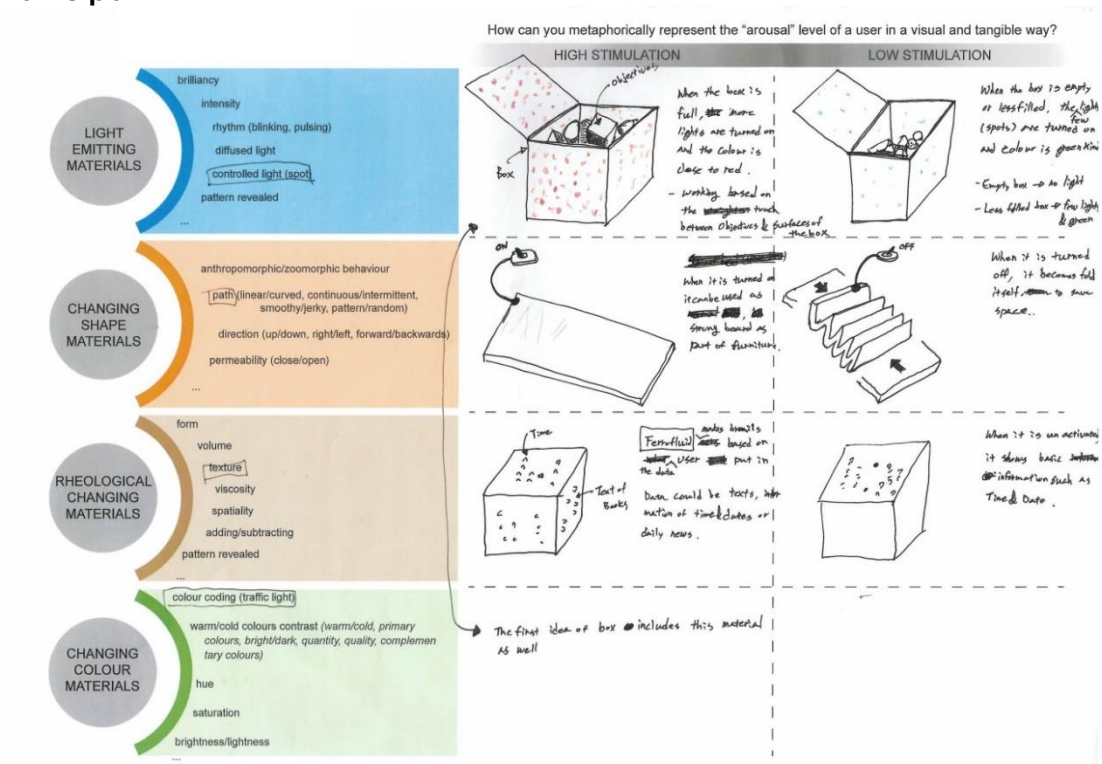
2) Findings from the workshop

Participant 1



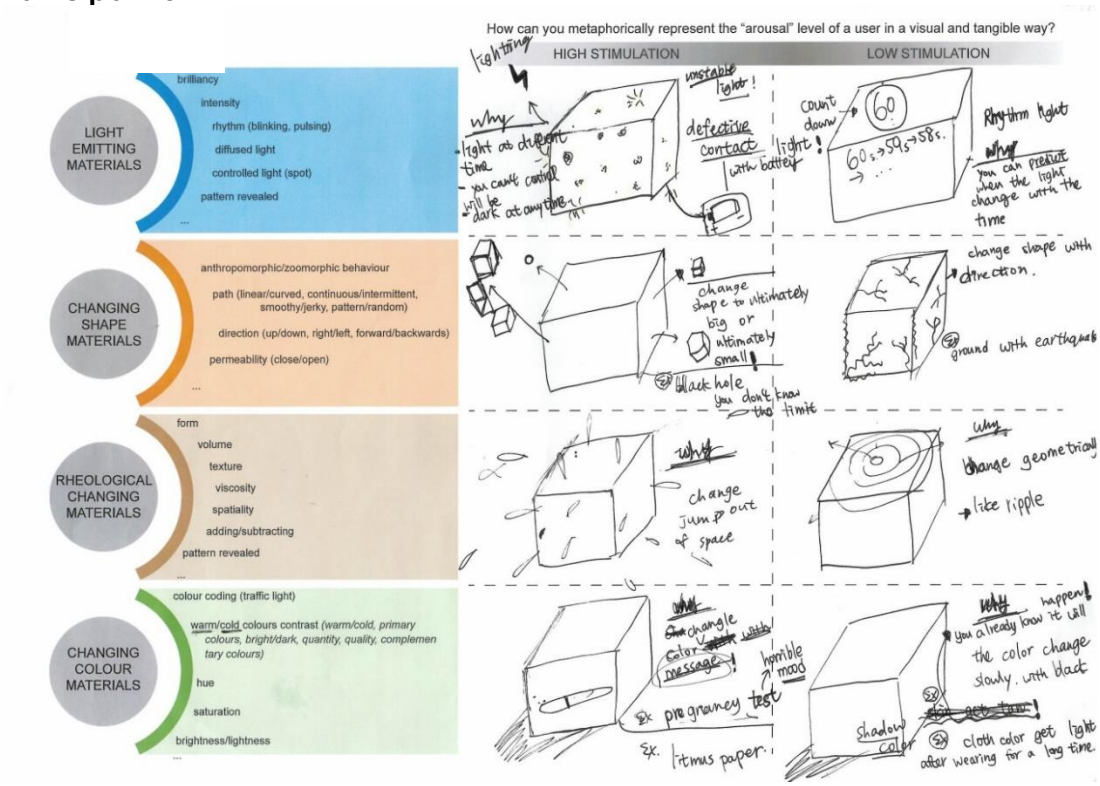
Participant 1 (Mary, Female, 26-year-old) represented the high stimulation status with all the surfaces of the cube spreading an intense and uniform light that gently pulses on one surface to simulate the low stimulation effect. The *Changing Shape Materials* have been interpreted to shape a continuous opening/closing of flaps and a further suggestion was given by the slightly collapsing shape of the box, following the up/down direction, representing the low stimulation. *Rheological Changing Materials* were adopted with the idea to radically change the shape of the box with the intent to represent the high stimulation of the user (*"box becoming a sphere"*). *Changing Colour Materials* were used to highlight the full/empty effect of the box with the low stimulation effect achieved through the combination of transparency and colourful effects.

Participant 2



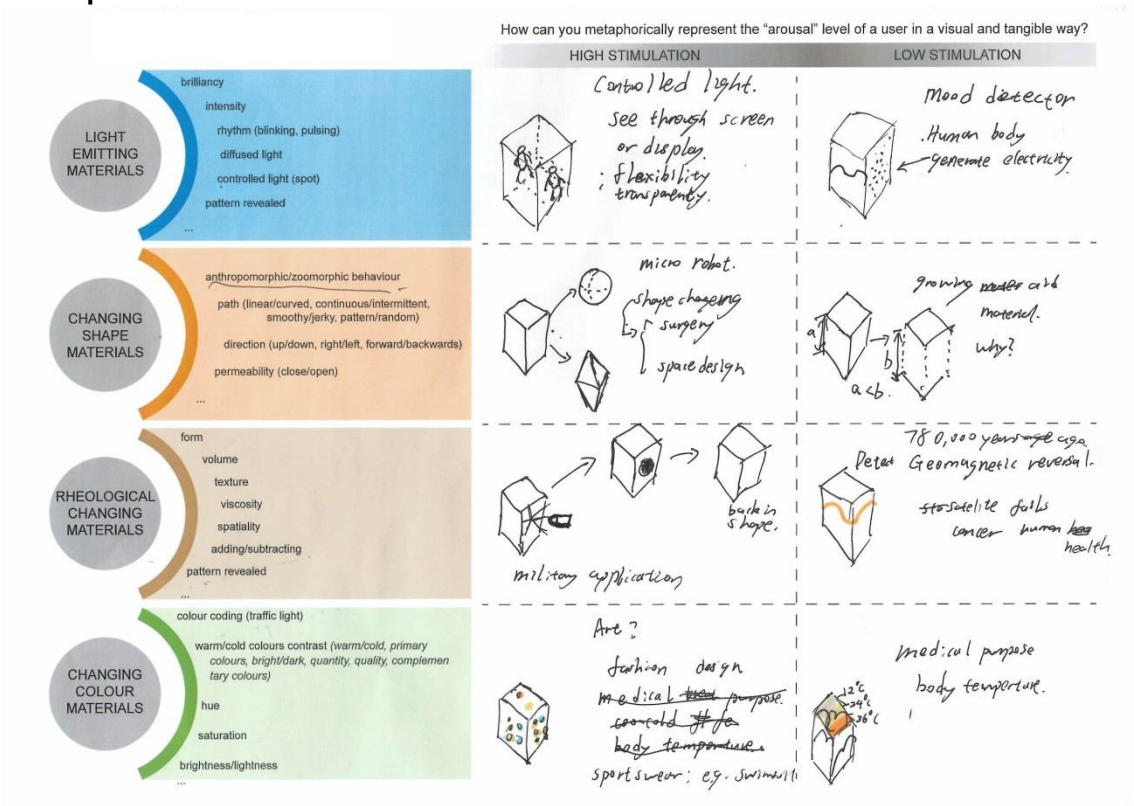
The second participant (Bob, Male, 32-year-old) interpreted the white box as a dynamic object that can be shaped to serve multiple purposes. In the embodiment of *Light Emitting Materials*, the cube was considered as a box container that shows the number of objects contained in with lighting signals. When full, several red spotlights light up the surfaces of the box reproducing the high stimulation of the container itself. The spotlights reduce gradually and change their colours towards green hues when the box is partially empty, generating a sense of low stimulation. The arousal effect was furthermore represented through the flat/crinkling surface recreating a sense of expansion/contraction imagined with the application of the *Changing Shape Materials*. The *Rheological Changing Materials* found an application as a 'braille' language. This descriptive application reproduces the higher/lower stimulation through the amount of data shared and by their spatial representation on one or more surfaces of the cube.

Participant 3



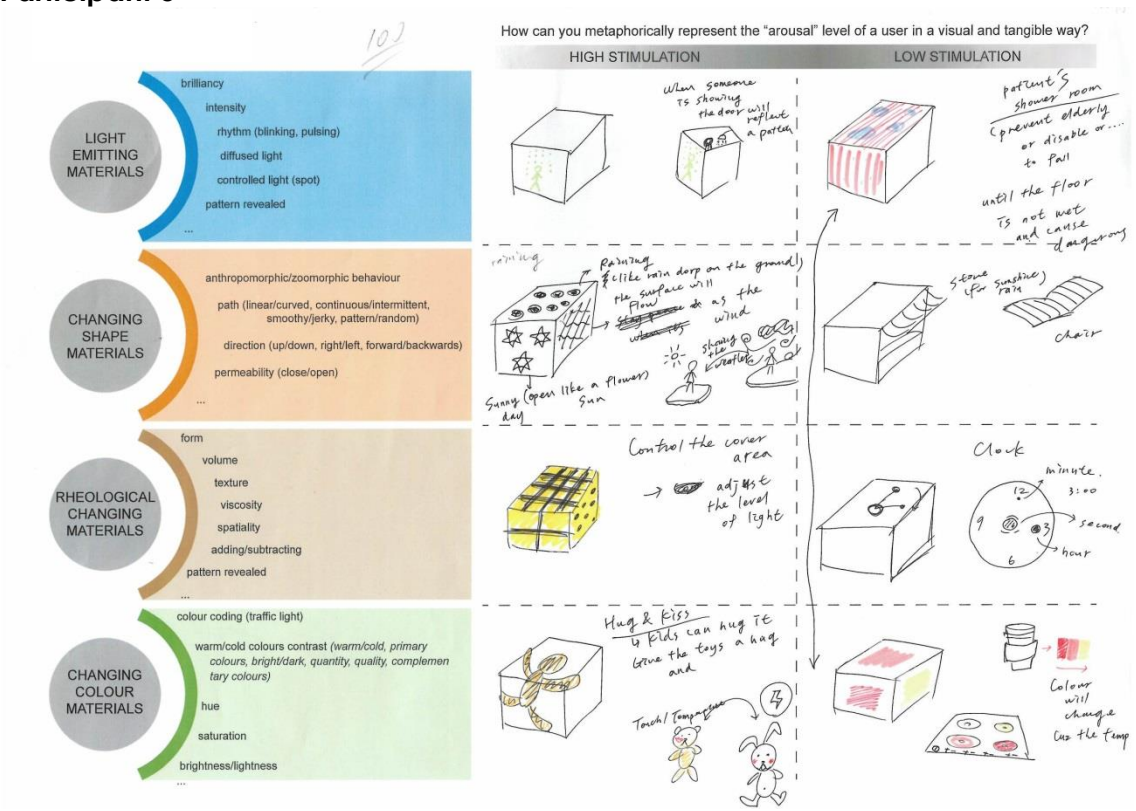
The third participant (Ning, Female, 24-year-old) adopted the *Light Emitting Materials* as unstable lights that suddenly change from bright to dark to represent the high stimulation status and clear and precise sequence of brightness and darkness effects to communicate low stimulation sensations. This participant stressed the predictability/unpredictability of the light effect by adding a timer to show exactly when the light will change and therefore recall a low stimulation stimulus. The *Changing Shape Materials* were adopted for their ability to achieve big/small shapes. Interestingly, the low stimulation was represented by a dramatic change of the shape that will eventually follow a clear direction and pattern. The *Rheological Changing Materials* were interpreted with the intent to simulate a composed, calm, and ripple-like pattern (low stimulation) in contrast with a compulsive and chaotic splash-like effect (high stimulation). Lastly, *Changing Colours Materials* were adopted as shadows (representing low stimulation) and bright, catching and alarming colours (like a pregnancy test) to represent the high stimulation status.

Participant 4



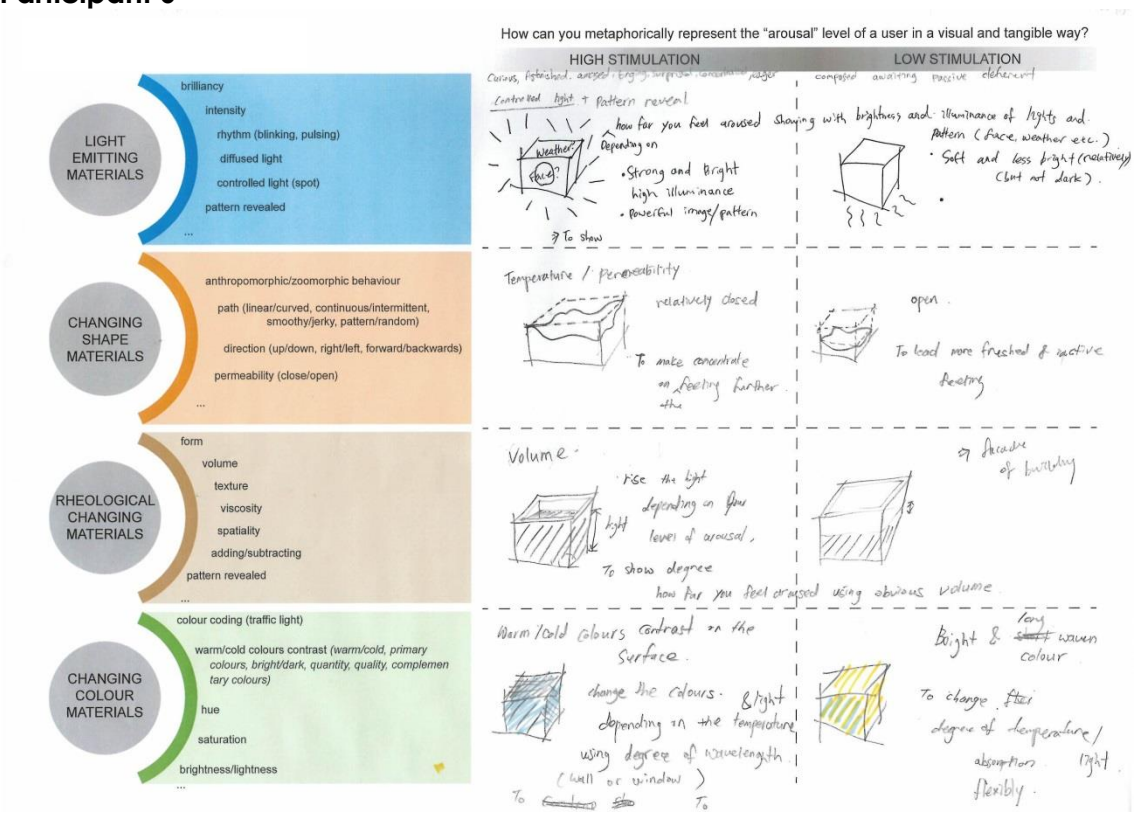
The fourth participant (Lang, Male, 22-year-old) interpreted the box as a 'mood detector' where transparency plays an important role. When fully transparent, the box reveals the lighting outline of a man (high stimulation) that gradually fades away by creating scattered dots, communicating the low stimulation of the user. This participant adopted the *Changing Shape Materials* for their ability to follow a defined or a random direction of movement: the box switches from a shape to another through a random pattern to represent the high stimulation status, while the up/down direction represents the low stimulation. No clear information can be observed for the remaining two materials.

Participant 5



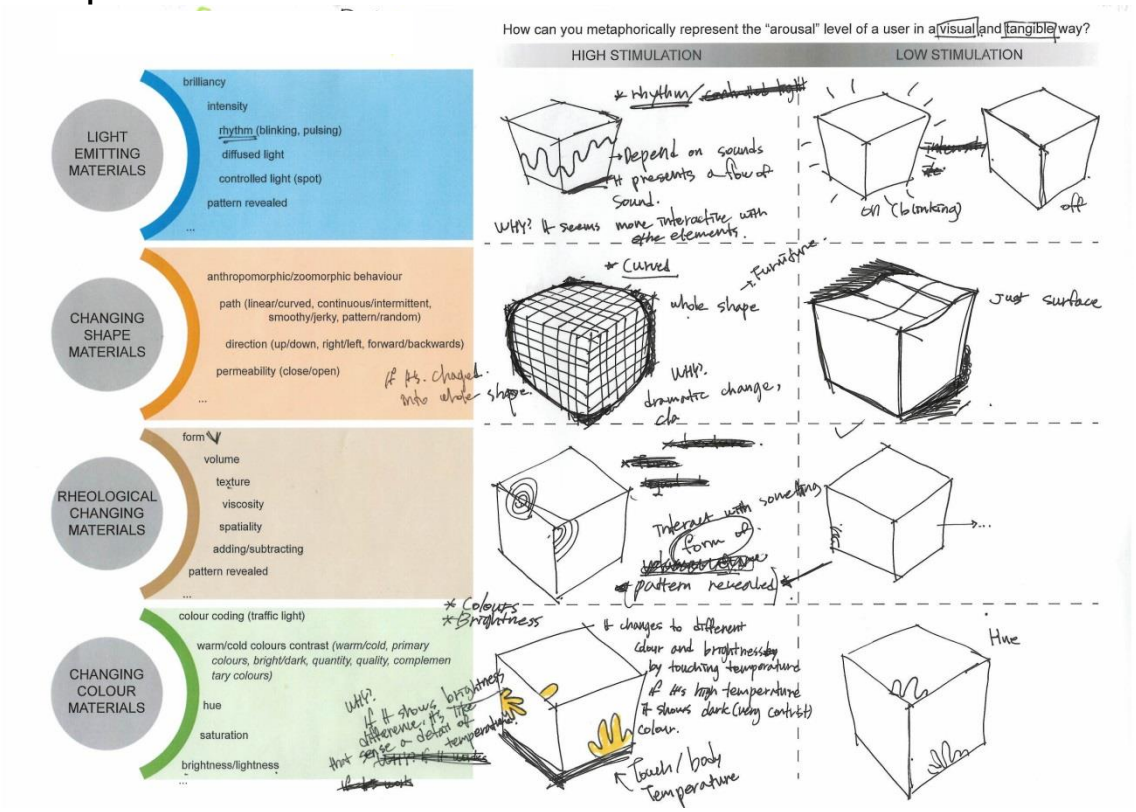
The fifth participant (Liu, Female, 24-year-old), considered the box as a living space, like a shower. *Light Emitting Materials* were interpreted to enrich the surfaces of the box, considered as a functional space: the shape of the user using the box (for example as a shower) can be revealed maximising the effect of the activity performed (high stimulation) or it can be blurred to create a private and reassuring environment. Transparency effects are therefore important and lights can work as a filter to go through the shape of the box or stay on the surface of it. The *Changing Shape Materials* support the idea to represent nature-inspired shapes (a sun-like shape that opens like flowers, moving rain drops, flowing water-like surface corrugated by the wind) that rise to communicate high stimulation. The concept of 'transparency' and *Rheological Changing Materials* was also interpreted to filtered out light from within the box and communicate a number of activities the user is performing. Moreover, these materials were embodied in a more descriptive way like a clock, where dots of different sizes can give the idea of minutes and hours spent doing an activity. The last material did not receive a clear interpretation.

Participant 6



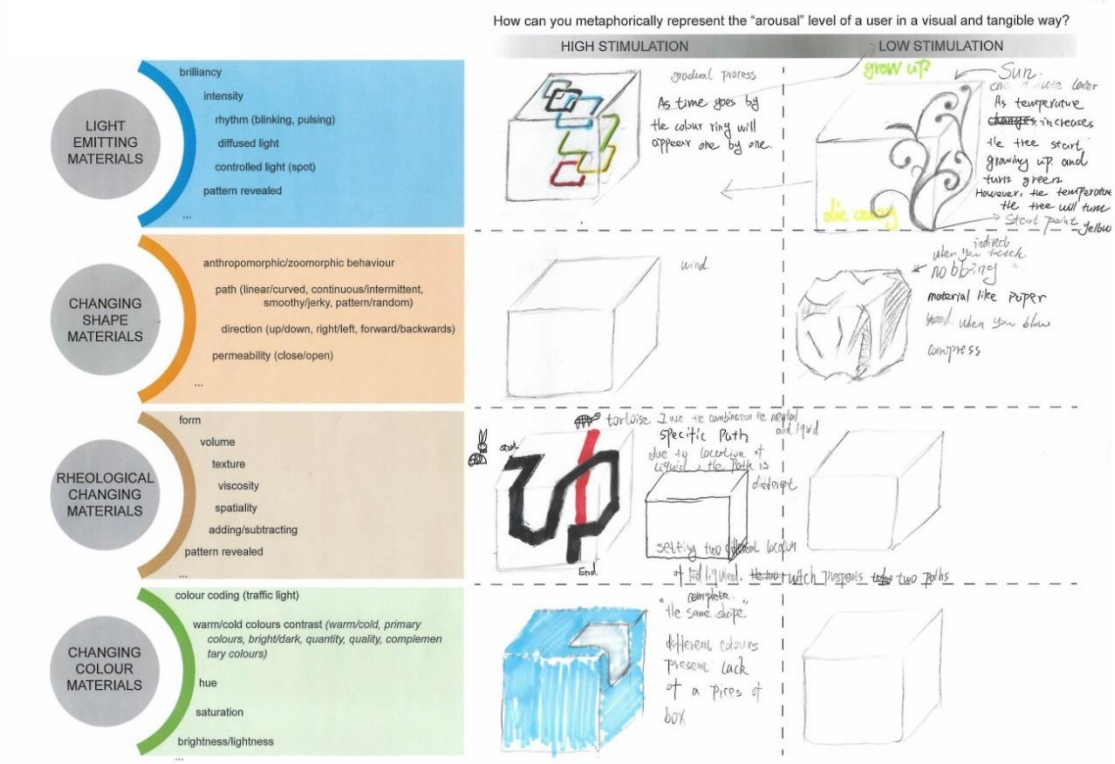
The sixth participant (Yin Jang, Female, 25-year-old) adopted strong and bright lights, with high illuminance, to cover all the surfaces of the box and convey a sense of high stimulation; the reduction of the brightness and the application of light over a limited area of the cube was interpreted as a sense of low stimulation. The *Changing Shape Materials* were applied to communicate a sense of concentration (closure, being focus, high stimulation) and the idea of openness through the permeability of the shape (open/close pattern). *Rheological Changing Materials* appeared appropriate to represent the level of stimulation by a continuous change in the volume that rises (high stimulation) and decreases (low stimulation). *Changing Colours Materials* have been applied adopting their potential to dynamically embody warm/cold colours contrast patterns. This participant considered the box as made of fabric where the woven connections can get the brighter or darker colours depending of the low or high stimulation the box wants to communicate; specifically, the cube has been interpreted as a 'change in temperature' detector, where outdoor lights is absorbed or reflected to convey the warm-cold sensation.

Participant 7



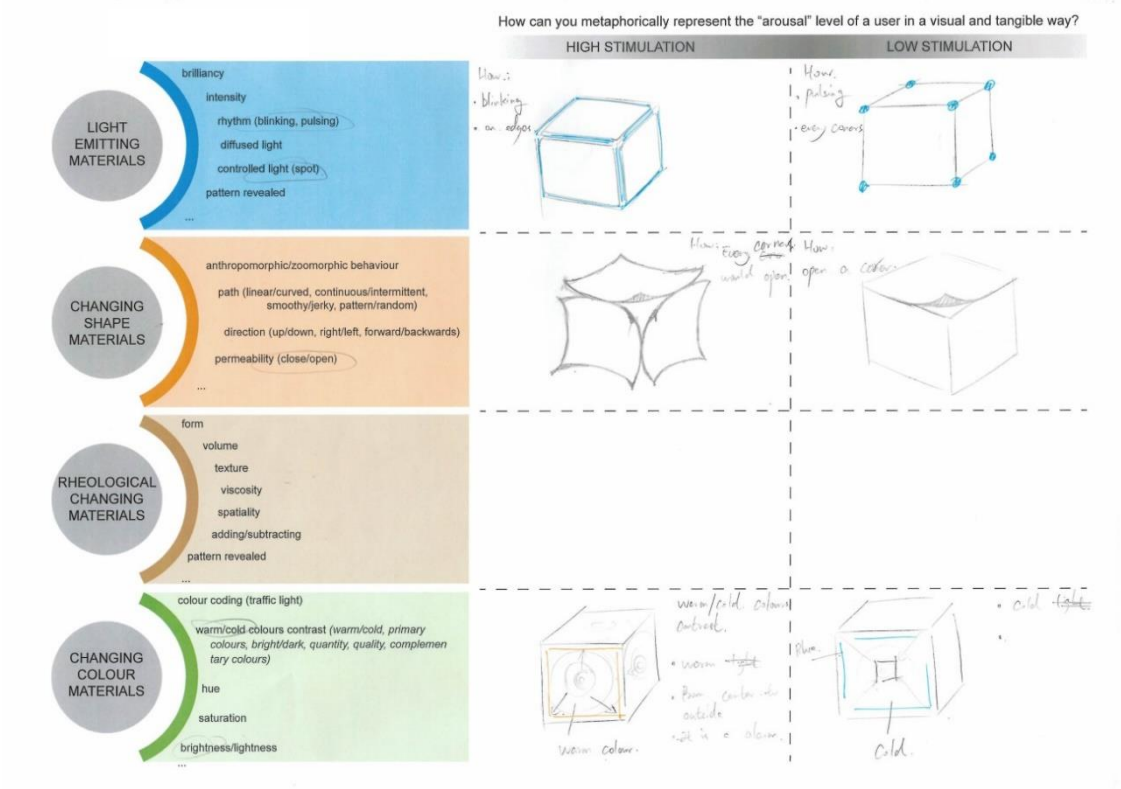
The seventh participant (Jisun, Female, 24-year-old), considered the rhythm of lights as an effective way to represent the level of stimulation of the human body. The high stimulation has been represented as a flow of lighting waves, whereas the on/off effects of blinking light embodied the low stimulation. *Changing Shape Materials* were adopted to communicate the level of activity of the user through a distortion of the whole cube (high stimulation) or just one surface (low stimulation). *Rheological Changing Materials* were adopted to reveal a pattern that gradually fades away to convey the idea of the reduction of stimuli of the user. The ability of *Changing Colour Materials* to modulate their brightness is once again adopted to maximise the effect of high/low contrast of colours and therefore communicate high stimulation (high colour contrast) and low stimulation (low colour contrast).

Participant 8



The eighth participant (Kate, Female, 24-year-old) shaped the *Light Emitting Materials* to create geometrical and sinuous shapes to represent both high and low stimulation. While in the high stimulation there will be the overlapping of different lighting layers that complete a pattern, in the low stimulation status a floral and nature-like pattern inspires this message. High and low stimulation is also represented by the transition from one shape to another in an expansion/compression effect, where the latter mimics a low stimulation and lower inclusion. The *Rheological Changing Materials* were adopted to shape a pattern on the surfaces of the box; the completion of each pattern composed indicates a specific activity performed and how far the user is from completing it. A similar concept of 'completion of a pattern' has been used with the *Changing Colours Materials* where the fully coloured shape indicates the activities performed and, therefore, the high stimulation of the user.

Participant 9



The last participant (Liu Park, Male, 24-year-old), applied the rhythm of lights to represent the high/low stimulation. The high stimulation effect is communicated through the blinking edges of the cube, while the low stimulation by pulsing effects at the corners of the cube. The Changing Shape Materials are interpreted as the possibility to enhance the 'permeability' of the cube. When only one surface bends, it is intuitive to perceive a lower level of stimulation is communicated, while the high stimulation is suggested when all the surfaces bend. In regard of the Changing Colour Materials, the application of the warm/cold colour contrast has been applied in combination with a defined sequence of appearance: cold colours were adopted to create a movement from the centre of the surface of the cube toward the edges representing a sense of expansion and therefore high stimulation, while the cold colours were applied from the edges toward the inner part of the surface, communicating a sense of contraction and low stimulation.

Appendix L

Report from the Pilot Study

1) The following table shows a detailed list of participants of the Pilot Study as they were distributed into two groups, younger adults (N = 13) and older adults (N = 4).

LIST OF YOUNGER ADULTS PARTICIPANTS				LIST OF OLDER ADULTS PARTICIPANTS			
Fictional name	*Age*	*Gender*	*Technology Familiarity score*	*Fictional name*	*Age*	*Gender*	*Technology Familiarity score*
Bob	22	M	66	*Bridget*	70	F	45
Aryanna	22	F	77	*John*	75	M	46
James	22	M	72	*Cheryl*	76	F	21
Richard	22	M	51	*Hanna*	76	F	17
Victor	22	M	62				
Andrea	24	M	78				
Merzad	25	M	42				
Liu	26	F	62				
Priya	27	F	48				
Abeer	28	M	71				
Alexis	28	F	74				
Bilal	29	M	61				
Adam	29	M	61				

2) Percentage of participants matching the Designer Model of the Function Representation, reporting 'scattered' and 'other' answers in both age groups investigated during the Pilot Study

		Younger adults			**Older adults**		
		Percentage (%) of participants who matched the Designer Model	Percentage (%) of participants who reported scattered answers	Percentage (%) of participants who reported 'other' answers	Percentage (%) of participants who matched the Designer Model	Percentage (%) of participants who reported scattered answers	Percentage (%) of participants who reported 'other' answers
Light Emitting Materials	Analogical messages	41.3	8.7	0	21.9	12.5	15.6
	Metaphorical messages	42.3	7.7	0	25.0	21.9	3.1
	TOT	**83.7**	16.3	**0**	**46.9**	34.4	18.8
Changing Shape Materials	Analogical messages	44.2	5.8	0	40.6	9.4	0
	Metaphorical messages	23.1	26.9	0	18.8	28.1	3.1
	TOT	**67.3**	32.7	**0**	**59.4**	37.5	3.1
Rheological Changing Materials	Analogical messages	42.3	7.7	0	34.4	12.5	3.1
	Metaphorical messages	19.2	30.8	0	21.9	15.6	12.5
	TOT	**61.5**	38.5	**0**	**56.3**	28.1	15.6
Changing Colour	Analogical messages	38.5	10.5	1	12.5	28.1	9.4

Materials	Metaphoric al messages	29.8	18.2	2	9.4	40.6	0
	TOT	**68.3**	28.8	2.9	**21.9**	68.8	9.4

3) Percentage of participants 'matching' the Designer Model of the Function Representation**,** reporting 'scattered' and 'other' answers in each signal presented in the Pilot Study. The green colour highlights signals where the percentage of their 'matches' did not exceed the sum percentages of either 'scattered'/'other' answers.

			Younger adults				**Older adults**			
SMs	Signals	Type of messages	Participants who matched the Designer Model (%)	Participants who reported scattered answers (%)	Participants who reported 'other' answers (%)	**TOTAL (%) ('scattered' + 'other') answers**	Participants who matched the Designer Model (%)	Participants who reported scattered answers (%)	Participants who reported 'other' answers (%)	**TOTAL (%) ('scattered' + 'other') answers**
Light Emitting Materials	*Signal 1.1*	*Analogical*	84.6	15.4	0.0	15.4	25.0	50.0	25.0	75.0
	Signal 1.2		76.9	23.1	0.0	23.1	50.0	0.0	50.0	50.0
	Signal 1.3		84.6	15.4	0.0	15.4	50.0	25.0	25.0	50.0
	Signal 1.4		84.6	15.4	0.0	15.4	50.0	25.0	25.0	50.0
	Signal 1.5	*Metaphorical*	92.3	7.7	0.0	7.7	100.0	0.0	0.0	0.0
	Signal 1.6		76.9	23.1	0.0	23.1	25.0	75.0	0.0	75.0
	Signal 1.7		69.2	30.8	0.0	30.8	25.0	75.0	0.0	75.0
	Signal 1.8		100.0	0.0	0.0	0.0	50.0	25.0	25.0	50.0
Shape	*Signal*	*Analogical*	84.6	15.4	0.0	15.4	50.0	50.0	0.0	50.0

	2.1									
	Signal 2.2		92.3	7.7	0.0	7.7	100.0	0.0	0.0	0.0
	Signal 2.3		84.6	15.4	0.0	15.4	75.0	25.0	0.0	25.0
	Signal 2.4		92.3	7.7	0.0	7.7	100.0	0.0	0.0	0.0
	Signal 2.5	*Metaphorical*	61.5	38.5	0.0	38.5	50.0	50.0	0.0	50.0
	Signal 2.6		69.2	30.8	0.0	30.8	75.0	25.0	0.0	25.0
	Signal 2.7		38.5	61.5	0.0	61.5	25.0	50.0	25.0	75.0
	Signal 2.8		15.4	84.6	0.0	84.6	0.0	100.0	0.0	100.0
Rheological Changing Materials	*Signal 3.1*	*Analogical*	92.3	7.7	0.0	7.7	75.0	25.0	0.0	25.0
	Signal 3.2		76.9	23.1	0.0	23.1	50.0	25.0	25.0	50.0
	Signal 3.3		76.9	23.1	0.0	23.1	50.0	50.0	0.0	50.0
	Signal 3.4		92.3	7.7	0.0	7.7	100.0	0.0	0.0	0.0
	Signal 3.5	*Metaphorical*	15.4	84.6	0.0	84.6	50.0	25.0	25.0	50.0
	Signal 3.6		53.8	46.2	0.0	46.2	50.0	25.0	25.0	50.0
	Signal 3.7		0.0	100.0	0.0	100.0	50.0	25.0	25.0	50.0
	Signal 3.8		84.6	15.4	0.0	15.4	25.0	50.0	25.0	75.0
ing Colour	*Signal 4.1*	*Analogical*	61.5	38.5	0.0	38.5	25.0	75.0	0.0	75.0

	Signal 4.2		76.9	15.4	7.7	23.1	25.0	50.0	25.0	75.0
	Signal 4.3		76.9	23.1	0.0	23.1	0.0	75.0	25.0	100.0
	Signal 4.4		92.3	7.7	0.0	7.7	50.0	25.0	25.0	50.0
	Signal 4.5	*Metaphorical*	46.2	53.8	0.0	53.8	0.0	100.0	0.0	100.0
	Signal 4.6		76.9	23.1	0.0	23.1	0.0	100.0	0.0	100.0
	Signal 4.7		46.2	53.8	0.0	53.8	0.0	100.0	0.0	100.0
	Signal 4.8		69.2	15.4	15.4	30.8	75.0	25.0	0.0	25.0

4) Extended report of the main differences and similarities in the interpretation of the Smart Radio as reported by participants of the Pilot Study.

- **Younger adults consider visual signals more familiar and able to catch their attention.**

Abeer (28 years old, Female), claimed that "*light signals work perfectly, especially when supported by an amplified stimulus, such as sound + light*". Playing with vision has a strong effect on the user perception and signals shown provide a general understanding of the situation with no effort (Bob 22 years old, Male – James 22 years old, Male - Andrea (24 years old, Male). Bilal (29 years old, Male) said that lights have the strength to always catch the attention of the user and if the aim is to deliver a message, then lights work properly. Victor (22 years old, Male) suggested working on the pulsing lights as a basic message in combination with the changing colours show the different level of activity of the connected user. Andrea (24 years old, Male) said that the adoption of colours is weak because the colourful patterns rely on personal interpretation and their meaning is not clear. He suggested combining *Light Emitting Materials* with *Changing Colour Materials* for an intuitive message: "*Instead of adopting colourful signals, would be appropriate to have one colour + one light signal (e.g.: pulsing light and green colour, blinking light and red colour)*". Similarly, Richard (22 years old, Male) rose the same point: "*Colours are confusing if not used with*

colour coding. The colourful pattern is not clear, especially in signals 4.6, 4.7. They have a similar spectrum so is not clear the difference". He envisioned the potential of the combination of the pulsing lights with the *Rheological Changing Materials* because "*…you can clearly see something changing*". The combination of *Light Emitting Materials* and *Changing Colour Materials* seems appropriate to create a powerful signal for Merzad (25 years old, Male). Aryanna (22 years old, female) said that: "*working with animation plus colours could be helpful but is important to keep in mind that colour coding reflects a specific culture; red as vivid and hot is just in a specific culture so could not potentially work with everyone. Working with animation would help*".

- **Younger adults consider haptic signals too ambiguous.**

James (22 years old, Male) considered the Rheological Changing Materials still "*too abstract and vague*". He said that this interface: "*…is not intuitive, so it is important to add some parameters and features that shape it in an intuitive way. The first four messages of the Rheological Changing Materials were kinematic and clear because the user could see the fluid moving. A good solution would be adding some speed and motion to reflect the user movements*". Bilal (29 years old, Male), said that: "*Rheological Changing Materials have a lot potential because of the movement involved. It creates entertainment and you can understand the activity simply watching the motion of the fluid. The touch is not even necessary*". Victor (22 years old, Male) said "*The touch interface created by the Rheological Changing Materials is amazing!*" and he suggested to adopt only one code (dimension or space of the dynamic shapes) to simplify the understandability of the message and avoid confusion. Aryanna (22 years old, female) also affirmed that Rheological Changing Materials create interesting interaction but the distance between bubbles should be represented by speed and movement: "Movement of shape should reflect the movement of the user". Interestingly, she claimed that the Changing Shape Materials: "*…remind me a yoga position (signal 3.8) and the soft movement is a good way to express relaxation*". Alexis (28 years old, Male) noticed a potential in the combination of the Changing Shape Materials with the Changing Colour Materials to clarify the information provided. He said: "*Changing Shape Materials were a bit difficult to understand but once you get the general coding and meaning of the different shapes, they appear really powerful*". Priya (27 years old, Female), was also impressed by the novelty of the Changing Shape and Rheological Changing Materials: "*I've never thought we could have interfaces that change their shape. It would be interesting to add vibration to the liquid in order to shape the actual activity to recall. This will provide more*

haptic information about the user". Richard (22 years old) suggested a combination of Light Emitting Materials and Rheological Changing Materials to work with both haptic and visual effects and maximise the way the message can be understood. A similar comment is given by Liu (26 years old, Female), saying that the analogical on/off message shaped by lights is intuitive and familiar while Changing Shape Materials and Rheological Changing Materials create the 'surprise effect' resulting in a highly entertaining interaction.

- **Older adults prefer haptic signals over visual signals.**

Hanna (76 years old, Female) explained that the adoption of symbols to shape analogical messages has to be kept simple and, in this way, she thinks the *Changing Shape Materials* can really convey an immediate message. She said that colours are not as immediate as they should; she noticed there was a colour coding after she went through the four analogical signals. Cheryl (76 years old, Female) claimed that *Changing Colour Materials* were not that intuitive and that they can work exclusively in combination with *Light Emitting Materials*. Hanna (76 years old, Female) said that *Colour Changing Materials* appear confusing, especially signals 4.6 and 4.7 where differences between them are not perceived. She suggested a correlation with a clear colour coding: blue-relaxed, red-active. In her opinion the *Rheological Changing Materials* are not working in terms of metaphorical messages. Nonetheless, she appreciated the effects created by the *Changing Shape Materials*, that must be implemented to make clear the different heights of the changing surfaces to build a robust meaning.

Feedbacks were provided about the overall evaluation of the Smart Radio, in terms of quality of interaction and its potential application in a real context of use.

- **Younger adults demand a clarification of the four ' human status' to be shared**

Bob (22 years old, Male) suggested to thoroughly clarifying the differences between the four stages of the activity of the connected user. Liu (26 years old, Female) noticed that subtle information are not always understandable (e.g. active but relaxed and stimulated but quiet) and she suggested to also sharing the music each connected user is listening in for a deeper interaction. Similar comment is provided by Andrea (24 years old, Male), Adam (29 years old, Male) and Merzad (25 years old, Male) saying that would be interesting to enhance the signals with audio feedback in the background to understand what the user is doing or just signals to catch the attention of the user when someone wants to communicate through the Smart Radio, as expressed by Alexis (28 years old, Male). Andrea

(24 years old – Male) stressed the importance to enhance the message sent: *"a good way is to work on the 5 senses. The radio should rebuild how the user perceives the activity/situation he is living with his 5 senses"*. For Andrea, an indicator of the actual movement of the user would also be beneficial: "*being highly stimulated doesn't really mean the user is moving..."*

- **Younger adults would prefer a simplified interaction: not symbols but touch-based interaction**

The way symbols adopted in the analogical messages appears extremely confusing for Aryanna (22 years old, Female); she reported how difficult was for her to get "*which one is which*" because they are mainly based on the cultural background of the user resulting not inclusive of the whole population. Considering the adoption of intuitive signals, she noticed how "*…for us is really familiar the sound of the waiting calls of the landline. You know when the user is busy or the phone is clear. To improve the concept, it is important to consider familiar signals, Icons could be misleading. The improvement of the communication could be achieved through the adoptions of familiar drawings*". She further suggested to simplify the interaction with the first knob in order to improve the communication and let the user understand when the device is actually sending/receiving information: "*maybe a touch gesture should be added to work on the intuitiveness: when I touch the device I send a message and the message could be an icon like and heart or a hand.*".

- **Both younger and older adults would like the Smart Radio to communicate emotions and health parameters**

Aryanna envisaged how important was for her to "share emotions, not just the level of activity, otherwise the message is misleading...when the user is highly active could potentially be in danger! So, the device could be stressful. Could the music communicate the feeling of the user in combination with the SMs signals?" Working on the emotions has, for Aryanna, the strength to create personalised messages based on the user who is communicating and therefore has a unique device. For James (22 years old, Male), it was relevant to create an emotional bond with the connected user through the Smart Radio and he suggested to enrich the interaction with a touch input. Adam (29 years old – Male) reported the importance to represent, somehow, the 'mood' of the person you are listening to. Richard (22 years old, Male) reinforced the idea that sharing emotion would add value to the device. Moreover, the introduction of some indicator of safety would be really interesting for him. He said: "would be great to understand where the user you are listening to is; it is nice to see whether he is active or not, but it is also important to

understand what he is actually doing. There could be only one button: "I'm not at home". Another signal that can be introduced is the availability to talk; each user can send a message when he/she wants to talk with someone." Andrea (24 years old, Male) suggested representing basic health parameters, like the heart rate. Priya (27 years old, Female) reported the importance to get a hint that your peers are fine. For Hanna (76 years old, Female) the addition of sound will be beneficial to recall the attention of the user. Moreover, she envisaged the potential of the device to be a monitoring device of falling detection in a non-intrusive way: "the idea to have a wristband is interesting but in order not to be intrusive, the bracelet should detect information itself. No button to be pressed!" In terms of the quality of the information shared, she said: "Communicating the heart rate is also interesting and it should communicate in an engaging way. In this way, everyone can get an idea if you are happy or worried. Emotions are not really communicated by words and this device can help you in doing so".

Appendix M

Report from the Smart Radio evaluation

1) The following table shows a detailed list of participants of the Main Study as they were distributed into two groups, under 60 years old (n = 31) and over 60 years old (n = 31).

UNDER-60-YEAR-OLD PARTICIPANTS				OVER-60-YEAR-OLD PARTICIPANTS			
Fictional name	Age	Gender	*Technology Familiarity score*	Fictional name	Age	Gender	*Technology Familiarity score*
William	21	M	51	*Sophia*	60	F	51
Samantha	24	F	82	*Diana*	60	F	45
Horacio	24	M	70	*Sharon*	63	F	7
Johnny	25	M	70	*Rose*	63	F	55
Anita	26	F	67	*Deborah*	64	F	44
Jenny	26	F	57	*Katrine*	65	F	35
Gianpaolo	27	M	74	*Ivan*	67	M	66
Mario	27	M	45	*Nick*	68	M	48
Marta	28	F	53	*Stevie*	69	M	84
Mary	28	F	53	*Allison*	69	F	50
Antonio	28	M	62	*Eddie*	70	F	19
Janet	28	F	66	*Mary*	70	F	12
Gabriele	29	M	60	*Sally*	70	F	23
Nastaran	30	F	92	*Whitney*	71	F	64

Bobby	30	M	60	*Stella*	71	F	57
Chul	32	M	66	*Sasha*	71	F	56
Janet	32	F	74	*Susan*	72	F	35
Alexandra	34	F	71	*Billy*	72	M	61
Paola	36	F	75	*Dany*	73	F	70
Stijn	39	M	48	*Abigail*	73	F	46
Paul	40	M	50	*Franky*	74	M	18
Margaret	42	F	44	*Rachel*	75	M	24
Estrella	44	F	71	*Justin*	75	M	51
Francesco	45	M	75	*Jessica*	76	F	12
Matthew	50	M	76	*Elizabeth*	76	F	36
Lyly	25	F	60	*Rachel*	77	F	10
Camilla	53	F	49	*Audrey*	77	F	21
Betty	56	F	39	*Jerry*	77	M	19
Tony	58	M	61	*Natalie*	83	F	29
Victoria	58	F	70	*Janine*	84	F	8
Mark	59	F	49	*Maggie*	84	F	0

2) Results from the Mann-Whitney U Test conducted to seek for a significance difference between 'matches', 'scattered' and 'others' answers given by the two samples

	Matches Light Emitting Materials	**Scattered** Light Emitting Materials	**Others** Light Emitting Materials	**Matches** Changing Shape Materials	**Scattered** Changing Shape Materials	**Others** Changing Shape Materials
Mann-Whitney U	436.5	375.	435.	417.5	399.	476.6
Asymp. Sig. (2-tailed)	.522	.116	.365	.366	.241	.913
	Matches Rheological Changing Materials	**Scattered** Rheological Changing Materials	**Others** Rheological Changing Materials	**Matches** Changing Colour Materials	**Scattered** Changing Colour Materials	**Others** Changing Colour Materials
Mann-Whitney U	480.5	454.5	465.	396.0	439.	432.5
Asymp. Sig. (2-tailed)	1.0	.710	.743	.227	.553	.219

a. Grouping

Variable: age

2) Percentage of participants matching the Designer Model of the Function Representation, reporting 'scattered' and 'other' answers in both age groups investigated during the Main Study

		Under 60-years-old			**Over 60-years-old**		
		Percentage (%) of participants who matched the Designer Model	Percentage(%) of participants who reported 'scattered' answers	Percentage(%) of participants who reported 'other' answers	Percentage (%) of participants who matched the Designer Model	Percentage(%) of participants who reported 'scattered' answers	Percentage(%) of participants who reported 'other' answers
Light Emitting Materials	*Analogical messages*	43.1	5.2	1.6	35.1	13.3	1.6
	Metaphorical messages	40.3	7.7	2.0	42.3	6.9	0.8
	TOT	**83.5**	**12.9**	**3.6**	**77.4**	**20.2**	**2.4**
Changing Shape Materials	*Analogical messages*	44.8	4.8	0.4	38.3	10.5	1.2
	Metaphorical messages	24.6	22.6	2.8	25.0	24.2	0.8
	TOT	**69.4**	**27.4**	**3.2**	**63.3**	**34.7**	**2.0**
Rheological Changing Materials	*Analogical messages*	41.5	8.5	0.0	40.3	7.3	2.4
	Metaphorical messages	18.1	26.2	5.6	19.4	25.0	5.6
	TOT	**59.7**	**34.7**	**5.6**	**59.7**	**32.3**	**8.1**
Changing Colour Materials	*Analogical messages*	37.5	12.5	0.0	34.7	13.3	2.0
	Metaphorical messages	24.6	19.0	6.5	33.1	16.9	0.0

	TOT	**62.1**	**31.5**	**6.5**	**67.7**	**30.2**	**2.2**

3) Percentage of participants 'matching' the Designer Model of the Function Representation, reporting 'scattered' and 'other' answers in each signal presented in the Main Study. The green colour highlights signals where the percentage of their 'matches' did not exceed the sum percentages of either 'scatter'/'other' answers.

			Under-60-year-old participants				**Over-60-year-old participants**			
Family of Smart Materials	Signals	Type of messages	Participants who matched the Designer Model (%)	Participants who reported scattered answers (%)	Participants who reported 'other' answers (%)	**TOTAL (%) ('scattered' + 'other') answers**	Participants who matched the Designer Model (%)	Participants who reported scattered answers (%)	Participants who reported 'other' answers (%)	**TOTAL (%) ('scattered' + 'other') answers**
Light Emitting Materials	*Signal 1.1*	*Analogical*	**87.1**	9.7	3.2	**12.9**	**67.7**	25.8	6.5	**32.3**
	Signal 1.2		**80.6**	19.4	0.0	**19.4**	**77.4**	22.6	0.0	**22.6**
	Signal 1.3		**100.0**	0.0	0.0	**0.0**	**83.9**	16.1	0.0	**16.1**
	Signal 1.4		**77.4**	12.9	9.7	**22.6**	**51.6**	41.9	6.5	**48.4**
	Signal 1.5	*Metaphorical*	**93.5**	3.2	3.2	**6.5**	**93.5**	6.5	0.0	**6.5**
	Signal 1.6		**74.2**	22.6	3.2	**25.8**	**83.9**	12.9	3.2	**16.1**
	Signal 1.7		**64.5**	29.0	6.5	**35.5**	**80.6**	19.4	0.0	**19.4**
	Signal 1.8		**90.3**	6.5	3.2	**9.7**	**80.6**	16.1	3.2	**19.4**
e Chan ging	*Signal 2.1*	*Analo gical*	**80.6**	16.1	3.2	**19.4**	**58.1**	32.3	9.7	**41.9**

	Signal 2.2		**96.8**	3.2	0.0	**3.2**	**83.9**	16.1	0.0	**16.1**
	Signal 2.3		**83.9**	16.1	0.0	**16.1**	**67.7**	32.3	0.0	**32.3**
	Signal 2.4		**96.8**	3.2	0.0	**3.2**	**96.8**	3.2	0.0	**3.2**
	Signal 2.5	*Metaphorical*	**58.1**	32.2	9.7	**41.9**	**58.1**	38.7	3.2	**41.9**
	Signal 2.6		**51.6**	45.2	3.2	**48.4**	**54.8**	45.2	0.0	**45.2**
	Signal 2.7		**48.4**	48.4	3.2	**51.6**	**45.2**	54.8	0.0	**54.8**
	Signal 2.8		**38.7**	54.8	6.5	**61.3**	**41.9**	54.8	3.2	**58.1**
Rheological Changing Materials	*Signal 3.1*	*Analogical*	**96.8**	3.2	0.0	**3.2**	**83.9**	12.9	3.2	**16.1**
	Signal 3.2		**74.2**	25.8	0.0	**25.8**	**80.6**	16.1	3.2	**19.4**
	Signal 3.3		**74.2**	25.8	0.0	**25.8**	**77.4**	12.9	9.7	**22.6**
	Signal 3.4		**87.1**	12.9	0.0	**12.9**	**80.6**	16.1	3.2	**19.4**
	Signal 3.5	*Metaphorical*	**25.8**	64.5	9.7	**74.2**	**16.1**	74.2	9.7	**83.9**
	Signal 3.6		**41.9**	48.4	9.7	**58.1**	**45.2**	45.2	9.7	**54.8**
	Signal 3.7		**19.4**	67.7	12.9	**80.6**	**29.0**	58.1	12.9	**71.0**
	Signal 3.8		**58.1**	29.0	12.9	**41.9**	**64.5**	22.6	12.9	**35.5**
Changing Colour Materials	*Signal 4.1*	*Analogical*	**64.5**	35.5	0.0	**35.5**	**58.1**	38.7	3.2	**41.9**
	Signal 4.2		**80.6**	19.4	0.0	**19.4**	**64.5**	32.3	3.2	**35.5**

	Signal 4.3		**71.0**	29.0	0.0	**29.0**	**83.9**	9.7	6.5	**16.1**
	Signal 4.4		**83.9**	16.1	0.0	**16.1**	**71.0**	25.8	3.2	**29.0**
	Signal 4.5	*Metaphorical*	**29.0**	61.3	9.7	**71.0**	**54.8**	45.2	0.0	**45.2**
	Signal 4.6		**48.4**	35.5	16.1	**51.6**	**64.5**	35.5	0.0	**35.5**
	Signal 4.7		**54.8**	29.0	16.1	**45.2**	**64.5**	35.5	0.0	**35.5**
	Signal 4.8		**64.5**	25.8	9.7	**35.5**	**80.6**	19.4	0.0	**19.4**

5) Number of participants who respectively scored '1', '2', and '3' their associations signal/meaning in the Main Study.

			Under 60-years-old			**Over 60-years-old**		
	signals	Type of messages	People scoring '1'	People scoring '2'	People scoring '3'	People scoring '1'	People scoring '2'	People scoring '3'
Light Emitting Materials	*Signal 1.1*	*Analogical*	0	6	21	1	1	19
	Signal 1.2		1	5	19	3	6	15
	Signal 1.3		0	9	22	9	1	16
	Signal 1.4		3	4	17	3	1	12
	Signal 1.5	*Metaphorical*	3	5	21	2	3	24
	Signal 1.6		2	12	9	1	13	11
	Signal 1.7		2	11	7	1	7	16
	Signal 1.8		3	8	16	3	3	19
Shape Changing Materials	*Signal 2.1*	*Analogical*	2	9	14	3	2	13
	Signal 2.2		0	4	26	4	5	17
	Signal 2.3		2	10	14	1	3	17
	Signal 2.4		0	6	24	1	3	26
	Signal 2.5	*Metaphorical*	6	9	3	2	7	9
	Signal 2.6		3	12	1	2	8	7

	Signal 2.7		8	4	3	1	7	6
	Signal 2.8		7	2	3	1	3	9
Rheological Changing Materials	*Signal 3.1*	*Analogical*	4	11	15	4	8	14
	Signal 3.2		1	9	13	0	11	14
	Signal 3.3		1	10	12	1	7	16
	Signal 3.4		0	9	18	0	5	20
	Signal 3.5	*Metaphorical*	4	4	0	1	2	2
	Signal 3.6		6	6	1	3	3	7
	Signal 3.7		2	4	0	2	3	4
	Signal 3.8		10	4	4	3	4	12
Changing Colour Materials	*Signal 4.1*	*Analogical*	2	6	12	0	4	14
	Signal 4.2		1	4	20	0	5	15
	Signal 4.3		3	4	15	1	5	20
	Signal 4.4		1	5	20	1	3	18
	Signal 4.5	*Metaphorical*	5	3	1	3	4	10
	Signal 4.6		8	5	2	2	10	8
	Signal 4.7		10	5	2	3	5	12
	Signal 4.8		8	6	6	4	2	19

6) Mann-Withney U Testa conducted to understand whether the ratings of under-60-year-old participants are significantly different than the ratings of over-60-year-old participants.

Light Emitting Materials								
	signal1.1	*signal1.2*	*signal1.3*	*signal1.4*	*signal1.5*	*signal1.6*	*signal1.7*	*signal1.8*
Mann-Whitney U	420.500	420.000	324.500	360.000	437.500	428.500	341.000	462.500
Asymp. Sig. (2-tailed)	.319	.347	**.012**	.066	.440	.438	**.038**	.778

Changing Shape Materials								
	signal2.1	*signal2.2*	*signal2.3*	*signal2.4*	*signal2.5*	*signal2.6*	*signal2.7*	*signal2.8*
Mann-Whitney U	397.000	327.500	475.000	453.500	414.500	417.500	446.000	421.000
Asymp. Sig. (2-tailed)	.211	**.008**	.933	.580	.327	.339	.596	.342

Rheological Changing Materials								
	signal3.1	*signal3.2*	*signal3.3*	*signal3.4*	*signal3.5*	*signal3.6*	*signal3.7*	*signal3.8*
Mann-Whitney U	417.000	445.500	426.500	466.500	444.000	441.500	423.000	362.000
Asymp. Sig. (2-tailed)	.336	.598	.416	.820	.470	.538	.280	.079

Changing Colour Materials								
	signal4.1	*signal4.2*	*signal4.3*	*signal4.4*	*signal4.5*	*signal4.6*	*signal4.7*	*signal4.8*
Mann-Whitney U	475.500	401.000	388.000	431.500	314.500	328.000	334.500	229.000

Asymp. Sig. (2-tailed)	.940	.209	.147	.428	**.009**	**.023**	**.031**	**.000**

a. Grouping Variable: age

7) Extended report of the main differences and similarities in the interpretation of the Smart Radio as reported by participants of the Main Study.

Lyly (28 years old, Female) and Francesco (45 years old, Male) reported how we currently use several devices based on lights having therefore a cognitive connection with already existing devices. Alexandra (34 years old, Female) considered colours and lights the best option because they are universally/culturally accepted (even the stand-by signal of electronic devices uses the green/red light) but she suggested how would be better to combine two modalities (touch and visual). Paul (40 years old, Male) considered lights a useful way to alert people and catch their attention like a "*phone ringing*". Billy (72 years old, Male) appreciated the lighting symbols and he found them like already existing devices while the other materials do not have a corresponding technology in the existing products and could be difficult to understand the new language of communication. Participants acknowledged the effectiveness of the lights but they prefer them combined with a stronger means like some touch stimuli (Betty, 56 years old, Female and Sophia, 60 years old, Female) to compensate the growing visual impairments of people and loss of perception. Sophia said: "*lights are straightforward but are better to add the touching stimuli (like Rheological Changing Materials) in order to compensate any loss of perception due to ageing factors. The sense of touch is not going to faint*". Ivan (67 years old, Male) said: "*half lights and half touch. A combination is good and maybe adding a vibrating signal to enhance the message".*

Under-60-year-old participants reported how was easier to discern between very different signals among the four proposed (blinking lights – highly stimulated and pulsing light – highly relaxed) (Samantha, 24 years old, Female). Gianpaolo (27 years old, Male) stressed how the meaning of each signal was not fully clear. He said the changing speed and intensity of lights give him the idea of danger and they do not help him understand the quality of the message, whether is positive or negative. Mario (27 years old, Male) and Antonio (28 years old, Male) said that lights metaphorically embedded make you easily understand the activity of the user. They claimed how a blinking light is intuitively

connected to the concept of speed (like the alarm of an ambulance) while the pulsing light is naturally associated to calm feelings and relaxation. Antonio highlighted how this coding of light signals emerging from his past experiences with interactive objects where this system is widely adopted. Chul (32 years old, Male) stressed how working with lights reduces the amount of mental errors because the user do not have to spend time and think. Alexandra (34 years old, Female) said the flashing of the lights naturally represents the level of the human activity so the user becomes confident in guessing its meaning. Francesco (45 years old, Male) reported how the pulsing, blinking light conveys and immediate message, clear and unobtrusive. Moreover, the lights have a high visibility and can be seen anywhere in the house. Diana (60 years old, Female) appeared fascinated by the light effects that she suggested to redesign the radio display where each face lights up when you are listening to the connected user and the volume knob becoming brighter once is turned on. Susan (72 years old, Female) found of difficult interpretation the metaphorical messages with *Light Emitting Materials*. She reported how the signals require a proper understanding of the code associated.

William, (21 years old, Male) said that: "*movable flaps are efficient enough to convey the message and the meaning of symbols appear reinforced by the movement*"; Gabriele (29 years old, Male) considered the opening/closing windows intuitive. William highlighted how the *Changing Shape Materials* give just a little margin for error and they help to show exactly the availability of the user. This participant appreciated the slow rising of the flaps, interpreted as a mimic of the human like behaviour. Janet (28 years old, Female) suggested that the flaps should always be opened and the changing breadth should communicate the different status of the user. Antonio (28 years old, Male) said that *Shape Changing Materials* work better communicating the availability of the user because: "*the immediateness of the movable flaps reduces the possibility of misleading interpretations*". Stella (71 years old, Female) appreciated how the moving flaps give a visual contribution to the device while Sasha (71 years old, Female) considers them "*really amusing*". Conversely, Justin (79 years old, Male) preferred symbols maximised with *Light Emitting Materials* to the movable flaps, considered not as effective as the first means.

Samantha (24 years old, Female), Johnny (25 years old, Male) and Mary (28 years old, Female) said how the changes in frequencies and shapes (sharp vs smooth) are effective but it is important to carefully discriminate between them and prevent confusion. Mario (27 years old, Male) found the four messages built on a metaphorical interpretation of the

material properties really chaotic; Marta (28 years old, Female) and Mario explained how people are not familiar with this kind of interfaces therefore, a further level of detail should be added to this interface in order to further characterize it. Mario (27 years old, Male) proposed the addition of the 'time' parameter that will eventually help to properly interpret the activity of the user with the *Changing Shape Materials* properties. The emerging issue is to let the material be dynamic and show the transition from two different states (Mario, 27 years old, Male and Bobby, 30 years old, Male) and to adequately recall the human behaviour, as 'reaching out' arms (Mary, 28 years old, Female). A combination of *Changing Shape Materials* with signals that users are already familiar with, such as the lights, will definitely empower them, as suggested by Marta (28 years old, Female) and Bobby (30 years old, Male) alongside the creation of a 'loop' in the changing movement, in order to enhance its visibility. Chul (32 years old, Male) explained how the 'speed of changing' would eventually make the difference for the interpretation of each message. The rhythm of the movement is an important issue also for Paola (36 years old, Female) and will provide a clear meaning to the properties of the *Changing Shape Materials*. An ideal and powerful interaction would be also be the combination of the crinkling shape with lights (Alexandra, 34 years old, Female). Lights could have a colour coding and since they result more familiar and well known means of interaction, they can help the user understanding what is not clear in the combined means. The principle is that in a combination of signals, if the user does not understand the first, he/she will get the second (Alexandra, 34 years old, Female). Allison (69 years old, Female) considered the anthropomorphic-like shapes created by the changing materials really effective: *"like a cat sleeping or a dog wagging the tail and jumping. Simple and understandable".*

Georgia (52 years old, Female) stressed the importance of the familiarity with the new interface by claiming how the users must have an education about the new means. Johnny (25 years old, Male) suggested a combination of the *Rheological Changing Materials* with lights to let the surface to stand out. Mark (59 years old, Male) found the adoption of tangible symbols an excellent way to communicate information, but he suggested to speed up their response time to make them clear. LyLy (28 years old, Female) appreciated the touching surface as a new experience and she suggested that it might be enhanced as a physical reproduction of sound. The movement of the surface is considered a good way to show a changing situation (Gianpaolo, 27 years old, Male) but the popping up symbols must be shaped with more definition, indicating when they are active. Gianpaolo found confusing the way the interface was prototyped and he claimed that the meaning of each signal should be enhanced through the movement of the interface; the symbols themselves do not communicate the information. Sharon (66 years old, Female) considered the symbols appearing on

the surface: *"easy and intuitive, you can't get wrong".* Justin (79 years old, Male) reckoned how the tangible symbols were effective and he envisioned applications for visually impaired people.

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the haptic shapes have a code of interpretation not fully understood and users have to understand widely different signals at first and then try to understand the others, that result too similar. Bobby (30 years old, Male) considered the *Rheological Changing Materials* visually extremely powerful and of immediate interpretation because of the combination of visual and touch sensations. He suggested to further enhance this combination through lighting effects. Paola (36 years old, Female) considered the *Rheological Changing Materials* as really confusing because of a missing association of similar interfaces and visual effects in the reality; moreover, she reported how the addition of an appropriate movement to the bubbles will create a realistic effect. Paul (40 years old, Male) suggested to deal with the poor understandability of these haptic interfaces by adding a template or a bar (like the charging bar of the phone) showing the reference code with a combination with sounds and vibration that could potentially improve the understandability of the messages (slow and quick vibration to show a changing action). Francesco (45 years old, Male) did not consider *Rheological Changing Materials* able to properly express what the user is doing. However, an interesting potential is remarked by Margaret (42 years old, Female) claiming how the changing interface could accurately repurpose the sense of movement of the human body. Ivan (67 years old, Male), reported how the combination of lights and vibrating signals will give great value to the whole interaction. Diana (60 years old, Female) said: *"I like the bubbles coming out from water. Playing with colours and size will recreate a lava lamp. That will be amazing!"* Conversely, Audrey (77 years old, Female) said the *Rheological Changing Materials* do not work properly while Justin (79 years old, Male) appreciated the contribution of *Rheological Changing Materials* for impaired people but he required a clarification of the messages in order to stand out, maybe with colours. Sasha (71 years old, Female) appreciated the sensorial effect created by the movable spots: *"they are interesting because they could actually convey the stimulation of who I'm listening in".* Sharon (66 years old, Female) found metaphorical messages with *Rheological Changing Materials* more difficult to understand compared to analogical messages. Allison (69 years old, Female) said that moving bubbles are unclear: *"I wish bubbles could be only with heights. We don't need to have shapes. Using symbols like (+) and (-) to show the level of activity"*.

Samantha (24 years old, female) said that colours have different meanings in different cultures therefore could be counter-productive to work on them. She noticed how symbols appear similar and that four different symbols could work better instead of only two alternated with colours. The misleading interpretation of colours rises also with Gianpaolo (27 years old, Male) claiming that: *"Working with colours, such as red and green is confusing.*

You don't really understand the meaning of the colour unless you see the whole interactions. Lips are red, so if you see the signal 4.1 you don't see a message but a representation of the reality". The combination of two icons with different colours associated resulted unclear for Gabriele too (29 years old, Male); he considered the adoption of 'appearing' icons at time, as in the other family of SMs, more effective. Tony (58 years old, Male) stressed this point considering symbols confusing and hard to understand. He said: *"… clarity comes from the use of one symbol. For example, is unnecessary to use two colours (green and red) for lips and mouth; one symbol appearing is enough. Avoid redundant messages is the key!"* Paola (36 years old, Female), suggested to combine light, and all its dynamic effects, to colours and create clearer signals. Margaret (42 years old, Female) said: *"colours and lights combined they match perfectly the kind of interaction you want to achieve and they look like they are the natural choice".* She also said that might be interesting to add the duration of the signal that can change just to communicate the status of the user. Overall, she appreciated the pleasantness created by the changing colours. –Elizabeth (76 years old, Female), was concern by the effectiveness of the application of colours given that ageing processes affect their perception. Susan (72 years old, Female) did not consider them intuitive at a glance, but she managed to apply the traffic light colour coding. Deborah (64 years old, Female) claimed that with colours it is easy to fall in a personal interpretation and you are never fully sure. Allison (69 years old, Female) considered traffic light coding effective, Sally (70 years old, Female) said that they were not straightforward, but on a daily base you will be used of these signals. Whitney (71 years old, Female) suggested a combination with colourful lights.

Johnny (25 years old, Male) suggested how colours can be improved by dynamically activating them and *"letting them move to actually see them changing".* Anita (26 years old, Female) thought that messages adopting changing of intensity of colours are efficient because: *"they can show hard/slow beat of the activity performed as in signals 4.6-4.7, resulting really powerful".* She also stressed how colours must have a proper coding and that working with only one colour could be more effective but with a combination of lights and changing intensity. Janet (28 years old, Female) believed that changing colour in combination with the *Changing Shape Materials* could create a meaningful signal. They can use movement and speed plus colours to show what the user is doing. She claimed that *"Tempo is a good indicator that must be used to enhance the signals".* Gabriele (29 years old, Male), found easier to understand very different messages that work as a beacon to get the meaning of the intermediates and the general colour coding designed. Paola (36 years old,

Female) claimed that the human mind is still looking for a colour coding and the key of interpretation must be clear. The same point is considered by Alexandra (34 years old, Female): *"Colourful patterns are really hard to be understood. The user didn't get the meaning of the colours. This results in a really demanding interaction because you have to play with the device just to understand the signals and get confident with colours".* Stijn (39 years old, Male) highlighted how the colour coding is based on the cultural background of people so the messages must be carefully coded. Sophia (60 years old, Female) stressed the importance to understand the interpretation key underpinning each signal: she interpreted the colourful patterns still using a colour coding (pale colours = relaxing; green = active). Brightness of colours as a way to convey different status of the user is really appreciated by Ivan (67 years old, Male). He suggested to clarify the colour coding by displaying the spectrum on different bars and play with the intensity. In order to have a clear understanding of the message, he thought each colours should have a dedicated bar that gradually change to communicate the desired information. The importance to adopt of a well-defined colour coding was also stressed by Elizabeth (76 years old, Female) and Eddie (70 years old, Female) saying that colours are working because the colour red can be linked to active status while blue shades are more relaxing and green is a balance between them. The brightness of colours can shape the activity of the user: the brighter the more active is. The representation of the activity of the user through brightness and intensity of colours it is clear to Mary (70 years old, Female) too, saying that the colours come up more when bright: *"I thought how the body would reacting if I was relaxed…and I imagined clear colours".* Audrey (77 years old, Female) said that *Changing Colours Materials* can work and you can identify the differences based on the strength of colours. Diana (60 years old, Female) considered the linear pattern not efficient. She suggested the adoption of a pie chart giving the idea of the amount of activity the user is performing (in association with a proper colour coding. Nick (68 years old, Male) noticed how colours can potentially work better due to the familiarity we already have with this means. He said: *"Generally speaking, for elderly is difficult to acquire a new language and discern information from new signals. For this reason, it is important to adopt something already familiar".* Whitney (71 years old, Female) appreciated the idea of colour brightness to express the activity of the user (bright colours standing for high activity versus pale colours to express a status of relaxation). These new interfaces allow representing what we cannot share verbally by re-creating the same emotions. Whitney said: *"colours give me an emotion that is potentially the same emotion felt by the connected user".* In this regard, Sharon (66 years old, Female) said that

colourful patterns are easier because *"you can attach meaning such as relaxation and stress to the brightness of the colours".* Sasha (71 years old, Female) defined changing colours as "*thoughts provoking*" and very intuitive. She considered signal 4.8 (primary colour contrast – Bob is highly stimulated) as the best because of his power to stand out. For Deborah (64 years old, Female), colourful patterns did not express any meaning and she suggested a combination of colours and lights in order to increase the perception of the meaning. Allison (69 years old, Female) said that bright and vibrant colours are easy to understand while pale colours are badly perceived. Sasha (71 years old, Female) said the colours can be enhanced with diffuse light, to increase the meaning of the signals.

8) Extended report about general feedback on the Smart Radio as reported by participants of the Main Study.

William (21 years old, Male) expressed the interest to understand whether the peers connected are safe or not; he suggested the device to emulate the status of the user by a constant changing shape. Moreover, he claimed how the 'proximity' issue is also important and he advocated the addition of sensors showing when the connected user is approaching home. William highlighted how information regard 'breathing' and general 'stress level' of the user connected can be a useful addition. A similar point emerged with Gianpaolo (27 years old, Male), saying that: *"it would be great to get health related information. It is interesting to play with the breath of the user and simulate it. At the same time, it is important to understand what does 'being active' mean: for a young user is a positive sign, for an old lady maybe not! Would be interesting to communicate emotions".* Interestingly, also for Marta (28 years old, Female) health-related information such as blood pressure, the heart rate, the amount of stress of the user connected must be shared. She also believed that the device should show unconscious information (feelings) that cannot be communicated by traditional device like mobile phones; therefore, the device should share the mood of the connected peers: *"it is like the baby monitor: you can also use it to monitor your baby".* Paola (36 years old, Female) said that sharing health related parameters would be a must with dedicated monitoring features: *"Since this device should enhance the communication, would be great to have an alarm that notifies when a user has not been using the radio for a while".* She stressed how the Smart Radio should create an emotional support to the user: *"For example, when one user send a sad message (sad face), you can send a message to support him".* Sophia (60 years old, Female) said that the device show when two users are in contact with the intent to enhance the emotional bond between the

two of them. Diana (60 years old, Female) stressed this idea saying that the information shared can be customized upon the user connected: *"Only if is a doctor I will share details about my health status".* For Matthew (50 years old, Male), Estrella (44 years old, Female) and Francesco (45 years old, Male) an emergency button to give the user the chance to call a friend/relative to rescue him. Gabriele (29 years old, Male) claimed that the "speaking functions" are important in any communicative device: "*Elderly need to talk and young users too, they need to speak with their relatives to know if they are ok. Never underestimate the verbal communication. It is important to know how the peer is doing and this device should fill the lack of contact between them. The device enhances the way we see/touch each other. Maybe some visual aids (pictures?) of the users talking will improve the communication".* Johnny (25 years old, Male) believes that sharing music is still a good way to keep a bond with our beloved. In this regards, he would love to share emotions within peers. Anita (26 years old, Female) would enhance the information shared with some video and messages, to properly understand the status of her peers. Also for this participant the addition of emotions is important, as she said: *"At least relate to happiness, relaxation and stimulation mood...just to understand what is going on.".* This issue is important for Jenny (26 years old, Female) too: *"In consideration of the option to talk with my grandma, if she's been inactive for a long time it is important to guess why and how is she feeling."* Furthermore, it is for her important to understand when is inconvenient to be in contact (have a chat and phone the user) and the device could somehow notify it. Similarly, Georgia (52 years old, Female), Estrella (44 years old, Female) and Sophia (60 years old, Female), suggested to improve the device communicating whether the people connected are feeling good or not and clarify the signals. Therefore, Georgia imagined the device sharing important information, like health condition. Betty (56 years old, Female) explained that it is important to know whether the connected user is available to be phoned, but also to distinguish between relaxing status and 'being down on the floor'. She said: "*The radio must be able to distinguish between: 'yes, she can be phoned' and 'yes, she is fine'*". Mark (59 years old, Male) highlighted that the device could potentially help people with problems in communication to say when they are all right. Therefore: *"The simpler the better. This device should be kept simple and playful".* Chul (32 years old, Male) also appreciated the simplicity of the device: "*these functions and interactions are enough. If we would have more functions, we would buy a smartphone. the device should have specific functions and improve family communication. Simple and Specific. An advanced version of the device could be portable or connected to a smartphone".* In this regard, Alexandra (34 years old, female) said that the status could be

improved understanding why the user is not available (be out with friends, sleeping, etc...): *"it Is important to share mood and better information about the status"*. LyLy (28 years old, Female) said that she was thinking to design a similar device to improve communication between hospital patients and their family and the she was considering to: *"reproduce the missing intimate interaction, maybe showing personal shapes, like your hand touching the device, or visual messages like your sign".* She further explained how the display of health parameters will help to monitor people, especially when they are sick and make the device part of the nursing homes and hospital equipment. Similar comments were provided by the over-60 years old participants. Susan (72 years old – Female) said that older adults prefer to know if their peers and family are alright: *"my son and daughter will be happy to check if I'm alright".* Likewise, Nick (68 years old, Male), explained that the quality of the information shared is imperative to improve the overall functionality of the device. Therefore, he suggested to improve the device sharing information not normally shared with conventional devices, like emotions. He explained that information must be detected autonomously to let the device be less invasive.

For Samantha (24 years old, Female), although the concept of the Smart Radio was interesting, she found confusing to distinguish the meaning between 'ear' and 'lips' symbols Therefore, she said symbols must be clarified: *"there's also a subtle point that listening is a passive activity itself whereas speaking is an active action. Therefore, there could be confusion between "can be listened to" and "fully active*". Matthew (50 years old, Male) said that playing with visual and haptic interface is powerful, especially considering elderly and blind people. He suggested to *"add some vibration would help too, just to give the idea of the activity of the user. It is important di simplify the concept and give the user less things to do. Instead of knobs, would be preferable to have a 'turn and touch' device...no more complex devices! The user should turn on the device and select the user by touching an icon, symbol. It is important to enhance what the user is doing through visual tools and working on vibration: one vibration of the lips = the user is busy, two vibrations = the user is available, etc..)".* Francesco (45 years old, Male), said that *"Elderly should be passively detected but still an analogical button would be preferable".* Antonio (28 years old, Male) suggested that: *"The smooth and gradual difference between the four status must be clearer. A good option would be to work on opposite status such as active/non-active, relaxed/not relaxed, quiet/not quiet.".* Gabriele (29 years old, Male) reported how signals like 'listening in' and 'listening to' appeared confusing: *"The two symbols give me a general idea but the description of the meaning doesn't really match.".* Horacio (24 years old, Male) suggested to play exclusively

with a 'switch between shapes' enhanced with lighting signals: he imagined the device to be like a transparent ball that can change shape based on what the user is doing: the bigger the shape, the more active the user is. Johnny (25 years old, Male) suggested the interface to be touch sensitive with a set of interactive faces representing the peers connected; when the user presses each face, he can be connected to the corresponding user and his own radio station. With the addition of a notification button that sends a message to the user when someone wants to communicate with him, the device could have the 'status' knob removed. Similarly, Margaret (42 years old, Female) reported that the interface should be improved with the faces of the connected users able to light up when available and use the SMs properties for other signals. She appreciated the idea to communicate information through visual effect limiting the amount of text. Stijn (39 years old, Male) reported the importance of using the device in combination with something already existing (maybe smartphone) in augmentation of what we already have. He said that it would be useful to understand if it is the right moment to call a peer or not. Betty (56 years old, Female) stressed how would be useful to know if the person you want to talk with is available to be phoned: *"Usually nobody wants to bother people, so it is important to understand what the user are actually doing and then see when they are able to be phoned or not".* The simplicity of the interaction is an important issue for Janet (28 years old, Female) saying that "*The amount of information shared is correct. More information shared could be confusing, most of all if we consider that our tech devices are full of features embedded we don't really use. Elderly wise, an ideal device should have only one knob".* Nastaran (30 years old, Female) said: *"The simpler the better...the device must stay on this level of information. Thinking about elderly people, the idea to use the shape of a familiar device is great: they don't have to put any cognitive effort understanding and remembering it because they already know how a radio works".* Similar issue emerged with Tony (58 years old, Male) saying that the definition of each meaning is not clear: *"It is important to understand what really people want to know and then design the interface. It is important to distinguish between young and old users: young users will need to know information that probably old users do not require. Plus, a young user will not buy this device, he will prefer an app on the phone. Is invaluable to understand what people want to know (young want to know: dad is up in morning, he is eating, he has taken medication...) and then design how to convey the message."* Bobby (30 years old, Male) suggested to add some video element: *"this device is close to the internet of things theory so it is interesting to add some real-time video to add a level of detail".* Also for Bobby the amount of information communicated is enough: *"if the signals are clear and*

understandable they are connected together and you don't really need a categorization. For the user listening in it is not important to discern whether dad is stimulated but relaxed or highly stimulated...he will understand it!". Mark (59 years old, Male) reported how people with stroke will find tangible interface more efficient but the use symbols must be clear and obvious. He envisaged that: *"the adoption of a wide range of shapes and symbols will provide a rich interaction".* Alexandra (34 years old, female) further reported that her parents are already familiar with communication software like skype and they would expect similar functionalities and interactions in any novel communicative device. The familiarity with already existing devices is important for Paul (40 years old, Male) too, saying that: *"The concept of the radio was confusing for me because I find more intuitive the concept of a telephone".* The simplicity of the device is requested also by the over-60-year-old participants, as expressed by Elizabeth (76 years old – Female). Nick (68 years old – Male) explained how symbols could be confusing and it is important to get all the users understanding them. He proposed to use dynamic text messages in combination with symbols to be sure the messages are properly conveyed without considering the cultural background of the listeners. He further said that the device should not be called 'Smart Radio', because of the missing radio stations, but he appreciated the idea of keeping familiar commands and functions. In order to make the Smart Radio similar to a conventional radio, Nick suggested to broadcast some noise background between connected users. Sally (70 years old, Female) explained how the adoption of sound will help to simplify the device; a sound reminder that someone is broadcasting information will replace the analogical messages and simplify the interface. Billy (72 years old – Male) explained how it was difficult to appreciate the signals of the Smart Radio because of their difficult interpretation; nonetheless, he was curious about the device and he said himself happy to welcome new technologies and get use of them.