Product Lifetimes And The Environment
2017 - Conference Proceedings
C. Bakker and R. Mugge (Eds.)

DOI: 10.3233/978-1-61499-820-4-54

PLATE conference
Delft University of Technology
8-10 November 2017

PLATE
Product Lifetimes And The Environment

Understanding material change: design for appropriate product lifetimes

Bridgens B.[a] and Lilley D.[b]

a) Newcastle University, School of Engineering, Newcastle-upon-Tyne, UK
b) Loughborough University, Design School, Loughborough, UK

Keywords
Material change
Cosmetic obsolescence
Patina
Graceful ageing
Materials library

Abstract
From the moment of purchase, pristine objects are subjected to an array of stimuli including wear, impact, heat, light, water and air which alter their tactile and aesthetic properties. Material change is often regarded as 'damage' or 'degradation', but has potential to be used as a tool to engender emotional engagement to an object and extend product lifetimes. The potential benefits, and complications, associated with material change in the context of designing for the circular economy and other sustainable product service systems is discussed. We present a framework for designers to better understand how materials change with use, and in turn how people respond to materials as they change. Key challenges are identified which must be overcome to use this framework in design practice: people's physical interaction with objects is poorly understood, it is difficult to simulate material change, materials resources for designers do not provide information about material change, and people's responses to aged materials depend on a complex web of interacting factors.

Introduction

Materials change: *"…the formal language of design has notably shifted to a space dominated by the smooth and opaque surface. Such impenetrable surfaces make it easy to forget that the materials from which it was made are kinetic, that it is their 'will' to decay or change state"* (Carr & Gibson, 2015, p. 9).

The process of material selection is usually focused on the pristine, mass-produced object that entices the purchaser, but from the moment of purchase the surface of an object changes in response to use and interaction with its environment (Figure 1). Abrasion, polishing, ablation, impact, accumulated dirt, mould and oxidation combine to create a surface 'patina' that discloses the life of the object (Candy et al., 2004; Giaccardi et al., 2014; Nobels et al., 2015): *"Industrial design usually produces objects to be used in the future, but rarely investigates how these objects will change in time"* (Nobels et al., 2015). Delight at the untouched, often shiny, appearance of new products which "invites sensual engagement" (Maffei & Fisher, 2013, p. 231) can rapidly change to dis-satisfaction with 'worn' or 'aged' materials which, coupled with persuasive advertising, drives the cycle of replacement of products which are still fully functional (Nobels et al., 2015; Woolley, 2003). Material change is commonly perceived as damage or degradation, and for many types of product 'cosmetic obsolescence' contributes to premature disposal and unsustainably short product lifetimes (Cooper, 2005; Lilley et al., 2016; Manley, Lilley, & Hurn, 2015b; Packard, 1963): *"Many objects lose value in time because they lose newness, which is the attractive factor in the purchase phase. Newness is a complex mixture of different sensorial properties like odour, shiny colour and the integrity of surfaces."* (Nobels et al., 2015).

Whilst 'graceful ageing' of material surfaces is a potential strategy for creating enduring products, emotional attachment is difficult to predict and often elusive (Connor-Crabb, Miller, & Chapman, 2016; Cooper, 2005; Tasaki, 1992). *"Objects capable of sustaining long-lasting relationships with consumers are rare"* (Chapman, 2005, p. 66) due to unreasonably high expectations, rapid 'acclimatization' and loss of novelty.

In this paper, we ask: "with a better understanding of material change and how it is perceived, could product lifetimes be extended by designing for positive experiences of material change through the life of a product?"

This paper explores how aesthetic changes to the surface of a material are perceived, and how material change could be more widely utilised as a design tool. Combining a literature review with user studies, a complex web of factors is identified which are presented in a 'framework for understanding material change'. The considerable challenges which must be overcome to enable designers to understand material change throughout the product lifespan are identified.

Figure 1. Materials change (clockwise from top left): a plastic spade is severely faded by sunlight (despite it being designed for outdoor use); sandstone develops a rich patina of lichen; wood has lost colour but the surface texture is accentuated after exposure to sunlight and salt from the sea; mild steel reacts with oxygen and water to produce beautiful but fragile rust. In each case the new material is on the left. Except for the spade, the new and old materials are similar but not identical samples.

A framework understanding material change in product design

An understanding of material 'durability', i.e. how a material changes in response to a wide range of physical, chemical and biological stimuli, is a vital first step in understanding how material change will influence the lifespan of a product. But this is not enough. A combination of material changes, interwoven over time, combine to create a surface 'patina' that discloses the life of an object. There is a dichotomy in how this patina is interpreted; it can result in dissatisfaction or allow an emotional bond to be forged with the object (Baxter, Aurisicchio, & Childs, 2016; DeSilvey, 2006; Giaccardi et al., 2014). *"It is important to note here that patina is not an issue to do with material resilience or durability, but rather, a societal preoccupation with what an appropriate condition is for certain typologies of material and objects to be in"* (Chapman, 2013, p. 141).

We propose that a complex web of factors must be considered which require a multi-disciplinary approach to understand an individual's response to a particular product in a particular condition. The interaction of these factors is summarised in Figure 2.

Materials engineering is required to understand how the choice of materials (intrinsic properties), and the specific application of these materials in a product (extrinsic properties) combine with an array of stimuli to produce changes to the material surface. Material properties, such as surface roughness, thermal conductivity and hardness, can be used to give an indication of sensory attributes, i.e. how the object will look and feel, and even how it will smell, sound (when struck) and taste (Ashby & Johnson, 2013; C.J. Barnes, 2004; Skedung et al., 2011; Wongsriruksa et al., 2012).

But there is a further step to move from sensory attributes to people's perception of the material – how does it make them feel? What is their emotional response to the material, and to the object of which it is part? (Chapman, 2005; Karana, Hekkert, & Kandachar, 2010; Manley et al., 2016; Mugge, Schoormans, & Schifferstein, 2005). For a new product, there is a complex set of interacting factors that mediate the owner's emotional response, including cultural influences, fashion, expectation, product context, past experience and preconceptions, provenance and duration of ownership, and uniqueness and personalisation. For older products that have undergone material change, these factors are still valid, but are joined by a further set of considerations:

- Has the owner spent time caring for the object, repairing, cleaning and maintaining it (Gregson, Metcalfe, & Crewe, 2009; Salvia, 2015)?
- How did the changes to the object's surface occur – rapidly or gradually; accidentally, deliberately, or during a memorable event (for example during a particular sporting event) (Manley, Lilley, & Hurn, 2015a; Odom & Pierce, 2009)?

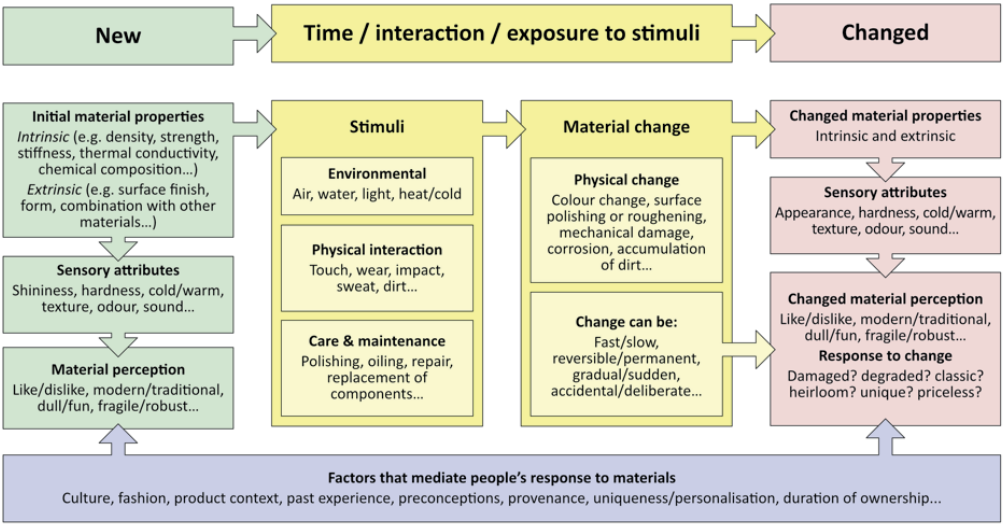

Figure 2. Framework for understanding material change in product design, showing interaction of material type, intrinsic and extrinsic properties, stimuli, and physical material changes, and experiential responses to those changes.

- Are the changes reversible or permanent?
- How do the changed sensory attributes compare to the original condition of the object (Pedgley, 2014)?

These myriad factors combine to demarcate the elusive difference between wear, damage, degradation and 'graceful ageing'. Understanding these factors is vital to enable designers to create enduring (as opposed to durable) objects: *"Some materials 'degrade' while others 'mature' by maintaining or improving certain qualities. The positive term of maturity is usually used for natural materials such as stone, paper, wood, and leather, which over the years can acquire scents, colours, and textures: characteristics that far from diminishing their quality, instead acquire an aura of antiquity and preciousness"* (Rognoli & Karana, 2014).

Designing for appropriate product lifetimes in the context of the circular economy

In response to the negative impacts of the linear 'take-make-waste' economy, and its increasing fragility in the light of material scarcity and price volatility, there is a growing focus on 'closing the loop' on resource use through a transition to the 'circular economy' (Braungart, McDonough, & Bollinger, 2007; British Standards Institution, 2017; Ellen MacArthur Foundation, 2015; European Commission, 2015; The Great Recovery, 2013). In addition, there is an increasing awareness of the importance of engaging citizens in the circular economy, in terms of consumer acceptance of new 'models of consumption' (Gullstrand Edbring, Lehner, & Mont, 2016; Hobson et al., 2017) and wider questions about the social and cultural consequences of the proposed circular production and consumption systems (Hobson & Lynch, 2016). As an alternative to the circular economy, or as part of an enabling strategy, new 'Product Service Systems' often involve a move from private ownership of products to provision of services, leasing, or shared ownership (Bardhi & Eckhardt, 2012; Rogers et al., 2015; Wilson et al., 2015).

The circular economy is normally described in terms of circular flows of materials, being: *"a simple, but convincing, strategy, which aims at reducing both input of virgin materials and output of wastes…"* (Haas et al., 2015, p. 765). However, it can equally be seen as a way of maintaining the value of products, components and materials. One approach advocated by proponents of the circular economy is 'design for longevity' (Park, 2009; The Great Recovery, 2013), with carefully orchestrated material change being one strategy to potentially increase product lifetimes through emotional attachment to an object.

In the context of material and product reuse through the circular- or sharing- economy, is it beneficial to engender attachment through material change? The answer is, of course, complex and answering it requires speculative life-cycle analysis of multiple possible product life scenarios, which will be different for every product. Any form of re-use, re-manufacturing or recycling will entail negative environmental impacts due to transportation and processing. Product longevity avoids these impacts and therefore has the potential to minimise environmental impacts. However, for products which require energy in the use phase (e.g. cars and electronic devices) (Suckling & Lee, 2015; Van Nes & Cramer, 2006) or substantial maintenance (Kara et al., 2008), it may actually be beneficial to replace (or upgrade) older inefficient products with newer models. Whether increasing product longevity minimises environmental impacts depends on the balance between impacts at the various stages of the product lifetime, and the end-of-life strategy (Cooper, 2016; Kwak & Kim, 2012), and currently the tools are not available for designers to carry out this type of analysis quickly and cheaply (Bridgens et al., 2017; Lee et al., 2015).

A key consideration is that whilst material change may be viewed positively for a product that is owned by an individual, it is likely to be seen as 'contamination' when the object is shared, changes owner or is in public ownership (e.g. public spaces and public transport vehicles) (Gullstrand Edbring et al., 2016). There are two distinct forms of contamination: technical contamination in which the purity of the materials is compromised making them more difficult to recycle (as opposed to downcycle) (McDonough & Braungart, 2002), and *interaction contamination* in which material change leaves traces of use on an object (Baxter, Aurisicchio, & Childs, 2017).

Challenges

Materials resources for designers

A range of material selection resources are used both to educate design students, and to inform material selection in design practice (Akin & Pedgley, 2016; Sörensen, Jagtap, & Warell, 2016; van Kesteren, 2008). Physical collections of materials provide the benefit of being able to handle samples and experience their tactile and aesthetic properties. Physical materials libraries present material samples in pristine condition, or in an unquantified state of degradation following handling and exposure to light (Figure 3). Akin and Pedgley (2016)'s review of materials library provision makes no reference to material change or durability.

Online resources provide detailed technical engineering properties including some measure of functional durability, for example numerical durability ratings for different types of environmental exposure (e.g. acid/alkali, fatigue, ultraviolet). These resources are just beginning to include sensorial properties (Ashby & Johnson, 2013) (Figure 3), but provide no information about aesthetic and tactile change with use. Material libraries are also typically devoid of context and extrinsic material properties, such as the influence of material form, thickness, processing, and combination with other materials in a product.

It could be argued that tacit knowledge built up from personal experience observing material change in a wide range of products equips designers to specify materials which will 'age' well in a particular application. This may be true for certain commonly used materials (e.g. ABS plastic, copper, oak, and so on), but tacit understanding is hampered by the complex web of factors that influence how a material will change in use, including the vast number of material variants and new materials, different surface finishes, different manufacturing processes and so on.

Simulating physical interaction

To study people's response to materials that are worn or changed, to create resources to improve designers' understanding of material change, and to facilitate the development of material surfaces which age in particular ways, it is necessary to simulate material change. *Accelerated ageing* is standard practice in many industries from wear testing of prosthetic joints to artificial

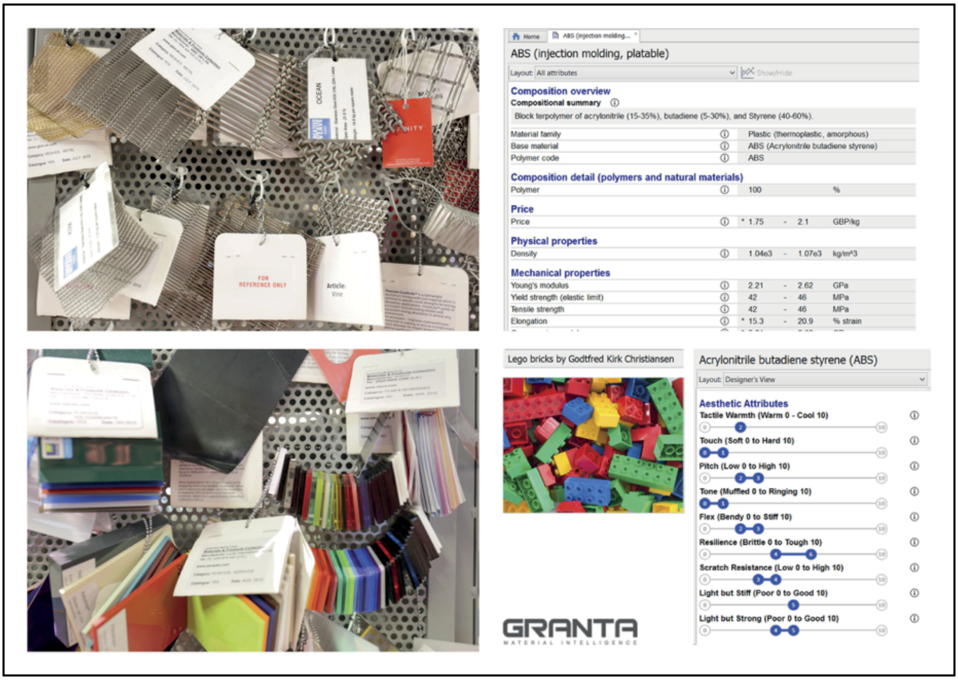

Figure 3. Pristine material samples presented at Central Saint Martins College of Art and Design Materials Collection, London (left); Granta CES Edupack materials database provides detailed engineering material properties (top right), and the new prototype Granta CES 'Products, Materials and Processes' database which includes design case studies and aesthetic or experiential material properties (bottom right).

weathering of construction materials, but there are no test methods for assessing the aesthetic and tactile changes of products in response to normal use, and very limited published work about how people physically interact with products.

In a recent study the authors attempted to develop accelerated ageing methods to simulate both 'careful use' (e.g. holding whilst in use and carrying in a pocket) and 'severe use' (e.g. carrying in a bag with keys, accidental dropping) of a mobile phone, to enable 'aged' material surfaces to be created for user testing, and to test a prototype layered surface finish which was designed to age spectacularly (Bridgens et al., 2017; Bridgens et al., 2015; Lilley et al., 2016). User testing of this layered material surface resulted in chipping and scratching of the surface, not the gradual wear that was anticipated. This damage to the layered phone surface demonstrated that it is not understood how people interact with their possessions and how this interaction impacts the object's surface. Hence physical test methods cannot currently simulate material use and ageing, making material evaluation and development difficult (Bridgens et al., 2017).

Conclusions

A framework has been presented which is intended to provide a tool which can be used to combine information from multiple sources to better understand the interaction of how products are used, how materials change in response to stimuli, and how people will respond to those changes (Figure 2). In each of these areas further work is required to provide sufficient information to enable this tool to be used in the design process.

The need for this information is becoming increasingly important as myriad new materials such as fibre reinforced composites, bioplastics and 'DIY materials' (Salvia, 2016; Tanenbaum et al., 2013) are developed, for which designers lack any tacit knowledge of how they will change. Accelerated 'wear and tear' testing should enable more rapid, lower risk, adoption of new materials in products.

Even if people's physical interaction with products was better understood, and suitable accelerated ageing tests could be developed to simulate 'wear and tear', a generic test is unlikely to achieve 'graceful ageing' as the stimuli required are different for each material, and may require a combination of stimuli over varying timescales. For example, ultraviolet light is required to emphasise grain in wood, wax and oil are beneficial to material change of leather and wood, moisture and oxygen are required for patination of copper.

Improved understanding of material change will enable designers to consider material change throughout the design process. Once material change is considered in tandem with form, use, ergonomics and operating environment, then it may be possible to design for a particular form of material change and extend the emotional durability of products: *"patina is a necessary design consideration to assist the extension of product life spans in graceful and socially acceptable ways"* (Chapman, 2013, p. 141).

For many types of product, lifetime extension and the avoidance of premature disposal due to 'cosmetic obsolescence', is the most effective strategy to reduce environmental impacts from the manufacturing and disposal of the object. However, as industries transition towards the circular economy or other modes of consumption, care must be taken to not jeopardise future re-use and recycling for the sake of modest increases in longevity. Simple, accessible lifecycle assessment tools are urgently required to enable designers to make informed decisions based on multiple product lifetime scenarios.

Acknowledgments

The authors would like to thank the UK Engineering and Physical Sciences Research Council who provided all funding for this work as part of the Closed Loop Emotionally Valuable E-waste Recovery project (EP/K026380/1), and Granta Design (https://www.grantadesign.com) and SCIN (http://scin.co.uk) who provided access to their materials specification resources.

References

Akin, F., & Pedgley, O. (2016). Sample libraries to expedite materials experience for design: A survey of global provision. *Materials & Design, 90*.

Ashby, M., & Johnson, K. (2013). *Materials and design: the art and science of material selection in product design*: Butterworth-Heinemann.

Bardhi, F., & Eckhardt, G. M. (2012). Access-based consumption: The case of car sharing. *Journal of Consumer Research, 39*(4), 881-898.

Baxter, W., Aurisicchio, M., & Childs, P. (2016). Materials, use and contaminated interaction. *Materials & Design, 90*.

Baxter, W., Aurisicchio, M., & Childs, P. (2017). Contaminated Interaction: Another Barrier to Circular Material Flows. *Journal of Industrial Ecology*.

Braungart, M., McDonough, W., & Bollinger, A. (2007). Cradle-to-cradle design: creating healthy emissions – a strategy for eco-effective product and system design. *Journal of Cleaner Production, 15*(13–14), 1337-1348. doi:http://dx.doi.org/10.1016/j.jclepro.2006.08.003

Bridgens, B., Hobson, K., Lilley, D., Lee, J., Scott, J. L., & Wilson, G. T. (2017). Closing the loop on e-waste: a multidisciplinary perspective. *Journal of Industrial Ecology*(in press).

Bridgens, B., Lilley, D., Smalley, G., & Balasundaram, K. (2015). *Ageing gracefully to increase product longevity*. Paper presented at the PLATE: Product Lifetimes and The Environment, Nottingham Trent University.

British Standards Institution. (2017). BS 8001:2017. Framework for implementing the principles of the circular economy in organizations – Guide: bsi.

C.J. Barnes, T. H. C. C., B. Henson, C.H. Southee. (2004). Surface finish and touch—a case study in a new human factors tribology. *Wear, 257*, 740.

Candy, F., Sommerville, S., Kälviäinen, M., & Oksanen, H. (2004). *Temporal Transformation of Materials: Can Designers Harness the Effects of Time to Create a Contemporary Aesthetic of 'Worldliness' within New Products?* Paper presented at the 4th International Conference on Design and Emotion, Ankara, Turkey.

Carr, C., & Gibson, C. (2015). Geographies of making: Rethinking materials and skills for volatile futures. *Progress in Human Geography*. doi:10.1177/0309132515578775

Chapman, J. (2005). *Emotionally durable design: objects, experiences* *and empathy*: Earthscan.

Chapman, J. (2013). Meaningful Stuff: Towards longer lasting products. *Materials Experience: fundamentals of materials and design*, 135.

Connor-Crabb, A., Miller, K., & Chapman, J. (2016). Design Strategies for the Eternal Reoccurrence of the New. *Fashion Practice*.

Cooper, T. (2005). Slower Consumption: Reflections on Product Life Spans and the "Throwaway Society". *Journal of Industrial Ecology, 9*(1-2), 51-67.

Cooper, T. (2016). *Longer lasting products: alternatives to the throwaway society*: CRC Press.

DeSilvey, C. (2006). Observed decay: telling stories with mutable things. *Journal of Material Culture, 11*(3), 318-338.

Ellen MacArthur Foundation. (2015). *Growth within: a circular economy vision for a competitive Europe*. Retrieved from

European Commission. (2015). *Closing the loop - An EU action plan for the Circular Economy*. Retrieved from Brussels:

Giaccardi, E., Karana, E., Robbins, H., & D'Olivo, P. (2014). *Growing traces on objects of daily use: a product design perspective for HCI.* Paper presented at the Proceedings of the 2014 conference on Designing interactive systems.

Gregson, N., Metcalfe, A., & Crewe, L. (2009). Practices of Object Maintenance and Repair How consumers attend to consumer objects within the home. *Journal of Consumer Culture, 9*(2), 248-272.

Gullstrand Edbring, E., Lehner, M., & Mont, O. (2016). Exploring consumer attitudes to alternative models of consumption: motivations and barriers. *Journal of Cleaner Production, 123*, 5-15. doi:10.1016/j.jclepro.2015.10.107

Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How Circular is the Global Economy?: An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. *Journal of Industrial Ecology, 19*(5), 765-777. doi:10.1111/jiec.12244

Hobson, K., & Lynch, N. (2016). Diversifying and de-growing the circular economy: Radical social transformation in a resource-scarce world. *Futures, 82*, 15-25.

Hobson, K., Lynch, N., Lilley, D., & Smalley, G. (2017). Systems of practice and the Circular Economy: Transforming mobile phone product service systems. *Environmental Innovation and Societal Transitions*. doi:10.1016/j.eist.2017.04.002

Kara, S., Manmek, S., Kaebernick, H., & Ibbotson, S. (2008). Assessment of Products for Optimal Lifetime. *CIRP Annals - Manufacturing Technology, 57*(1), 1-4.

Karana, E., Hekkert, P., & Kandachar, P. (2010). A Tool for Meaning Driven Materials Selection. *Materials & Design, 31*(6), 2932–2941.

Kwak, M., & Kim, H. M. (2012). *To Extend, or to Shorten: Optimal Lifetime Planning.* Paper presented at the ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Lee, J., Suckling, J. R., Lilley, D., & Wilson, G. T. (2015). What is 'value'and how can we capture it from the product value chain?

Lilley, D., Smalley, G., Bridgens, B., Wilson, G. T., & Balasundaram, K. (2016). Cosmetic obsolescence? User perceptions of new and artificially aged materials. *Materials & Design, 101*, 355-365. doi:http://dx.doi.org/10.1016/j.matdes.2016.04.012

Maffei, N., & Fisher, T. (2013). Historicizing shininess in design: finding meaning in an unstable phenomenon. *Journal of design history, 26*(3), 231-240.

Manley, A., Lilley, D., Bridgens, B., Hurn, K., & Lofthouse, V. (2016). *Worn out or worn in? How cosmetic wear affects semantic appraisals of materials*. Paper presented at the NordiCHI'16 the 9th Nordic Conference on Human-Computer Interaction, Gothenburg, Sweden.

Manley, A., Lilley, D., & Hurn, K. (2015a, 17-19 June). *Cosmetic Wear and Affective Responses in Digital Products: Towards an understanding of what types of cosmetic wear cause what types of attitudinal responses from smartphone users.* Paper presented at the PLATE, Nottingham Trent University.

Manley, A., Lilley, D., & Hurn, K. (2015b). Wear and affect: cosmetic obsolescence of plastics in digital products.

McDonough, W., & Braungart, M. (2002). *Cradle to cradle: remaking the way we make things* (First edition ed.): North Point Press.

Mugge, R., Schoormans, J. P., & Schifferstein, H. N. (2005). Design strategies to postpone consumers' product replacement: The value of a strong person-product relationship. *The Design Journal, 8*(2), 38-48.

Nobels, E., Ostuzzi, F., Levi, M., Rognoli, V., & Detand, J. (2015). *Materials, Time and Emotion: how materials change in time?* Paper presented at the EKSIG 2015-TANGIBLE MEANS experiential knowledge through materials.

Odom, W., & Pierce, J. (2009). *Improving with age: designing enduring interactive products.* Paper presented at the CHI'09 Extended Abstracts on Human Factors in Computing Systems.

Packard, V. (1963). *The waste makers*: Penguin Books Harmondsworth.

Park, M. B. (2009). *Product life: designing for longer lifespans.* Kingston University London.

Pedgley, O. (2014). *Desirable Imperfection in Product Materials*. Paper presented at the DRS2014 Design Research Society Conference, Umea Institute of Design.

Rogers, J., Cooper, S., Cooper, S., Densley Tingley, D., Braithwaite, N., Moreno, M., . . . Salvia, G. (2015). Product Longevity and Shared Ownership: Sustainable Routes to Satisfying the World'S Growing Demand for Goods. *AIMS Energy, 3*(4), 547-561.

Rognoli, V., & Karana, E. (2014). Towards a new materials aesthetic based on imperfection and graceful ageing *Materials Experience: fundamentals of materials and design* (pp. 145-154).

Salvia, G. (2015). What is broken? Expected lifetime, perception of brokenness and attitude towards maintenance and repair. *Product Lifetimes And The Environment*.

Salvia, G. (2016). The satisfactory and (possibly) sustainable practice of do-it-yourself: the catalyst role of design. *Journal of Design Research, 14*(1), 22-41.

Skedung, L., Danerl, K., John Kettle, Arvidsson, M., Berglund, B., & Rutland, M. W. (2011). Tactile perception: Finger friction, surface roughness and perceived coarseness. *Tribology International, 44*, 505-512.

Sörensen, C. A., Jagtap, S., & Warell, A. (2016). *Material selection in industrial design education – a literature review*. Paper presented at the International Conference on Engineering and Product Design Education, Aalborg University, Denmark.

Suckling, J., & Lee, J. (2015). Redefining scope: the true environmental impact of smartphones? *The International Journal of Life Cycle Assessment, 20*(8), 1181-1196. doi:10.1007/s11367-015-0909-4

Tanenbaum, J., Williams, A., Desjardins, A., & Tanenbaum, K. (2013). *Democratizing technology: pleasure, utility and expressiveness in DIY and maker practice.* Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.

Tasaki, A. D. B. a. L. H. (1992). The Role and Measurement of Attachment in Consumer Behavior. *Journal of Consumer Psychology, 1(2)*, 155-172.

The Great Recovery. (2013). *Report 01: Investigating the role of design in the circular economy*. Retrieved from

van Kesteren, I. (2008). Product Designers' Information Needs in Materials Selection. *Materials & Design, 29*(1), 133-145.

Van Nes, N., & Cramer, J. (2006). Product lifetime optimization: a challenging strategy towards more sustainable consumption patterns. *Journal of Cleaner Production, 14*(15), 1307-1318.

Wilson, G. T., Bridgens, B., Hobson, K., Lee, J., Lilley, D., Scott, J. L., & Suckling, J. (2015). *Single product, multi-lifetime components: challenges for Product-Service System development*. Paper presented at the PLATE: Product Lifetimes and The Environment, Nottingham Trent University.

Wongsriruksa, S., Howes, P., Conreen, M., & Miodownik, M. (2012). The Use of Physical Property Data to Predict the Touch Perception of Materials. *Materials & Design, 42*, 238-244.

Woolley, M. (2003). *Choreographing obsolescence-ecodesign: the pleasure/dissatisfaction cycle.* Paper presented at the Proceedings of the 2003 international conference on Designing pleasurable products and interfaces.