Materials, use and contaminated interaction

Weston L. Baxter[1]*, Marco Aurisicchio, and Peter R.N. Childs*

Design Engineering Department, Imperial College London, Exhibition Road, SW7 2AZ, London, United Kingdom

Abstract

Materials help communicate meaning to users. This meaning changes with time as the object transforms due to use. Through a two-phase study, this research develops new understanding of how people appraise used objects and the mechanisms driving contamination—the aversion that one has towards engaging with used objects. In the first phase, observations of indicators of use were collected from participants in order to develop a general typology for indicators of use and deduce the sensorial properties of used objects. In the second phase, these observations were analysed to isolate the data, which caused feelings of aversion. The subset of observations marked with aversion was labelled as contaminated. Further analysis revealed three mechanisms driving contamination—hygiene, utility, and territory—presented together as the HUT contamination model. Sensorial properties from the first study were mapped to contamination mechanisms and properties most frequently contributing to contamination were identified. The properties contributing to the various contamination mechanisms differ significantly. Hygienic contamination typically results from transient object states, utility contamination from permanent changes to object characteristics, and territorial contamination from object settings and contextual factors. As expected, the majority of the indicators contributing to contamination are related to material properties. This work acts as a link between material selection and contaminated interaction with used objects.

Keywords

Interaction; Contamination; Used objects; Sensorial Properties

1 Introduction

Materials have a critical role in user experience. When interacting with objects, materials stimulate users' senses and contribute to the meaning-making process together with other factors such as shape and context. An example of the importance of the sensory stimuli produced by materials is shown by Schifferstein [1] who looked at how containers made of different materials (e.g. glass, metal, and ceramic) impact the resulting experience of drinking. In many cases, the drinking experience was greatly affected by the cup material and other sensory perceptions of the cup. To understand how users experience materials and derive meaning, research is aiming to characterise their sensorial properties. Currently there is a growing interest in this area and research effort has been directed at supporting the understanding and selection of materials for the creation of specific meaning in new goods [2]–[8].

[1] Corresponding author. Tel.: +44 7913361017; E-mail address: w.baxter13@imperial.ac.uk

A seemingly under investigated area is that of meaning creation with used goods. Interacting with used goods has long been a consideration for public spaces, but is increasingly important with the growth in sharing schemes and second-hand markets including reuse, remanufacture and the implementation of a circular economy. In such situations, many people change their perceptions and interactions with objects and avoid engaging with the good. This aversion towards second-hand goods is a result of 'contamination' from something or someone [9]–[11]. One study, for example, reported that many consumers felt that a shared toy would not meet the user's standard of health, which contributed to the majority of respondents saying that they would not rent a toy for children [12]. In a car-sharing scheme, contamination appears to separate users rather than build a brand community [13]. While some sources of contamination require cultural interventions, design decisions can play a key role in mitigating contamination and improving experiences with objects.

The aim of this paper is to understand the origins of perceived use and contamination to help designers create better experiences with objects. Though we anticipate that several factors influence the perception of contamination, materials are expected to be one of the most significant. Use and contamination rely on consumers' sensory perceptions, thus this study focuses on sensorial properties inherent to materials (e.g. colour, smoothness, etc.) and interaction between materials (e.g. resistance, loudness, etc.).

The aim is accomplished through a two-phase study. The first phase, based on an analysis of used objects, identifies and categorizes indicators of use and their sensorial properties. The second phase links the properties found in the first study to types of contamination. In the context of our study, 'used' refers to objects that have left their new state. Wear is a related term referring to the physical result of use. 'Indicator of use' includes signs of wear but can also incorporate other aspects signalling use such as contextual factors. Finally, 'contamination' is defined as the process through which the quality, meaning, or value of an object change due to interaction with someone or something. As expected, contamination is most often used in a negative context resulting in an aversion to objects. Though in the present paper we consider this negative contamination we acknowledge that contamination (sometimes referred to as contagion) can occur in a positive light as well.

Results show that indicators of use can be viewed in a typology consisting of five categories: (1) knowledge of previous use, (2) object context, (3) object settings, (4) object characteristics, and (5) object states. Most of the indicators of use studied in this research fall into the object characteristics and object states categories. Corresponding sensorial properties were inferred from the indicators of use recorded by the participants during observations. For example, a stain on a bus seat changes the seat's colouration, while a grease mark on a bus window changes the window's transparency. Sensorial properties in this study differ from previous studies in that they reflect changes from a new to a used state rather than absolute properties. Indicators of use leading to contamination were identified. Contamination was found to be driven by three mechanisms presented as the HUT contamination model: hygiene, utility and territory. These mechanisms are unique but not mutually exclusive. Insights regarding contaminated interactions are derived by mapping sensorial properties from the first phase of the research to the mechanisms of contamination from the second.

2 Sensorial properties of used objects

Used objects typically vary in some way from their original state. This variation is perceived through signs or indicators [14]. Such perceptions are important in understanding user experiences and behaviour. Indicators of use, for example, contribute to replacement decisions by consumers [15]. In addition, they also play an important role in evaluating and acquiring second hand goods. Virtual

marketplaces, such as Amazon.com, eBay, and AbeBooks, rely on sellers to detail the condition of the objects on sale to help buyers make informed decisions. Brick-and-mortar stores offering used goods allow consumers to personally inspect the object and judge the quality of the goods. Consumers inspect objects through sensorial properties—things that they can see, smell, touch, hear and taste. Understanding these properties is important to help consumers make informed valuations (beautiful/ugly, clean/dirty, functional/broken, etc.) and subsequent decisions about acquiring, using, or disposing of an object.

Research around consumer perceptions and evaluations of sensorial properties has received significant attention recently [3], [4], [8], [16]–[26]. These studies generally focus on linking some sensorial property to user reactions and evaluations. In the case of used objects, the focus has generally revolved around designing positive, enduring object evaluations [27]. Power tools, for example, have a rugged image that is reinforced by the nicks and scratches that they sustain in use [28]. This narrative or story told through changes to the surface of a material is referred to as the patina [29]–[31]. The patina reflects both man-made and natural changes to the material. A similar concept is that of "beausage", an ungainly and possibly unsuitable moniker given its rhyming connotations, formed by the combination of beauty and usage that refers to the beauty developed through consistent use [32].

The focus on creating objects that age well reflects a sentiment of improving the object's meaning over time by understanding the product's signs related to the users [33]. This type of work, focused on 'designing in' features that make positive interactions, may often overlook the important step of understanding and 'designing out' features leading to negative interactions. Negative interactions may result for multiple reasons. Creating a patina, for example, may enhance meaning for a user who understands the narrative, but may create a barrier for another user who sees traces of use by another person. Understanding the factors related to negative interaction including feelings of aversion is increasingly important as technology enables larger second-hand markets. Still, previous work has largely overlooked issues of this nature [34].

3 Contamination

Contamination can be seen as the process through which the quality, meaning, or value of an object change due to interaction with someone or something. As such it implies that an object has been used in some way and it often leads to apprehension towards or aversion to the object. Aversion to objects touched or used by others is not a new concept. Conducting an in-depth study of the indigenous people of New Guinea [35], Anna Meigs found that members of a community will not consume food produced or served by a woman who marries and relocates to that community. The belief is that some of the woman's essence has transferred to the food and the members of the community will be 'polluted' with her properties if they accept it. This idea of a foreign or unclean object contaminating a target object is reflected throughout cultures. Several Biblical accounts, for example, reflect the transfer of 'essence' from a source to a target through the literal or figurative act of touching an object[2]. This transfer of essence has been described under two related "laws." The "laws of sympathetic magic" suggest that a source magically transfers some of its properties to the target through touch [36], [37] and the "law of contagion" states that a source will continue to influence a target even after it stops touching it [38], [39].

[2] Examples include Leviticus 11, Deuteronomy 23, Isaiah 52, Matthew 8, and Luke 8

A related area of research is that of interpersonal contamination. Goffman has presented six modes of interpersonal contamination: (1) violation of personal space, (2) touching or bodily contact, (3) glancing, looking and staring, (4) noise pollution, (5) talking to or addressing, and (6) bodily excreta (fluids, odour, body heat, markings left by the body) [40]. Belk has added to this list the acquisition of possessions of another person that have been intimately associated with that person and has described contamination as one of the ways in which a person can incorporate an object into the extended self [41]. As expected, the sensitivity of individuals to interpersonal contamination varies significantly [42] according to one's relation and history to the contact source [43]. Nemeroff showed this in a study in which participants were asked to draw germs as belonging to themselves, a stranger, a lover, or a disliked peer. Lover's germs were depicted as less threatening than disliked peers' germs. Participants said that they were as likely to get infected from all individuals but the severity of the illness followed a linear trend least severe with a loved one and most severe from a disliked peer [44].

This notion that someone or something has contaminated an object before the user engages with it has important practical implications. It leads to simple and even subconscious behaviours in day to day living. An example is the act of avoiding seats on public transportation or in a café that appear unclean. In a larger context, contamination can prevent acquisition intentions [11], [12], negatively impacts interaction [13], and decreases the valuation of the product [9]. Contamination can also prevent consumers from taking possession of an object. In some cases, consumers cleanse the object of any sign of previous use before taking possession of it [45]. These negative consequences of contamination present major barriers to the diffusion of second-hand markets and sharing schemes such as product-service systems.

We have limited our research to negative contamination mediated by used objects. This excludes related topics such as positive contamination (e.g. a desire for things used by celebrities or attractive people [46]), aversion to inherently disgusting things (e.g. bodily fluid, specific colours), and contamination resulting from direct interpersonal conditions (e.g. contaminated personal space).

4 Research Approach

The approach employed in this research to study the origins of perceived use and contamination involved two phases as illustrated in Figure 1. Phase 1 focused on understanding perceived use. It started by collecting a large data set of observations about used objects. For each observation the principal information component is the indicator of use, which captures the variation of an object from its new to its used state. After data collection the indicators of use were classified using five categories, which revealed that use is signalled by object characteristics and states more than object settings and context. As expected, these states and characteristics generally resulted from changes in the object due to material properties. Fundamental material properties then become important in understanding possible indicators of use and related sensorial perceptions. At this point a list of the sensorial properties underlying the indicators of use was developed based on a previous classification and a general inductive approach to qualitative data analysis.

Phase 2 focused on understanding contamination. During this phase the observations were further analysed to identify when a used object would also be classed as contaminated. To achieve this, the observations were screened to identify when encounters with used objects would evoke feelings of aversion. Analysis of the indicators of use associated with contaminated used objects led to the identification of three main contamination mechanisms, namely hygiene, utility, and territory. The mechanisms are to be intended as overarching concepts into which each indicator of use can be grouped. The next step consisted of identifying the sensorial properties of contaminated used objects

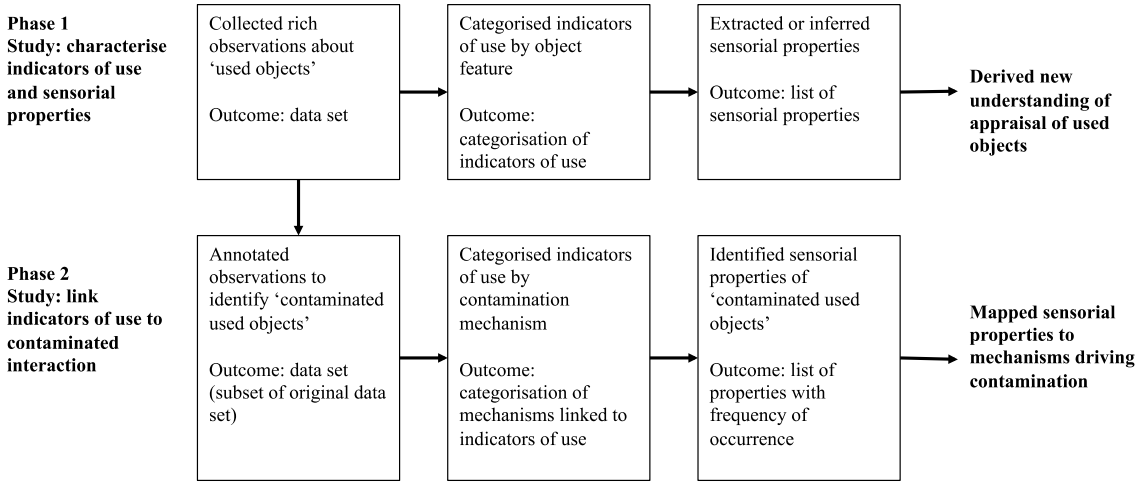

Figure 1 Research study approach

and understanding their frequency of occurrence. Overall the study conducted in Phase 1 delivered new understanding of the appraisal of used objects, while the study conducted in Phase 2 allowed mapping sensorial properties to the mechanisms driving contamination. The combination of the two studies provides an extensive exploration of indicators of use, object-level sensorial properties mainly linked to changes to material properties, and resulting contaminated interaction.

5 Characterising indicators of use and sensorial properties

The primary objective of this phase of the study is to identify and categorize indicators of use. The study uses both qualitative and quantitative methods of analysis to develop a general typology of indicators of use and identify common sensorial properties. These sensorial properties are perceptual changes between the new and used state of an object and often result from the technical material properties of the object (e.g. hardness might allow a surface to be scratched). After this the research looks at how material or other product features contribute to the perception of an object being used. At the conceptual design stage, materials and other design features can be selected to control indicators of use and mitigate, where possible, contamination effects.

5.1 Method

This section details the method employed to characterise indicators of use and sensorial properties.

5.1.1 Participants

Prior to the study, several informal discussions and pilot sessions showed that participants without a design background had a more difficult time fulfilling the task at hand with adequate detail. Thus, participants were deliberately recruited to have a background in design. Twenty-one participants engaged in the study. Participants included design faculty members (3), PhD researchers (9), under-graduate or Master's students (7), and design practitioners (2). All participants were living in the United Kingdom at the time of the study but the origin of participants was split relatively evenly between North America, Europe, and Asia.

5.1.2 Procedure

Participants were invited to partake in the study through an email explaining the requirements. The task included attending an initial meeting and then recording observations about used objects and their indicators of use in a provided journal over the course of one day. During the initial meeting a free lunch was offered to encourage participation. Participant information was gathered and all participants

were given a pocket-size journal. Each participant was asked to make a minimum of 30 observations indicating that an object had been used. Observed indicators needed to be unique but participants were encouraged to list multiple indicators for the same object. A book, for example, may have a coffee stain, a bookmark, highlighted sections and warped pages, and all could be recorded as individual observations. In practice, participants recorded observations for around 30 distinct objects with a few showing multiple indicators. Participants were further encouraged to make the observations across multiple locations (office, home, during travel, etc.) in order to cover a varying level of private and public environments. Finally, participants were asked to record images of the observed indicators to support interpretation of the observations.

The procedure for recording the observations involved filling in four columns of the journal with the following information: observation number, location of observation, used object observed, and indicator of use. This procedure was defined after multiple pilot studies using various instructions. Other possible instructions, such as explicitly focusing on the object's material, were found to be leading and produced results that either did not provide context or were confusing to participants. The procedure allowed us to gather adequate information to generate a general typology of indicators and identify common sensorial properties. It also provided enough contextual information to assess if used objects were also perceived as contaminated in the second phase of the research.

5.1.3 Data analysis

At the end of the study all journals were collected and transcribed. Entries were checked for completion and validity and participants were asked necessary follow-up questions. Transcribed results were then anonymized and codified to provide consistent descriptions of places, objects, and indicators. Next, the indicators of use were categorized according to a general typology and evaluated on the basis of sensorial properties. This achieves the first part of the research aim—identifying and categorizing indicators of use.

A total of 710 observations (average 33.8 per participant) were gathered in this study. Observations were deemed invalid if the entry was incomplete or off topic (e.g. recording what they liked about the object rather than an indicator of use). In total, 28 observations were deemed invalid while an additional 8 observations were dependent on some knowledge of previous use and were beyond the scope of the study. These have been removed from the final data set resulting in 674 usable data points. After codification, each observation was labelled as being conducted in a private or public setting to establish if the data set provided good coverage of both contexts. This was confirmed by the observations conducted in a private setting summing up to 32% of the total observations and those in a public setting to 55%. The remaining 13% of the observations occurred with objects that travel with the individual (clothes, bags, phones, etc.) and thus occur in both private and public settings

The data set was initially analysed in two ways. First, codified indicators were grouped through an iterative pattern recognition process to develop the typology presented in Figure 2 consisting of five categories: (1) knowledge of previous use, (2) object context, (3) object settings, (4) object characteristics, and (5) object states. These categories provide a comprehensive characterisation of the indicators. The typology ranges in terms of proximity to the object with the outermost category being knowledge of previous

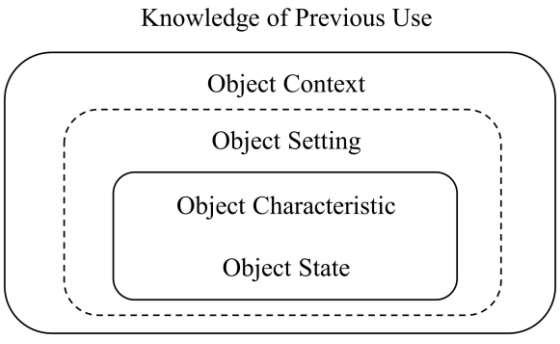

Figure 2 Categorical levels of indicators of use

use. Knowledge of previous use is the highest-level indicator, and the least reliant on object changes. This emerged in a few observations and has been included for context but it does not appear in further analysis since it is beyond the scope of this study. Object context considers the location and position of the object being considered and any accompanying objects. Object setting, the first level dealing directly with object features, considers reversible configurations of an object. Object characteristic and object state, the innermost indicators of use, directly relate to deviations in expected and perceived sensorial properties of the object with a clear emphasis towards materials and interactions with materials. Indicators such as object characteristics and object states represented 80% of the observations and were described by either explicitly stated or otherwise inferred sensorial properties. As expected, descriptions of sensorial properties identified deviations from an expected new condition mostly reflected by changes to material properties.

The data set was subsequently analysed to identify and understand the sensorial properties underlying indicators of use categorised as object characteristics and object states. In many cases, sensorial properties were directly conveyed with comments such as the café table "felt sticky" or a toaster had a "smell from recent use". The remaining observations were rich enough to infer the relevant sensorial properties of the used object. For example, a stain on clothing would imply a changed colouration, and scratches on a surface may point to smoothness. Participants were contacted for clarification in situations where a sensorial property could not be determined through the description provided in the journal.

Where possible, sensorial properties from an existing list were used [26]. Consistent with this existing list, *elasticity* and *strength* are technical properties but are used as sensorial properties due to general familiarity to people. We also note the important role that materials played in the identification of the resulting sensorial properties. Technical material properties determine changes in an object causing an indicator of use but often have nothing to do with the resulting sensorial properties. While *hardness* may cause a scratch to appear on a surface, the resulting sensorial properties have nothing to do with hardness (or softness); rather they reflect *roughness* as the scratch raises the surface, and loss of *colourfulness* as the scratch removes a layer of paint. Thus knowledge of the technical properties of the materials used to embody an object, coupled with an understanding of the likely interactions with that object over the course of use, produced the sensorial properties described below and their links to contamination.

5.2 Results

This section presents the indicators of use and the sensorial properties of used objects identified in this phase of the research.

5.2.1 Indicators of use

The four types of indicators of use in Table 1 provide an understanding of the signals that an object has been used. The first three categories directly relate to the object and comprise the majority of recorded observations. The fourth category—object context—differs from the previous ones in that it considers contextual factors such as the location of the object or the presence of accompanying objects. Object characteristic (45%) and object state (35%) categories directly relate to sensorial properties at the level of object features (e.g. materials) and comprise the majority of the analysis in the following section. Object setting (4%) and object context (16%) categories do not immediately relate to sensorial properties at a material level and are discussed in this section for reference.

Table 1 Categorized indicators of use

Category	Examples
Object Characteristic	Dents, scratches, cracks, loose, wear, ripped, stained, corrosion, sharp/dull
Object State	Clean/dirty, wet/dry, warm/cold, loud/quiet, empty/full (e.g., weight), smell
Object Setting	On/off, opened/closed, set positions, locked/unlocked, lit/unlit
Object Context	Location—where is the object located?
	Accompanying objects—do other objects imply use?

Object characteristics refer to permanent changes. It appears that this type of indicator is easily identified since it was the best represented category with 45% of the observations. Among the most commonly mentioned characteristics there were stains, scratches, and dents. Respondents described an indicator in terms of the change to an object relative to its perceived or assumed normal state. For example, participants reported that a book spine was loose, implying that a new binding would be stiff. This category also included permanent changes that are natural conditions of use or aging. Circumstantial corrosion or changes in performance, for instance, may be the natural consequences of lapsed time but they show a deviation from a new condition.

Object states are indicators which, with a reasonable degree of effort, could be reverted back to an original condition. This category was also well represented with 35% of the observations. As with the previous category, participants discussed the state of the object in relation to what a new object may exhibit. The most common indicator of an object's state was some commentary on its level of cleanliness. The presence of dirt, lime scale, water, smudges or grease implies that something or someone has altered the condition of the object. Similarly, the temporal heat left in gloves or a chair or any number of transient smells indicate recent use. There are conditions in which the object state may lead to changes in object characteristics. A single cigarette smoked in an automobile may lead to a temporal smell but years of smoking may create a practically irreversible odour. In such cases, the temporal nature of the indicator should be considered for proper classification.

Object settings are non-permanent changes to an object's designed configurations. A particularly informative example occurs when a car contains two key fobs for two separate users [47]. Many modern cars are capable of recalling a number of settings and match those settings to the key fob used. This allows people who share a car to each have their own place. If a driver accidently uses the other fob, different music settings, seat adjustments, and mirror placements would, for example, be experienced. Other examples of settings included the adjusted height of an office chair, pressed buttons, (un)locked doors, cabinets, lockers, keyboard height adjustment, and faucets left on or off. This category accounted for 4% of the observations.

Object context differs from the other three categories in that considerations extend beyond the target object. In such cases, the object itself might not change but something in the surrounding environment implies use. Two main themes comprise these indicators: location and accompanying objects. Location refers to instances when the object was not expected to be in a location (e.g. a chair in the hallway) or its position had been altered from the last encounter by the participant (e.g. chairs aligned in a circle). In other instances, accompanying objects often implied use of the target object. For example, seeing an opaque milk carton situated next to a cup containing milk made a participant assume that it had been used to pour the milk although there was no sign that the carton had been used. This differs from simply having knowledge of previous use since use can be deduced from the context at hand. Contextual indicators of use represented 16% of the observations.

An example of each of these categories is shown in Figure 3. The door handle is an example of knowledge of previous use since no other indicator implies that it has been used. Object settings are shown with a foldable chair configured in a flat position propped up against the wall. Object context is shown with a littered bottle and displaced chair implying that the table has been used. A wet towel represents an object state. Finally, object characteristics are shown with a candy machine that is faded in the sun and has chipped paint.

Figure 3. Examples of indicators of use described clockwise from upper left. Knowledge of previous use: handle with no signs of use. Object setting: chair in collapsed setting. Object context: littered bottle indicating someone had used the table. Object characteristic: outdoor candy machine with faded colour and chipped paint. Object state: towel wet from use.

5.2.2 Sensorial properties and use

Twenty one sensorial properties emerged in this study including eight that were not part of the list upon which we build our work [26]. The sensorial properties are presented in Table 2 grouped by the senses engaged, and matched to technical classifications. This is intended to show the various senses that users engage when observing an object, and how technical designers might begin addressing them. The sensorial and technical properties in Table 2 also highlight the overwhelming bias towards tactual and visual senses. This may be a reflection of the amount of information gained through these senses. Finally, Table 2 provides two examples of how observations translate to sensorial properties. The objects used in the examples intentionally differ in terms of complexity in order to show how any object can be assessed across the sensorial properties. The eight new sensorial properties are now described.

Wetness and *stickiness* are sensorial properties related to the cleanliness of an object. These categories directly relate to the material, rather than contextual factors, in that fundamental material properties impact how well a liquid is absorbed or a substance adheres to a surface. Perhaps more importantly, these two sensorial properties are determined by materials in that they relate to how well the underlying material could be cleaned.

Sharpness is the general term for how sharp (dull) an object is. Knives, edges of paper, and scissors were all commonly reported as being used because they were no longer as sharp as they once were. Other items, such as rented ice skates, were reported as being used since they had recently been sharpened.

Resistance refers to the ease of movement of a component of the object. A new book may initially be stiff and resist opening, while a used book shows reduced resistance to opening.

Separation is simply the discontinuity of an object. Objects may become separated due to a failure of a joining process or through cutting, ripping, or tearing away materials. In some cases, separation was perceived because part of the object was clearly missing (separated) from the rest of it, as it is the case with an unevenly ripped piece of toilet paper.

Loudness is significant because the presence of or changes in noise can indicate use such as the squeal coming from worn brake pads.

Pattern and *flatness* each relate to perceived changes in the surface characteristics of an object. Pattern refers to a change in the original arrangement of the object such as a carpet flattened in varying directions creating a visual pattern. Flatness is the morphing of a surface as seen in water-damaged pages of a book or deep ruts in a road frequented by heavy vehicles.

Clearly, the sensorial properties emerging from using an object and altering it from its state of new are highly dependent on the material properties. Ductility and elasticity depend on the modulus of a material, warmth depends on the ability of an object to retain (discharge) heat, and so forth. This provides appropriate directions for designers who can evaluate material options and other object features as a means of eliminating indicators of use due to interactions. It also allows design decisions to go beyond ‘avoiding wear and tear’ to intentionally identify the cause of the indicator of use and compensate appropriately.

Table 2
Summary of sensorial properties, related technical classification, and examples of indicators of use[a]

Sensorial Property		Technical Classification[b]	Example: Car	Example: Book
Visual	Colour Intensity (intense-mild)	Optical		Faded cover due to UV radiation
	Colourfulness (colourless)	Optical	Stain on the seat	Pen markings and coffee stains
	Transparency (opacity)	Optical	Scratches on window	
	Glossiness (matte)	Optical	Steering wheel made matte where hands go	Edges of book are matte from rubbing
	Reflectiveness (not reflective)	Optical	Water stains on mirror	
	Pattern (uniformity)[c]	Optical	Fabric flattened at feet	
	Flatness (unevenness)[c]	Manufacturing		Warped pages due to water damage
	Separation (completeness)[c]	Mechanical		Cover of the book is ripped
Tactual	Softness (hardness)[d]	Mechanical	Seat cushion hardened due to use	
	Weight (heavy-light)	Atomic		
	Ductility (ductile-tough)	Mechanical		Corners are deformed
	Strength (low- high)[d]	Mechanical	Windshield is chipped	
	Elasticity (low- high)[d]	Mechanical		
	Smoothness (roughness)	Mechanical	Fabric of seat changes in smoothness	
	Warmth (warm- cold)	Thermal		
	Sharpness (sharp- dull)[c]	Manufacturing		Paper edges have dulled over time
	Stickiness (not sticky)[c]	Chemical	Cup holder has a sticky residue in it	
	Wetness (dry)[c]	Chemical		
	Resistance (compliance)[c]	Manufacturing		Book binding has become more loose over time
Olfactory	Odorous (odourless- fragrant)	Chemical	Traces of cigarette smoke	
Auditory	Loudness (quietness)[c]	Acoustic	Squealing when braking	

[a] The examples chosen in this table are used to demonstrate the relationship between indicators of use, sensorial properties and technical material properties. The indicators of use under each example are compiled from a number of observations to provide exaggerated examples.
[b] The technical classification aims to link sensorial properties to technical material property categories. This additional information provides potential cues for design enhancement.
[c] Indicates sensorial properties not included in a previous sensorial list used by [26].
[d] Indicates that several sensorial properties adopted from [26] also have technical definitions. These terms are maintained due to the use of the term by the lay person but the inconsistency is noted as a potentially problematic area of communication between designers and users.

6 Linking indicators of use to contaminated interaction

In the previous section we have determined a general typology for indicators of use and their associated sensorial properties. To substantiate these results in the context of contamination we conducted a secondary analysis of the observations. In this second phase of the research, we have isolated those indicators of use that would contribute to contamination. The result is captured in the HUT contamination model shown in the remainder of this section. Where the first phase of research identified indicators leading to the perception that an object has been used, this phase accomplishes the second part of our aim, which is to link indicators of use to contamination. Together the two phases of this research show how the technical features of an object (materials, joining processes, geometry, etc.) and the interactions between an object and its users produce indicators of use, and how these indicators subsequently result in contaminated interaction.

6.1 Method

This section details the method employed to link indicators of use to contaminated interaction.

6.1.1 Participants

Following the first phase of research, informal interviews showed that participants could easily identify if they had an aversion to objects but they had much more difficulty articulating why. Hence, to gain useful insights it was judged critical to collect deep qualitative data. To achieve this we recruited two participants. Both participants were also involved in the previous phase of the research. This enabled a more informed evaluation of the observations.

6.1.2 Procedure

Using the complete data set collected during the first phase of the research, the participants were asked to independently create a subset of the indicators of use contributing to contamination—described to them as interaction that arouses feelings of aversion. Observations contributing to contamination were marked by the participants on a binary scale (does or does not cause aversion) rather than establishing a degree of contamination. The rationale for this is that the degree of contamination differs according to the person involved, the context and the object at hand, and therefore it is easier to establish trends rather than absolutes. In this part of the research it was essential that participants be able to empathically interpret the observations recorded by others to form a perceived interaction. This involved understanding the sensorial mode (touching, seeing, smelling, etc.) and context (public space, private residence, etc.) behind the observations. For example, a person may have no problem seeing a wet towel that belongs to someone else but touching one may well become a problem. Similarly, touching your wet towel at your home is different from touching a wet towel used by another person in a gym. To a large extent, the mode and context of an interaction was described through the participant's location, the observed object, and the indicator of use reported in the previous study. Still, this information could be understood differently so after the task each of the two participants was interviewed extensively about the results. The responses from participants were then analysed to determine trends.

6.1.3 Data analysis

The two participants identified a total of 548 observations contributing to contamination. Participant assessment of the indicators of use contributing to feelings of aversion tended to agree (correl. 0.58). Discrepancies were generally the result of imagined interaction that went beyond the data provided. For instance, one participant noted aversion for fingerprints on a screen, while the other did not. When

questioned, the participants explained that they had imagined different sources for the greasy fingerprints, and through explanation and reasoning both tended to agree.

Observations contributing to contamination were grouped according to underlying patterns. For these patterns, we tried to understand the fundamental mechanisms driving aversion through interviews with the participants. Three mechanisms driving contamination emerged: hygienic contamination, utility contamination, and territorial contamination. Together these mechanisms form what we call the HUT contamination model. The mechanisms are not mutually exclusive. Examining the frequency with which an observed indicator contributed to one or multiple mechanisms of contamination informs the nature of interaction amongst the various contamination drivers. This analysis is visualised in Figure 4 using the eulerAPE software [48].

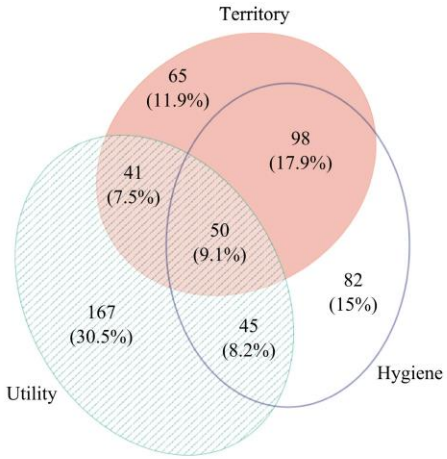

Figure 4 Frequency of HUT drivers of contamination occurring alone or together across indicators of use.

In this study we have linked the overall observations to one or multiple categories of contamination as well as to the indicators of use and the associated sensorial properties. The result is a three-part breakdown of how frequently the five indicators of use and the 21 sensorial properties contribute to each of the mechanisms driving contamination. Studying the relationship between contamination and the sensorial properties associated to the indicators of use, any observation based on knowledge of previous use, object context and object setting was excluded. As discussed in the previous study, a single indicator of use may contribute to multiple sensorial properties, e.g. a scratch may contribute to smoothness and colourfulness. This resulted in a total of 557 instances in which a sensorial property contributes to contamination. Table 3 summarizes the number of instances per sensorial property.

It is also important to mention that that the highly contextual nature of contamination has made it challenging to precisely compute the strength between a given sensorial property and the resulting contamination. We believe that a scenario can emerge in which nearly any sensorial property contribute to a mechanism of contamination but we have made no attempt at finding these absolute relations. Rather employing a quantitative assessment of our qualitative analysis, we have aimed at generating trends from our data to gain useful insights as presented in the next section.

Table 3 Number of instances contaminated interaction corresponded to a given sensorial property

Sensorial Property	Number of instances
Colour Intensity	48
Colourfulness	130
Transparency	28
Glossiness	21
Reflectiveness	34
Pattern	13
Flatness	23
Separation	45
Softness	5
Weight	8
Ductility	19
Strength	18
Elasticity	9
Smoothness	38
Warmth	11
Sharpness	8
Stickiness	12
Wetness	33
Resistance	8
Odorous	35
Loudness	11
Total	557

6.2 Results

This section presents the three identified mechanisms driving contamination: hygiene, utility, and territory. We refer to these as the HUT drivers of contamination. Hygiene contamination occurs when indicators of use are perceived to pose a threat to one's health. Utility contamination occurs when indicators of use show a decrease in perceived value or functionality. Territorial contamination is the result of an object perceived as being marked, i.e. belonging to someone else.

The categories of contamination were found to have a degree of overlap. Consider the example of a plastic pen with a lid that has been chewed. It is likely that a person exposed to such pen may feel aversion toward using it. When asked about the pen, the same person may explain that the teeth marks have created sharp edges making it unpleasant to hold or touch and that the chewing has warped the cap such that it falls off easily. These are examples of utility contamination as the pen has lost some of its functionality. The person may also explain how the teeth marks signal that the pen belongs to someone else and that because it has been chewed it is not sanitary. These are examples of territory contamination and hygienic contamination, respectively. The interplay between these mechanisms is shown in Figure 4. Notably, all three types of contamination occurred simultaneously in 9.1% of contamination cases. Utility had the largest individual occurrence of contamination at 30.5%. Hygiene and territory are the drivers that most commonly occurred together accounting for 17.9% of contaminated observations.

Hygienic contamination is marked with communicable object states and object characteristics as well as knowledge of previous use, object settings and object context. This type of contamination occurs when indicators of use resemble a hazard to health. Object states, for example, are often able to

transfer, in a literal sense, their properties such as moisture, sticky residue, smells, and grease. Sensorial properties related to hygiene and object states, as seen in Figure 5, include wetness, stickiness, odorous, transparency, glossiness, and reflectiveness. Object characteristics mainly contribute within this category in terms of permanent changes in colour. Changes in colour intensity or colourfulness, most often due to stains, indicated that the object was at one time contaminated and participants questioned if the material had been properly cleaned. Finally, knowledge of previous use, object settings and object context all contributed heavily to hygiene. A common sentiment from participants is that the condition of the object reflects likely cleaning behaviour of the previous user. Thus, messy or damaged objects were thought to be less hygienic since participants assumed that they were poorly cared for.

Utility contamination is most often marked with permanent changes to object characteristics. It occurs when an object is perceived to have a decreased ability to fulfil its functions. Functions can be technical, aesthetic, social, economic and latent [49], [50]. Some of the most prominent properties relating to these changes are separation, reflectiveness, flatness, strength, colour intensity, colourfulness, smoothness, and transparency (see Figure 5). These properties are not surprising since they are the consequences of normal wear and tear, and subsequent negative appraisals of objects.

Territorial contamination is primarily marked with revertible changes to object settings and the context around an object. Settings are often chosen by a user in an intentional attempt to personalize the object and contextual factors mainly refer to accompanying objects, e.g. a photo on a desk is an indicator that the desk is being used. It is, however, important to note that object characteristics and object states also contribute to territorial contamination often leaving a personal mark in some way. Figure 5 shows that some of the most prominent properties relating to transient object states, object characteristics, object settings and contextual factors are warmth, odour, glossiness, stickiness, ductility, reflectiveness and smoothness. Bite marks on the end of a pencil (smoothness), for example, indicate that the object has been used by another person and leaves a claim on the object as theirs. Patterns generated (or destroyed) from repeated use such as numbers worn off on keyboard keys seemed to give a narrative of how someone uses the object. Transient properties may be more salient cues of territory concerns because they have a lifespan, i.e. the object has been touched recently enough that the property has not subsided or been cleaned. Examples include the odour of a loved one's perfume on a shirt, body heat leaving a chair warm, sticky residue on a handle, or finger grease making a surface glossy.

This study completes the link between the sensorial properties of use and subsequent contaminated interaction. Consider, for instance, the role of the sensorial properties of materials in the HUT contamination triangle of Figure 5. A designer might select a material for a product that, through subsequent interactions, results in a change in colourfulness. Such a change is likely to impact all three drivers of contamination. Similarly, an object that is likely to show some form of separation will mainly contribute to utility contamination. Finally, materials that create or retain a foul odour are likely to contribute to hygienic and territorial contamination. The rest of the properties could be considered in a similar fashion to understand how early design decisions can mitigate contaminated interaction. As stated previously, these trends should be taken in context since any given sensorial property could contribute to one or multiple drivers of contamination.

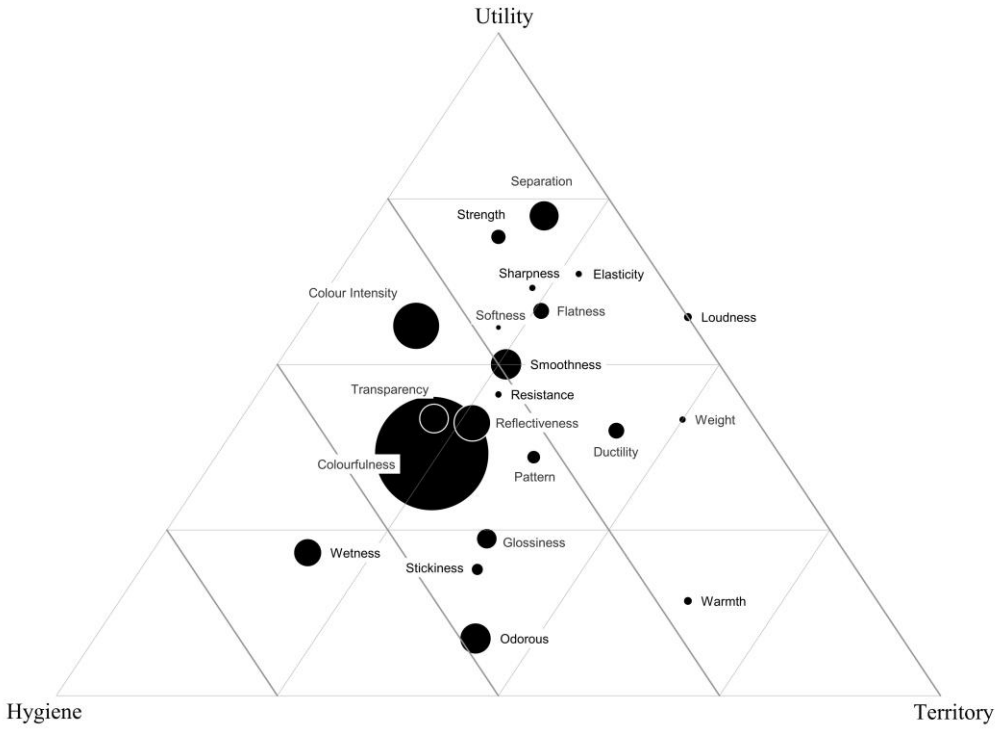

Figure 4. HUT contamination triangle. Location of a sensorial property is determined by the frequency with which the property contributed to each of the three contamination mechanisms. Size of a sensorial property is determined by its overall occurrence relative to the others.

7 Discussion

Karana et al. concluded that the meaning attributed to a material depends on: (a) the type of material, (b) the product in which the material is embodied, (c) how the product is used, and (d) the background of the user [26]. This research expands that work by proposing that the meaning attributed to a material is determined by the condition of the material used to embody a product. Meaning derived from indicators of use can help people assess the degree to which used objects are hygienic, offer utility, and are perceived as one's own property.

Studying the perception of use and contamination has helped understand how design decisions (material selection, joining processes, etc.) are linked to contaminated interaction. Object characteristics (permanent indicators) determining utility contamination may be best accounted for through traditional design for durability such as the rate of surface wear, material strength, and joining processes. Territorial and hygienic contaminations are less intuitive and are certainly less accounted for in current design practice. Territorial contamination is mitigated by erasing signs of previous users. This requires introducing design defaults for object settings and contextual factors. Careful consideration should be given to understanding the object characteristics and object states that inform about previous users and these should, where possible, be eliminated. Finally, hygienic contamination largely results from transient properties. These require stronger consideration of the role of services or maintenance in preserving the condition of the object. In these cases, materials could be selected that

are more easily cleaned and maintained. The prevalence of hygienic contamination in our results suggests that transient conditions show more salient indicators of use and should be a priority in design.

Design strategies should also consider the application and use of the object. Objects used for a long time by one individual exhibit vastly different conditions than those of shared objects. When owning an object, hygiene is a minimal concern because the object—and any cleanliness issues—belong to the person. Territory is reinforced by materials that change over time and create a positive narrative in the patina. Utility is also viewed differently since it is likely that the individual takes better care of the object and can preserve the quality of the object to the standard that is deemed fit. This contrasts with situations where objects are used briefly and between users as readily seen in workplaces, restaurants, transport and other public spaces. In such situations, any sign of previous use can readily give rise to all forms of contaminated interaction. Designers should carefully consider how they might mitigate or control changes over time given the context of the object.

Engineering design capacity to confront contamination needs to be developed across all areas. Utility contamination benefits from significant engineering work in durability and the designer's ability to easily perceive and communicate durability concerns the way in which a user does. The mitigation of utility contamination is simplified by the fact that objects can be easily analysed in a laboratory setting and the user is often not needed. The more nuanced areas of hygiene and territory contamination require more attention since the cues can be subtle and the consequences drastic. In these situations the object is often avoided completely since it is either perceived as belonging to someone else or as unclean. These forms of contamination also require design research that involves examining objects in use and observing and talking with users—a method still unfortunately uncommon among many designers.

This research is primarily limited by the breadth of observations collected, our ability to infer sensorial properties, and participants' ability to imagine interactions with used objects. Because of this there are likely to be additional sensorial properties not included here which contribute to contamination. Sensorial properties relating to taste, for example, are not included in our data set though it is easy to imagine the presence and usefulness of such properties in the context of food design. Future studies might explore this and other sensorial properties relating to used objects as a way of building on the present work. Future studies may also aim to expand materials maps to reflect technical parameters that map to sensorial properties and subsequent contamination.

8 Conclusions

The indicators of use and sensorial properties presented in this paper expand current understanding of meaning attribution as it relates to used objects. In addition to previously identified factors such as the type of material, the product in which the material is embodied, how the product is used and the background of the user, this research suggests that the meaning attributed to materials depends on the condition of the material over time. In this research the perception of an object's condition is studied through indicators of use, sensorial properties and contaminated interaction. Hygiene, utility and territory concerns emerge as the principal driver of contaminated interaction. Mitigating contaminated interaction requires careful design decisions centred on material selection.

References

[1] H. N. Schifferstein, “The drinking experience: Cup or content?,” *Food Qual. Prefer.*, vol. 20, no. 3, pp. 268–276, 2009.

[2] M. F. Ashby and K. Johnson, *Materials and design: the art and science of material selection in product design*. Butterworth-Heinemann, 2013.

[3] G. V. Georgiev and Y. Nagai, “A conceptual network analysis of user impressions and meanings of product materials in design,” *Mater. Des.*, vol. 32, no. 8, pp. 4230–4240, 2011.

[4] L. Wastiels and I. Wouters, “Architects’ considerations while selecting materials,” *Mater. Des.*, vol. 34, pp. 584–593, 2012.

[5] E. Karana, P. Hekkert, and P. Kandachar, “A tool for meaning driven materials selection,” *Mater. Des.*, vol. 31, no. 6, pp. 2932–2941, 2010.

[6] E. Karana, “How do materials obtain their meanings?,” *Middle East Tech. Univ. J. Ofthe Fac. OfArchitecture*, vol. 2, no. 27, pp. 271–285, 2010.

[7] A. Jahan, M. Y. Ismail, S. M. Sapuan, and F. Mustapha, “Material screening and choosing methods–a review,” *Mater. Des.*, vol. 31, no. 2, pp. 696–705, 2010.

[8] L. Wastiels, H. N. Schifferstein, A. Heylighen, and I. Wouters, “Relating material experience to technical parameters: A case study on visual and tactile warmth perception of indoor wall materials,” *Build. Environ.*, vol. 49, pp. 359–367, 2012.

[9] J. J. Argo, D. W. Dahl, and A. C. Morales, “Consumer contamination: How consumers react to products touched by others,” *J. Mark.*, pp. 81–94, 2006.

[10] P. Rozin and A. E. Fallon, “A perspective on disgust,” *Psychol. Rev.*, vol. 94, no. 1, pp. 23–41, 1987.

[11] L. O’Reilly, M. Rucker, R. Hughes, M. Gorang, and S. Hand, “The relationship of psychological and situational variables to usage of a second-order marketing system,” *J. Acad. Mark. Sci.*, vol. 12, no. 3, pp. 53–76, Jun. 1984.

[12] Q. Liu, H. -m. Li, X. -l. Zuo, F. -f. Zhang, and L. Wang, “A survey and analysis on public awareness and performance for promoting circular economy in China: A case study from Tianjin,” *J. Clean. Prod.*, vol. 17, no. 2, pp. 265–270, 2009.

[13] F. Bardhi and G. M. Eckhardt, “Access-Based Consumption: The Case of Car Sharing,” *J. Consum. Res.*, vol. 39, no. 4, pp. 881–898, 2012.

[14] K. Krippendorff, *The Semantic Turn: A New Foundation for Design*. Cambridge, Mass: CRC Press, 2005.

[15] N. Van Nes, “Understanding replacement behaviour and exploring design solutions,” in *Longer Lasting Products: Alternatives to the Throwaway Society*, T. Cooper, Ed. Surrey: Gower, 2010, pp. 107–132.

[16] L. Wastiels, H. N. Schifferstein, A. Heylighen, and I. Wouters, “Red or rough, what makes materials warmer?,” *Mater. Des.*, vol. 42, pp. 441–449, 2012.

[17] E. Karana, O. Pedgley, and V. Rognoli, *Materials Experience: fundamentals of materials and design*. Butterworth-Heinemann, 2013.

[18] D. Atkinson, P. Orzechowski, B. Petreca, N. Bianchi-Berthouze, P. Watkins, S. Baurley, S. Padilla, and M. Chantler, “Tactile perceptions of digital textiles: a design research approach,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2013, pp. 1669–1678.

[19] A. Krishna, “An integrative review of sensory marketing: Engaging the senses to affect perception, judgment and behavior,” *J. Consum. Psychol.*, vol. 22, no. 3, pp. 332–351, 2012.

[20] X. Chen, F. Shao, C. Barnes, T. Childs, and B. Henson, “Exploring relationships between touch perception and surface physical properties,” *Int. J. Des.*, vol. 3, no. 2, pp. 67–76, 2009.

[21] H. N. Schifferstein, “From salad to bowl: The role of sensory analysis in product experience research,” *Food Qual. Prefer.*, vol. 21, no. 8, pp. 1059–1067, 2010.

[22] Y. Nagai and G. V. Georgiev, “The role of impressions on users’ tactile interaction with product materials: An analysis of associative concept networks,” *Mater. Des.*, vol. 32, no. 1, pp. 291–302, 2011.
[23] K. Forslund, M. Karlsson, and R. Söderberg, “Impacts of geometrical manufacturing quality on the visual product experience,” *Int. J. Des.*, vol. 7, no. 1, pp. 69–84, 2013.
[24] X. Chen, C. J. Barnes, T. H. C. Childs, B. Henson, and F. Shao, “Materials’ tactile testing and characterisation for consumer products’ affective packaging design,” *Mater. Des.*, vol. 30, no. 10, pp. 4299–4310, 2009.
[25] E. Karana and P. Hekkert, “User-material-product interrelationships in attributing meanings,” *Int. J. Des.*, vol. 4, no. 3, pp. 43–52, 2010.
[26] E. Karana, P. Hekkert, and P. Kandachar, “Meanings of materials through sensorial properties and manufacturing processes,” *Mater. Des.*, vol. 30, no. 7, pp. 2778–2784, 2009.
[27] E. van Hinte, *Eternally Yours: visions on product endurance*. 010 Publishers, 1997.
[28] M. Park, “Defying Obsolescence,” in *Longer Lasting Products: Alternatives to the Throwaway Society*, T. Cooper, Ed. Surrey: Gower, 2010, pp. 77–105.
[29] W. Odom and J. Pierce, “Improving with Age: Designing Enduring Interactive Products,” in *CHI ’09 Extended Abstracts on Human Factors in Computing Systems*, New York, NY, USA, 2009, pp. 3793–3798.
[30] W. Odom, J. Pierce, E. Stolterman, and E. Blevis, “Understanding Why We Preserve Some Things and Discard Others in the Context of Interaction Design,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, New York, NY, USA, 2009, pp. 1053–1062.
[31] E. Giaccardi, E. Karana, H. Robbins, and P. D’Olivo, “Growing traces on objects of daily use: A product design perspective for HCI,” in *Proceedings of the 2014 conference on Designing interactive systems*, 2014, pp. 473–482.
[32] G. Petersen, *Just Ride: A Radically Practical Guide to Riding Your Bike*. Workman Publishing, 2012.
[33] K. Krippendorff and R. Butter, “Product semantics: Exploring the symbolic qualities of form,” *Innovation*, vol. 3, no. 2, p. 4, 1984.
[34] J. Pierce and E. Paulos, “Second-hand Interactions: Investigating Reacquisition and Dispossession Practices Around Domestic Objects,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, New York, NY, USA, 2011, pp. 2385–2394.
[35] A. S. Meigs, *Food, sex, and pollution: A New Guinea religion*. Rutgers University Press New Brunswick, NJ, 1984.
[36] M. Mauss, “A General Theory of Magic, trans,” *Robert Brain Lond. UK Boston MA Routledge Kegan Paul Ltd*, 1972.
[37] C. Nemeroff and P. Rozin, “The Contagion Concept in Adult Thinking in the United States: Transmission of Germs and of Interpersonal Influence,” *Ethos*, vol. 22, no. 2, pp. 158–186, 1994.
[38] P. Rozin and C. Nemeroff, “The laws of sympathetic magic,” *Cult. Psychol. Essays Comp. Hum. Dev.*, pp. 205–232, 1990.
[39] P. Rozin, L. Millman, and C. Nemeroff, “Operation of the Laws of Sympathetic Magic in Disgust and Other Domains,” *J. Pers.*, vol. 50, no. 4, pp. 703–712, 1986.
[40] E. Goffman, *Relations in Public*. Transaction Publishers, 2009.
[41] R. W. Belk, “Possessions and the Extended Self,” *J. Consum. Res.*, vol. 15, no. 2, pp. 139–168, 1988.
[42] P. Rozin, M. Markwith, and C. McCauley, “Sensitivity to indirect contacts with other persons: AIDS aversion as a composite of aversion to strangers, infection, moral taint, and misfortune.,” *J. Abnorm. Psychol.*, vol. 103, no. 3, p. 495, 1994.
[43] P. Rozin, C. Nemeroff, M. Wane, and A. Sherrod, “Operation of the sympathetic magical law of contagion in interpersonal attitudes among Americans,” *Bull. Psychon. Soc.*, vol. 27, no. 4, pp. 367–370, Apr. 1989.

[44] C. J. Nemeroff, “Magical thinking about illness virulence: Conceptions of germs from ‘safe’ versus ‘dangerous’ others,” *Health Psychol.*, vol. 14, no. 2, pp. 147–151, 1995.
[45] G. McCracken, “Culture and Consumption: A Theoretical Account of the Structure and Movement of the Cultural Meaning of Consumer Goods,” *J. Consum. Res.*, vol. 13, no. 1, pp. 71–84, Jun. 1986.
[46] J. J. Argo, D. W. Dahl, and A. C. Morales, “Positive Consumer Contagion: Responses to Attractive Others in a Retail Context,” *J. Mark. Res. JMR*, vol. 45, no. 6, pp. 690–701, Dec. 2008.
[47] W. L. Baxter, M. Aurisicchio, and P. R. N. Childs, “A psychological ownership approach to designing object attachment,” *J. Eng. Design,* 2015. 10.1080/09544828.2015.1030371.
[48] L. Micallef and P. Rodgers, “eulerAPE: drawing area-proportional 3-Venn diagrams using ellipses,” *PloS One*, vol. 9, no. 7, p. e101717, 2014.
[49] M. Aurisicchio, N. L. Eng, J. C. O. Nicolas, P. R. N. Childs, and R. H. Bracewell, “On The Functions Of Products,” *68-10 Proc. 18th Int. Conf. Eng. Des. ICED 11 Impacting Soc. Eng. Des. Vol 10 Des. Methods Tools Pt 2 LyngbyCopenhagen Den. 15-19082011*, 2011.
[50] P. R.N. Childs, “Engineering freakout,” *Int. J. Mech. Eng. Educ.*, vol. 41, no. 4, pp. 297–305, 2013.