KEER2014, LINKÖPING | JUNE 11-13 2014
INTERNATIONAL CONFERENCE ON KANSEI ENGINEERING AND EMOTION RESEARCH

Characterizing Perceptions of Material Sustainability through Drinking Vessels

Kiersten Muenchinger

University of Oregon, USA, kiersten@uoregon.edu

Abstract: Our perceptions of the environmental impacts that materials have tend to be formed by vernacular knowledge and experience. We are familiar with recycling aluminum cans, so aluminum must be sustainable because it is so recyclable. We bring our own mugs to the coffee shop because we see ceramic mugs as more durable than disposable paper cups. Images of plastic bottles littering our landscapes lead us to believe that polymers are harmful because they don't degrade. Our perceptions of the sustainability characteristics of these materials – aluminum, ceramic, and polymer – are influenced by our experience with products made from these materials. To date, Kansei engineering studies to assess perceptions of the sustainabilities of materials have been conducted with materials samples. The goal of this study is to see how people perceive the sustainability of a material used to make a specific product. For the study, a series of seven drinking vessels, each made of a different material, was fabricated. Each vessel was designed to have the same environmental impact as its companions, as calculated based on the 2007 Okala single-figure Life Cycle Assessment (LCA). This paper examines how people perceived ten unique sustainability attributes of these drinking vessels, and which of these attributes may have a dominant effect on the product's overall perceived sustainability. Clarifying which attributes of sustainability influence peoples' understanding of a product's overall sustainability will help product designers and engineers select materials for products that consumers will accept, understand, and champion for their reduced environmental impacts.

Keywords: Materials Selection, Sustainability, Product Development, Life Cycle Assessment, Kansei Engineering

1. INTRODUCTION

Consumers today consider the sustainability of a product to be important. Companies know that sustainability influences consumers in their purchasing decisions. New product developers are trying to develop more environmentally friendly, sustainable products that consumers will enjoy. Qualitative strategies (Graedel, Allenby, 1995; Lewis, Gersakis, 2001) and quantitative assessment tools such as the Okala LCA and Sustainable Minds LCA, help designers create more sustainable products. However, tools do not exist that include the intuitive response that a customer has to the sustainability of an object. The visceral response a person has to an object may not correlate to the qualitative strategies chosen by the designer, nor to the calculated impact of a product determined by LCA. It would be beneficial for designers and companies to incorporate peoples' subjective responses to sustainable attributes when intentionally designing more sustainable products with tools that couple consumer perception with calculated decision-making.

Materials choice can improve the sustainability of products, and is a frequent feature-area that is used to affect sustainability and drive consumer perception of a sustainable product. However, sustainability assessment tools do not take into account the knowledge, or lack of knowledge, that consumers have regarding materials (Crabbé, et al., 2013; Hsu et al., 2013). While materials provide discreet features through their material properties, including mechanical properties, chemical properties, optical properties and thermal properties, the sustainability of the material is defined with a combination of elements from all of the material properties. The fact that a connection exists between materiality and sustainability is well documented, but very few studies have been conducted to relate the intangible characteristics of materials to the concrete materials choices designers have at their disposal (Karana et al., 2009). Whether or not a material is perceived to be – and in practice would be – recycled, bio-degradable, or natural, as examples, is dependent on the product (Karana, 2012). Full life-cycle assessments place the materials in context with the use and functions of the product (Clancy, et al., 2013), but they are not practical nor necessarily accurate during the development of a yet un-realized product.

Breaking apart the many issues of sustainability that a material embodies can clarify the discreet issues that materials address. This study was designed to test consumer perceptions of materials on ten sustainability-oriented attributes. Discovering the kinds of attributes that customers are concerned with will help fulfill their expectations of greener products (Tseng and Huang, 2013). Because the product form influences how a material may or not behave sustainably, it should also influence the consumer perception of a material's sustainability. The product used for this study is a drinking vessel, or cup, chosen for it's clear use-scenario – beverage consumption – and the great variety of consumer-accepted materials and forms possible for a functional product.

A series of seven drinking vessels, each made of a different material, was fabricated. Each vessel was designed to have the same environmental impact as its companions, as calculated based on the 2007 Okala single-figure Life Cycle Assessment (LCA). A Kansei-engineering study with word-pairs developed to address various aspects of sustainability was conducted to investigate which sustainability attributes people relate most strongly with each product and, by extension, the materials used to make the product.

2. METHODS AND MATERIALS

Seventy people participated in the Kansei cups ranking exercise, all of whom were students at the University of Oregon. Their ages ranged from 18 to 28. There were 25 female and 45 male participants. Two groups of students, each enrolled in a product design course, were given the opportunity to participate. Participation in the study was concluded prior to the introduction of course information regarding material sustainabilities. Forty-three of the participants were provided with extra credit for their course as compensation for participating in the study. For the two students who participated from both courses, only the results from their first experience with the study are included in these results.

2.1. Cups

The sample cups used in this study were designed to be fabricated specifically for this study. Each cup is a different material, and 5 different manufacturing processes were used: sand cast secondary aluminum, slip cast ceramic, blown 100% recycled glass, blown primary glass, injection molded primary polypropylene, and rotationally molded primary high-density polyethylene. They were designed for their height, opening diameter and base diameter to be as similar as possible, considering the different requirements in proportion necessary for different fabrication processes. The wall thicknesses for the cups vary. The wall thickness for a given vessel was defined by the overall ecological impact of the vessel based on the material and the fabrication process used, and calculated using the 2007 Okala LCA tool (White et al., 2007). The goal was to create a set of vessels with as close to the same ecological impact as possible. All dimensions of the vessels needed to obey the manufacturing requirements for each process, including wall thickness and draft angle. The differences in impact for the theoretical vessels ranged from 4.58 to 4.85 Okala impact factor points. (See Table 1)

Table 1: Okala Impact Factor calculations for theoretical cups

Material	Material Impact Factor	Fabrication Process	Fabrication Impact Factor	Wall Thickness	Total Impact Factor Points
Aluminum, secondary	17	Cast	18	1 mm	4.81
Ceramic, sanitary	19	Heat	0.003996	1.4 mm	4.67
Glass, 100% recycled	6.5	Heat	0.003996	7 mm	4.58
Glass, primary	9.1	Heat	0.003996	5 mm	4.82
Polypropylene, primary	13	Injection Mold	10	5 mm	4.48
High-density Polyethylene, primary	12	Rotational Mold	14	3 mm	4.85

The fabricated vessels differed from the theoretical vessels due to the ability for manufacturers to fabricate at the required wall thicknesses, and for the ability to hold tolerances for the given fabrication processes. Also, the final aluminum cup was spun rather than cast. The rotational molder also provided linear low-density polyethylene (LLDPE) cups made from the same mold that produced the HDPE cups, as the final product was a better fill with LLDPE than with HDPE. Images of the virtual and final production cups are in Figure 1.

Figure 1: Rendering of cups (left) and production cups (right). Cups are from Left to Right, spun secondary aluminum; slip cast ceramic; blown 100% recycled glass; blown primary glass; injection molded primary polypropylene; rotationally molded, primary high-density polyethylene; and rotationally molded, primary linear low-density polyethylene.

The cups were provided to the participants as a 7-member sample set, one of each cup, in a box with an identifier letter. All cups in that box were labeled with the same identifier letter to monitor potential differences in the respondents' reactions to different sample sets. The cups were not identified with either the name of the material, or the fabrication process used.

Similar to previous Kansei studies of the perceptions of materials' sustainabilities (Muenchinger, 2012; Muenchinger 2013b), the participants in this study were asked to rank each cup on 10 word pairs. The word pairs were designed to target qualitative strategies of sustainable design. The word pairs were: *Rare – Common; Delicate – Durable; Lasting – Degradable; Raw – Sophisticated; Harmless – Toxic; Inexpensive – Costly; Luxurious – Meager; Natural – Artificial; Precious – Valueless; Recyclable – Waste*. Materials selection goals outlined by Graedel and Allenby (Graedel and Allenby: 240) of choosing abundant (*Rare – Common* and *Inexpensive – Costly*), non-toxic *(Harmless – Toxic)*, natural *(Natural – Artificial),* and minimal and minimally processed *(Luxurious – Meager* and *Raw – Sophisticated)* materials were included in the word pairs. Additional design for waste minimization strategies from Lewis and Gertsakis (Lewis and Gertsakis: 86-87) including extending the product life *(Delicate – Durable* and *Precious – Valueless),* using recyclable materials *(Recyclable – Waste)* and minimizing the impacts of disposal *(Lasting – Degradable)* were also used.

3. RESULTS

During each testing session, at least 2 ceramic cups were broken by the participants. The broken cups were replaced immediately with new ceramic cups, and the participant who was working with the cup was able to finish the survey. Because the breaking was heard and seen by other people in the testing space, the breaking ceramic cups may have influenced responses from more participants than just the few who broke the cups themselves.

Average ranking results for each of the cups examined are provided in Table 2. They have been modified from the original scoring sheets to position the more environmentally friendly word of the pair at the "1" side of the ranking on the 1-7 scale.

Table 2: Average rankings of 7 cups on 1-7 scales.

Cup	Spun AL	Slip Cast Ceramic	Blown Recycled Glass	Blown Primary Glass	Injection Molded PP	Roto Molded HDPE	Roto Molded LLDPE
Common (1) to Rare (7)	4.20	5.25	2.90	2.71	2.29	1.99	1.59
Durable (1) to Delicate (7)	1.53	6.25	3.70	4.06	1.84	2.13	2.31
Degradable (1) to Lasting (7)	5.53	3.28	5.56	5.46	5.20	4.83	4.79
Raw (1) to Sophisticated (7)	3.30	2.62	4.57	4.58	3.89	3.50	3.34
Harmless (1) to Toxic (7)	2.96	3.52	2.07	2.09	4.29	4.53	4.59
Inexpensive (1) to Costly (7)	4.61	2.90	4.26	3.90	2.39	2.06	1.91
Meager (1) to Luxurious (7)	3.96	2.87	4.50	4.33	2.57	2.07	1.93
Natural (1) to Artificial (7)	3.84	3.32	3.56	3.68	6.17	6.19	6.34
Precious (1) to Valueless (7)	4.11	4.91	3.80	3.93	5.37	5.83	5.91
Recyclable (1) to Waste (7)	2.60	4.22	3.09	2.83	4.07	4.03	4.01

3.1. Individual word-pair results

It is visually apparent in the chart of the data (Figure 2) that there is no one cup that is perceived to be sustainable on all of the word-pairs.

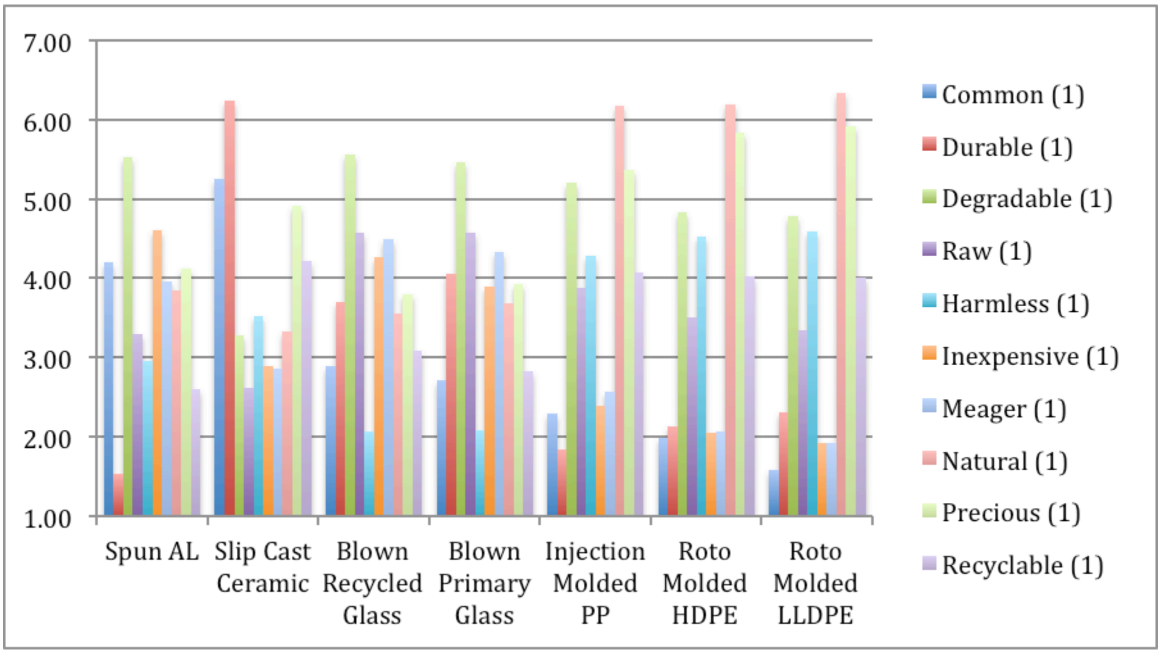

Figure 2: Rankings of seven cups for each of ten attributes of sustainability. Attributes are ranked on scales of 1-7, with 1 indicating highest sustainability and 7 indicating lowest sustainability.

3.2. Trends

From Table 2 and Figure 2, outlying factors are apparent:

- Of the 70 individual rankings in the matrix, 35 tended toward midline. 50% were outliers from midline. 23 outliers were below 3 (33% of total), 12 above 5 (17% of total).
- The blown recycled glass has the narrowest range in responses. 7 of the 10 word-pairs average in the 3.00-5.00 midline area.
- The polypropylene cup has the widest ranges of responses. Only 3 of the 10 word-pairs average in the 3.00-5.00 midline area.
- The polymer cups were ranked similarly in all word-pairs.
- The glass cups were ranked similarly in all word-pairs.
- The aluminum cup is seen as the most durable. It is the strongest perception of any factor and of any cup tested.
- Very low durability of the – very thin – ceramic cup is perceived. All other durability factors lie 2 points or more lower.
- None of the cups are seen as highly degradable. The cup with the strongest perception of degradability is the ceramic, which as noted above is not seen as durable.
- The perception of harmlessness is strongest in the 2 glass cups.
- The three polymers are not perceived as natural. The strongest negative perception of sustainability is the artificiality of the LLDPE cup.
- The aluminum cup has the strongest perception of recyclability.

4. DISCUSSION AND CONCLUSION

Compared to prior studies of peoples' perceptions of the sustainabilities of materials (Muenchinger, 2012; Muenchinger, 2013a; Muenchinger, 2013b), this study produced a more diverse and divergent response than materials samples in the form of spheres or flat plaques provoked. The responses from this cups study did not bunch in the midline area as occurred in the prior studies. These identifiable products with a specific use elicited stronger opinions. Future studies with other products would provide insight into where our perceptions of materials are influenced by a particular product use. Cups, for example, have a highly intimate use scenario, as they are held in our hands, come in contact with our mouths and deliver sustenance to our bodies.

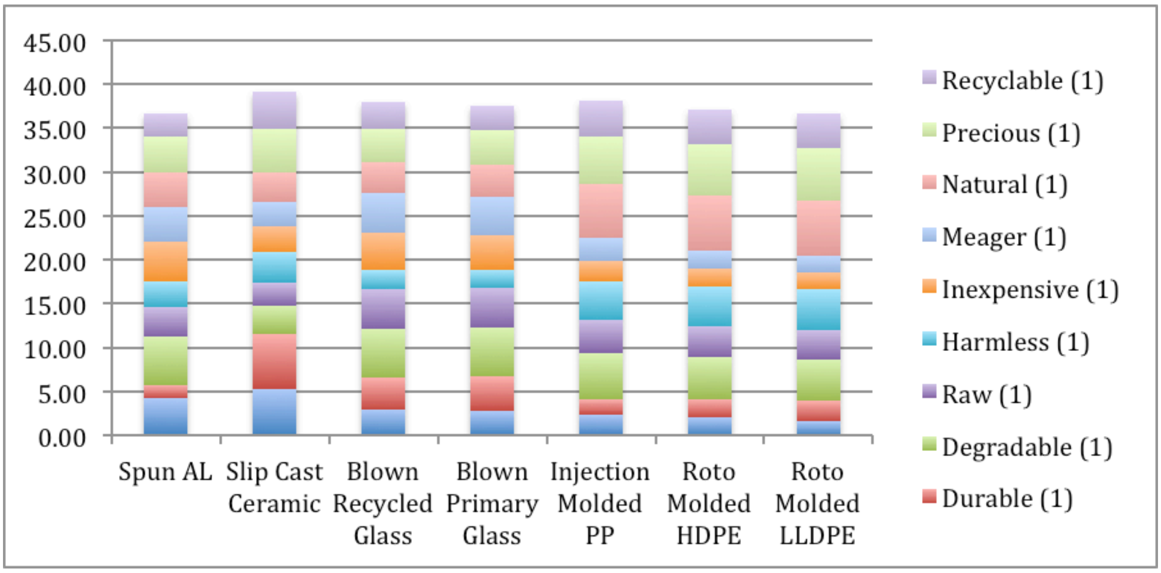

Figure 3: Sum totals of average sustainability perceptions for seven cups.

4.1. Perceptions of Spun Aluminum Cups

The sum totals of the average perceptions across all 10 word-pairs for each cup show the spun aluminum cup with the lowest total (36.64) as seen in Figure 3, implying the strongest perception of sustainability inclusive of these 10 word-pairs.

- The aluminum cups were perceived to be the most Durable, despite the thinnest wall of all of the cups.
- They were perceived to be the most Recyclable of all of the cups. This result differs from the study of spherical material samples (Muenchinger, 2013b) in which the aluminum sample was not perceived to be particularly recyclable. The aluminum cups did not have the high degree of polish that the spherical material samples in the previous study had.
- The spun aluminum cup was the second most Raw cup.
- It was the most Costly material. It is interesting that this material is perceived to be both Raw and Costly. Intuitively, one might consider a more processed-looking, sophisticated material to be perceived as more costly. In this case, the spun aluminum cup held a perception of cost and a perception of rawness.

4.2. Perceptions of Slip Cast Ceramic Cups

The slip cast ceramic cups had a sum total average of 39.13 (Figure 3), the highest of all of the cups in this study.

- The only cup perceived to not be Durable is the ceramic cup, which is also the cup that was consistently broken during the tests. It had a wall thickness similar to that of the aluminum cup, and was consistently broken during testing.
- While none of the cups were perceived to be particularly Degradable, this cup had the lowest perception of Degradability at 3.28. This may have been influenced by the breaking.
- This cup had the strongest perception of being Waste rather than Recyclable. People may not perceive recyclability in ceramics because municipal ceramics recycling is rare.
- Raw, Inexpensive and Meager were the most sustainable traits for the ceramic cups. These perceptions also may have been influenced by the breakage and the thin walls of the cups. The wall thickness was unusual (1.4mm) compared to a typical ceramic drinking vessel (5mm).
- Natural and Degradable may be perceived as similar qualities, but the ceramic cups are the only cups that had similar perceptions in these two categories. The ceramic cups had the strongest perception of being Natural compared to Artificial at 3.32.

4.3. Perceptions of Blown Primary and Recycled Glass Cups

The two glass cups showed similar responses in all of the word-pairs. The recycled glass cups were thicker, and visually were less consistent and more wavy than the primary glass cups. The mold, blowing and finishing processes for these two cups was the same.

- Both glass cups were perceived as the most Harmless of all of the cups. The perception of glass being non-toxic or inert is a strong quality for sustainable design.
- Both glass cups were perceived as the least Raw and least Meager, and most Precious of all of the cups. These perceptions were not the strongest in this study, but they do point to an appreciation for the basic material qualities of glass.
- The glass cups had strong sustainability perceptions of being Natural and, implied by least Raw, least Meager and most Precious, strong perceptions of high-quality. ‘Natural’ and ‘high-quality’ are materials perceptions that Karana notes would aid the consumer-acceptance of bio-plastics (Karana, 2012). The material qualities of glass could be used to inspire the chemical development of bio-plastics to achieve similar results.
- While both cups were perceived as recyclable, they were not strong in this perception. With long-standing municipal recycling of glass bottles, there is common knowledge of glass recycling. The cup product could move the perception that glass in this particular form or in this

particular product is not recyclable, but this did not seem to be the case for the aluminum cup. Perhaps the perceptions of Preciousness, Luxury and Sophistication of the glass cups reduce the perception of Recyclability.
- The recycled glass cups were perceived as the least Degradable of all of the cups. The aluminum and primary glass cups were close.

4.4. Perceptions of Injection Molded Polypropylene Cups

The injection-molded polypropylene cups were the most dimensionally precise and consistent of all of the 7 cups fabricated for this study. It had the thickest wall of the three polymer cups at 5mm. This is thicker than a typical polymer cup that would be found for retail purchase, which would measure around 2mm in wall thickness. This cup is thicker than a normal polymer cup due to the design intent of testing cups with equivalent Okala impacts.

- While all of the polymer cups were perceived and ranked similarly on the word-pairs, the polypropylene cup was perceived to be the most durable and the least Degradable of the three polymer cups. This perception may be influenced by this cup's thicker wall.
- This cup was perceived as less Raw than the other 2 polymer cups. This may be due to the tighter tolerances held in injection molding. The tight tolerances do not seem to make the cup appear highly Sophisticated, or processed, however, as the score is mid-range at 3.89.
- This cup is perceived to be slightly more Costly and Luxurious than the other polymer cups, but as both of these word-pair rankings are well below the mid-range, it does not appear that the precision of injection molding has strong influence on the overall sustainability perceptions on these word-pairs. The materiality appears to influence the perception of sustainability to a much greater degree than the production process.

4.5. Perceptions of Rotationally Molded Linear Low-Density Polyethylene Cups

Surprisingly, the rotationally molded LLDPE cup has the second-lowest total (36.73) average (Figure 3). While all of the polymer cups were ranked as highly Artificial and Valueless and had higher ratings for Toxicity and Lasting-ness than the other cups, the sum total for LLDPE was the second lowest overall after the aluminum cups. The polymer cups are more divergent than the other cups in how the various factors of sustainability are seen.

- They are all perceived to be highly Common, Durable, Inexpensive and Meager. Excluding Durable, these attributes tend not to be considered good attributes for new products even though they are attributes of environmentally friendly products.
- The strong perception of Valueless-ness is contrary to the perception of being Inexpensive. How a product can be both Inexpensive and Precious may be a prime target area for sustainable design tactics.
- The perception of Artificiality of polymers is an issue being addressed with bio-polymers such as polylactic acid (PLA). Artificiality is a prime area to target for the acceptance of polymers as a sustainable material.

4.6. Overall Analysis

The Kansei study of the perceptions of the sustainabilities of various materials is stronger and more nuanced when testing products compared to testing materials samples. The product testing with cups corroborates results from prior studies, such as polymers having a strong perception of Artificiality, and Inexpensiveness (Muenchinger, 2012; Muenchinger, 2013a). This perception is strong and consistent across multiple studies. Because these perceptions are so strong, the goal of imbuing polymers with materials properties that convey 'naturalness,' as described by Karana (2012) is not a strong strategy for current polymer products. Based on the strong Natural response to glass, transparency may influence the perception of naturalness, and that is a possible material property for polymers. However, focusing on 'high-quality' as it pertains to Durability, a trait that is strong for polymers across several studies, is a sustainability story that consumers are more likely to emotionally understand and trust.

Statistical analysis of these results should be performed to determine which sustainability factors, or word-pairs, are more important or more noticeable to customers. The important factors are the ones that more dominantly influence purchasing decisions and would therefore have a stronger effect on market-driven sustainable products.

Fabricating equal-impact products for this study should also be examined. Using products with equal impacts was intended to eliminate a variable for this Kansei study of perceptions. Whether equalizing the field of products in this way had an affect on the study is unclear. Statistical analysis of the results may show the value of testing equal-impact products. Future product-based studies would be more accessible on less similar products, and could be performed confidently if the quantitative effects of impact are negligible.

The desire from consumers, designers and companies to have more sustainable products is a driver that will remain indefinitely. There is a long-term need to continue assessing human perceptions around materials and sustainability. There is a gap in product design's toolbelt. A public reference database of materials and metrics would aid new sustainable product design. As our knowledge grows, the usefulness of the database will only increase.

More complete tools give us confidence in our developments, and in our definitions of what a sustainable product is. Kansei studies of materials will help us attain more specific and more consumer-accepted sustainable product definitions.

ACKNOWLEDGMENTS

REFERENCES

Clancy, G., Fröling, M., Swanström, M. (2013) Changing from petroleun to wood-based materials; critical review of how product sustainability characteristics can be assessed and compared. Journal of Cleaner Production. 39, 372-385.

Crabbé, A., Jacobs, R., Van Hoof, V., Bergmans, A., Van Acker, K. (2013) Transition towards sustainable material innovation: evidence and evaluation of the Flemish case. Journal of Cleaner Production. 56, 63-72.

Graedel, T.T., Allenby, B. R. (1995). Industrial Ecology. Englewood Cliffs, NJ: Prentice-Hall.

Hsu, C., Lee, W., Chao, W. (2013) Materiality analysis model in sustainabiilty reporting: a case study at Lite-On Technology Corporation. Jornal of Cleaner Production. 57, 142-151.

Karana, E., Hekkert, P., Kandachar, P. (2010) A tool for meaning driven mateirals selection. Materials and Design. 31, 2932-2941.

Karana, E. (2012) Characterization of 'natural' and 'high-quality' materials to improve perceptions of bio-plastics. Jornal of Cleaner Production. 37, 316-325.

Lewis, H., Gertsakis, J. (2001). Design + Environment: A Global Guide to Designing Greener Goods. Sheffield: Greenleaf Publishing Limited.

Muenchinger, K. (2013a) Combining Kansei Engineering and LCA to Convince Clients that Sustainable Polymer Choices Exist. Proceedings of IDSA National Education Conference.

Muenchinger, K. (2013b). Using Kansei-based metrics in conjunction with LCA Impact Factors to Enhance Sustainable Materials selection of Wood, Polymers and Metals. The International Journal of Designed Objects. 7(3), 61-71.

Muenchinger, K. (2012). Using Kansei-based sustainability metrics in conjunction with LCA impact factors for sustainable materials selection. Proceedings of the International Conference on Kasei Engineering and Emotion Research, KEER2012 (pp197-203). Taiwan: College of Planning and Design, National Cheng Kung University.

Tseng, S., Huang, S., (2013) A framework identifying the gaps between customers' expectations and their perceptions in green products. Journal of Cleaner Production. 59, 174-184.

White, P., Belletire, S., St. Pierre, L. (2007). Okala: Learning Ecological Design. Phoenix.

BIOGRAPHY

Kiersten Muenchinger is an Associate Professor and the founding Director of the Product Design Program at the University of Oregon. Her research and creative practice focus on unusual materials use with an emphasis on sustainability and metrics. She utilizes Kansei engineering studies to quantify consumer perceptions of the green-ness of product materials, and references them with Okala Life Cycle Assessment data. Her original product work was featured recently in the Salão Design exhibition in Brazil. Before joining UO, Kiersten held design engineer positions with IDEO, Sottsass Associatti, Walt Disney Imagineering, and the Long Now Foundation.