HIERARCHIC DESIGN AND MATERIAL IDENTITY

Siv Lindberg[1]*Ann-Sofie Hartzén[2,3], Thomas Wodke[4], Mikael Lindström[1,5*]

[1]*Innventia AB, Box 5604, SE-114 86 Stockholm, Sweden*

[2]*University of Gävle, Faculty of Engineering and Sustainable Development, Department of Building, Energy and Environmental Engineering, Högskolan i Gävle, SE-801 76 Gävle, Sweden*

[3]*Systems and component design, Machine design, KTH, SE-100 44 Stockholm, Sweden*

[4]*Fraunhofer-Institute for Environmental Safety and Engineering Technology UMSICHT, Osterfelder Straße 3 46047 Oberhausen, Germany*

[5]*Experience Design Group, Konstfack, University College of Arts, Crafts and Design, Lm Ericssons väg 14, SE- 126 26 Hägersten, Sweden*

*corresponding authors:

siv.lindberg@innventia.com *(material identity)*

mikael.lindstrom@innventia.com *(hierarchical design*

ABSTRACT

One of the keys to the commercial success of new materials is according to research, that they should be introduced with unique aesthetic properties emphasizing that they are different to the regular ones. Designing identity into new materials, by using a Hierarchic Design process to convey meaning to materials is the scope of our research on materials identity. The Hierarchical Design concept constitutes of design at three different levels: (i) component design (materials' components), (ii) materials design or composite design, and (iii) product design. Designing new materials using a Hierarchic Design process is to convey functionality, meaning and identity to materials through multidisciplinary collaboration. This requires an effective interface between scientists with different backgrounds such as chemistry, mechanical engineering, design and psychology.

Our interviews with designers, informants and brand innovators show that there is willingness and a strong interest from this group to work more closely with the materials scientists, making it possible for them to influence the material's physical qualities, expression and how it can be processed. In this way they can be sure to have a material that fulfills the requirements in a design project. Two studies using the Product Semantics methodology to quantify the non-technical properties of bio-composites in the context of other materials reveal two main principal components in both cases; the 1st is related to the quality and value, and the 2nd component relates to naturalness and environmental friendliness. This indicates that materials perceived to be high in naturalness and environmental friendliness was not rated high on quality attributes and vice versa. These results demonstrate a challenge at the material/composite design level; which strategies to develop in order to design these new materials to express e.g. a high degree of naturalness without compromising the impression of quality?

INTRODUCTION

Traditionally materials development has been driven by two different driving forces, see figure 1. The development within aerospace, medicine and military has demanded new materials in order to overcome technological problems, to find *e.g.* super light materials,

materials compatible with the human body or materials that will be transparent to radiation of certain wavelengths. Money has not been a limitation; there has been a need for small volumes of very special materials that can solve a given problem. Over time some of these materials have turned into commodities and become available in larger volumes at reasonable prices, i.e. Teflon® and super alloys. The second big driving force has been to find cheaper high volume solutions for the manufacturing industry. In order to maintain the profit margins on a tougher market, new and cheaper material solutions have been needed. These materials can be seen as substitutes, they are developed to substitute materials that already exist, and they usually have to fit in the existing production processes in order to be competitive price wise. They have to be cheaper and better performing in order to take market shares. Forest based renewable composites have traditionally been viewed as sustainable replacements for existing oil-based materials.

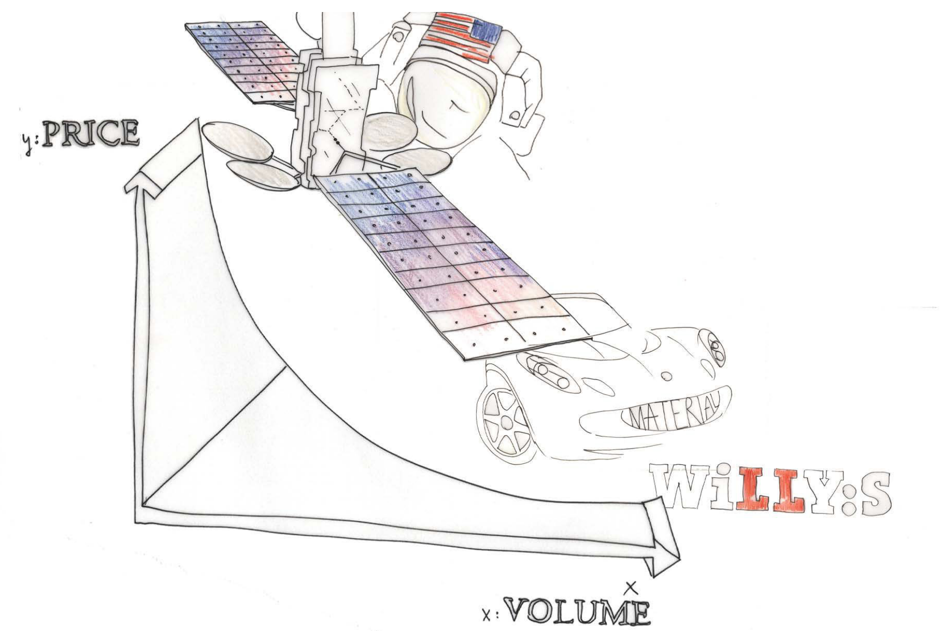

Figure 1. The relation between price and volume for commercial materials.(1) New materials are expensive but once the volume gets big and patents expire, the price will fall. The figure also demonstrates the two driving forces in materials development; the development of technology driven high tech materials and the search for cheaper commodity materials. Drawing Farvash Razavi and Nandi Nobell.

The fear of an oil shortage and the global warming discussion have introduced a third driving force in the development of new materials; the bio based, low carbon foot print materials that can save humanity from peak oil and the global warming crisis. A major question connected to the bio based driving force is: How do we introduce new materials on the market?

HIERARCHIC DESIGN

We introduced the R&D&D concept (Research & Design & Development) in which we aim to develop a composite material concept that will allow for tailor made materials for specific applications [1]. A composite material consists of different components, fibres, polymers, plasticisers, binders, fillers, pigments, and different modifiers like anti-oxidants and fire retardants. The structure in the material will define the material properties. Relevant material properties can be tailored by designing the components, the composition of components and the product property requirements. We call our approach Hierarchic Design and define three different levels of design:

Component design. On this level we study and develop different components, polymers, compatilisers and reinforcement of fibres. At this level the fibre is designed. Contrary to well-defined man-made fibres like carbon fibre or glass fibre where the mechanical properties can be found in a hand book, bio based cellulose fibres have a wide spectrum of properties. Depending on which specie the fibre is extracted from and where it has been growing, when it has been harvested, and how it has been processed, the fibres will have different properties. In addition, the fibre wall as well as the fibre surface can be modified and tailored to have given chemical and structural features.

Material design. This is the level where the material is given its final structure. On this level we decide which components to blend and in what proportions. Should the fibres be randomly oriented or parallel? Should the fibres be un-bleached or bleached? From which plant species should they be derived? Surface modified or with a cross-linked fibre wall? What polymer should be chosen and which production process? Hot pressing, moulding or injection moulding will give very different structures.

Product design. The product design will define the material properties needed in an optimised design. The designer and the production engineers will give the product and process restrictions and hence define the material structure. The material structure can then be calculated from the models developed at the other levels and the right combination of components and production processes can be chosen.

Hierarchic Design is a process in which materials scientists and designers need to communicate material-selection based information, e.g. measurable technical characteristics of materials and material-perception based information, e.g. sensory perception, emotions and experience. The new forest based renewable composites should not only fulfil technical requirements, they should also appeal to users' senses and render an intended meaning to products. Designing new materials by using a Hierarchic Design process is to convey functionality, meaning and identity to materials through multidisciplinary collaboration which in turns requires an effective interface between scientists with different backgrounds such as chemistry, mechanical engineering, design and psychology.

CASE STUDY: DRIVERS FOR USING NEW MATERIALS IN DESIGN

The new materials face a challenge in that they are generally unknown to the consumer market. What makes the designer select a new material, e.g. a new bio composite for a design project? As part of the research project – The Materials Statement, we have performed interviews with designers, brand innovators and material informants to find out why they want to use a new material in a project, their opinion on how identity is formed in a new material and what the opportunities and difficulties are with choosing a new material. The interviews were done in a semi structured form, with a numbers of questions that the subject could answer freely to.

The preliminary results (table 1) indicate a will and a strong interest from the designers to work more closely with the materials scientists. This makes it possible for them to be first with a new material and to through design influence how the new material will be perceived on the market. Through the cooperation with materials scientists they can influence how the material is designed and processed in order to express certain physical properties. In this way they can be sure to have a material that fulfills the requirements in a design project. They also indicate the importance of using the material in the right product so that the material's qualities are enhanced.

Table 1 Drivers for selecting new materials in product design and actions taken to create meaning and identity for new materials. Results from interviews with designers, brand innovators and material informants.

Question	Drivers	Results from interviews
Reasons for selecting a new material for a design projects.	Newness as a quality	To be first with a new material is something that increases the brand value for product companies. On a competitive market there is always a need to stay ahead of the competition and have products that are being viewed as the latest in design. One of the most common questions posed to the material informants from designers and architects concerns what new materials they have on display.
	Influence	Being the first designer to work with a material gives the possibility to influence how a material will be perceived and thus create its personality and value on the market. The lure of doing something new, and going down a new path is strong. Also working directly with the materials scientists and having the possibility to be involved in the creation of the material; its behaviour and expression, and to see its potential in product design is attractive to some designers
	Environmental interest	A strong interest in environmental issues and sustainability is something that several designers express. They want to find new materials that have less impact on the environment than existing ones. This can also be a driving force for working with materials scientists as some of the designers express that there is a lack of environmental friendly materials on the market. They have a desire to contribute to the development of more sustainable materials.
	New functions or qualities	To find a material that has a new function or quality that can deliver something new to the product. It can be a surface, how the material feels to the touch or its appearance. It can also be the ability to use a new production method when choosing this material.
	Needs	In some design projects, designers experience needs that cannot be fulfilled with the materials that are on the market today. This creates a demand for new materials that have specific functions or expressions. This can also be a driving force to work directly with the materials scientist, being able to develop a material with the desired qualities.
How to create personality and identity to new materials.	Hands-on	Try the material to get information on its performance, feeling, and appearance, the processing possibilities and limitations in order to find the materials unique qualities. The designer often wants to collaborate with the materials scientists in order to gain their knowledge about the material and have the opportunity to suggest changes to the material. If possible the designers prefer to work in a team with the scientists to be able to influence the materials functions, expressions and how it can be processed.
	Display material in products	Displaying the material in a product or demonstrator that enhances the material. It could be a specific function, a physical property or an expression that should be communicated. For example, if a material's sustainable quality is to be shown it is important that the product itself is sustainable in production, use and waste. Otherwise there will be a discrepancy between the material statement and the product. If the material is used in the right type of product it should add something new to the product like a new expression or a new function.
	Marketing	An important tool to communicate the material identity. A new material needs to be explained to the material buyers and consumers. Demonstrators or products can be used for this purpose in combination with other marketing channels like home pages, ads, etc. Some of the designers suggest using storytelling as a marketing method. The story behind the material, the materials' lifecycle from origin to recycle, can be used to communicate the materials unique qualities. Self-confidence is mentioned as important when communicating the material identity; the way a material is launched plays a large part in how it will be perceived and therefore how the materials' identity will be formed.

MATERIAL PERCEPTION AND IDENTITY

Material perception is concerned with how we perceive what things are made of. The perception of material properties can involve all of our senses; steel has certain gloss, feels smooth and cold, and makes a certain sound when hit with a metallic object. Wood feels warm, rougher than steel, have certain colours and textures and by knocking on e.g. a wooden wall, we can determine whether it is solid. The advent of computer graphics and robot vision has advanced our knowledge on how humans infer material properties through the visual system based on how light is reflected from the surface [2].

Product semantics was defined by Krippendorff and Butter as "a vocabulary and methodology for designing artefacts in view of the meanings they could acquire for their users and the communities of their stakeholders" [3]. Petiot [4] defined product semantics as the "study of the symbolic qualities of man-made forms in the context of their use, and application of this knowledge to industrial design". Kansei Engineering [5] is a methodology for translating emotional and sensory responses to product design parameters. Design alternatives are rated on adjective scales (e.g. strong, rough, natural, quality etc.).

A CASE STUDY: THE IDENTITY OF NEW BIO-PLASTIC COMPOSITES

A product semantic approach was adopted to investigate the semantic space of different materials. Sixty (30+30) participants evaluated wood fibre-reinforced polypropylene (PP) or polylactide (PLA) composites, together with common materials, i.e. metals, wood and plastics. The descriptive words used in the study are in part based on previous elicitation studies [6, 7] and on workshops with designers and materials scientists. In a first step, 7 injection moulded wood fibre reinforced PLA composites were evaluated with 4 metals, 5 wood and fibreboard samples and 3 petroleum based plastic (PP) composites. Subsequent principal component analysis was used to reduce the semantic space to a smaller set of factors.

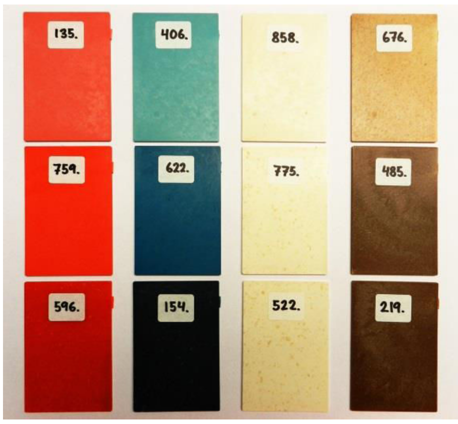

Figure 1 Example of wood fibre-reinforced polypropylene or polylactide composites used in the project.

A principal component analysis yielded two factors based on the criterion that the eigenvalue should exceed 1. Together, the two factors explained 82 % of the total variance. All variables present communalities of over 0.5. The first factor involves high loadings on *quality exclusive, exciting* and *beautiful*, and high opposite loadings on *cheap*; whereas factor 2 reflects the attributes *natural* and *environmental friendliness*. We named factor 1, Quality and Value; and Factor 2, Naturalness and Environmental friendliness, see figure 2. Quality and *naturalness/environmental friendliness* are represented by two orthogonal factors meaning that they have no correlation. The Naturalness factor is represented by the wood and wood fibre samples whereas the Quality factor is represented by the metals. The wood plastic composites (PLA and PP) represent the opposite to wood on the naturalness.

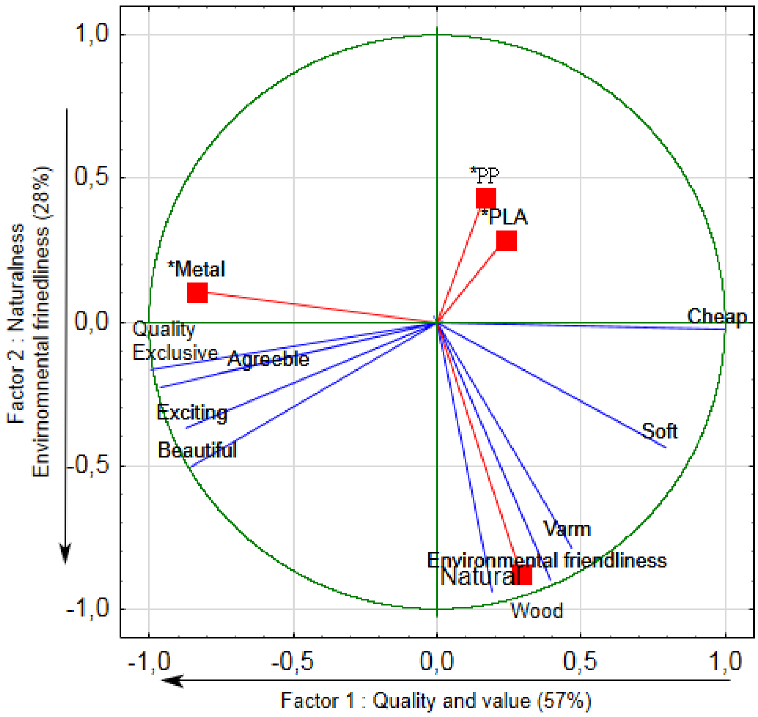

Figure 2 PCA of attributes in a 2-D solution for 21 materials. Semantic attributes are shown as blue vectors and materials as supplementary variables whose projection on the 2 factor solution are shown as red squares.

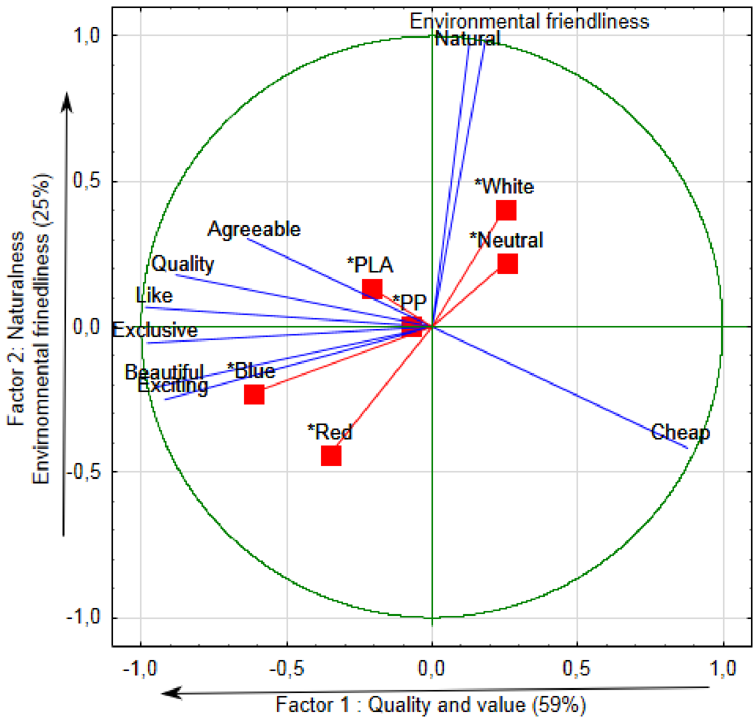

Figure 3 PCA of attributes in a 2-D solution for 18 wood plastic composites or different colours and compositions. Semantic attributes are shown as blue vectors and materials as supplementary variables whose projection on the 2 factor solution are shown as red squares.

In order to investigate the impact of different strategies at the material design level, the same Product Semantic methodology was adopted to 18 wood fibre-reinforced plastics. Fibre type and amount, type of plastic (PLA or PP), colouring (dyed fibres and/or plastic). A principal component analysis yielded a very similar factor structure as in the case with different materials and the factors were again interpreted to be related to Quality and Value (factor 1); Naturalness and Environmental friendliness (factor 2), see figure 3. Again, material sample perceived to be high in naturalness and environmental friendliness was not rated high on quality attributes. In this case, colour appears to be the most determinant property for the impression of naturalness or value. White coloured and uncoloured samples were to a larger extent related to the Naturalness factor (factor 2) whereas in particular blue samples were related to the Value factor (factor 1).

The results are in accordance with Karana [8], who found natural colours (mostly brownish) to be an important determinant in the expression of naturalness together with visible grains and fibres, and a rougher surface. High quality materials were related to smooth surfaces, glossy and reflective.

Our results demonstrate a challenge for the material design level; which strategies to develop in order to design these new materials to e.g. increase the express of naturalness/environmental friendliness without compromising the impression of quality. On-going work within this project concerns sensory analysis (visual and tactile exploration) of different material compositions in relation to material properties (e.g. surface chemistry, topography, texture, friction, gloss, colour, and optical homogeneity). Models based on sensory perception coupled with the structure of emotional responses will permit a mapping process from perceptual words to material design elements using techniques such as Kansei Engineering.

CONCLUSIONS

In this paper we have presented a concept for developing new bio based materials that we call Hierarchic Design, consisting of three different levels of design. The component level is where the different components of a material are studied and developed. The material design level is where the material is given its final structure depending on the desired properties of the material. The product design level is where the products requirements, regarding use, expression and production, define what structure the material should have.

By involving the designers already at the material design level it is possible to more accurately tailor a material to a specific product or market segment. The scientist has knowledge about the materials' technical qualities, and the designer has knowledge about the users' need and wants. These requirements cannot be fulfilled solely by a materials physical qualities but also involve the materials expression, the sensory perception of the material and the emotions and experiences the user gets from the material, in order for the product to expresses the intended meaning.

Results from interviews with designers and brand innovators show that there is both a will and an strong interest from the designers to work more closely to the materials scientist, making it possible for them to influence the material's physical qualities, expression and processing techniques. This way they can be sure to have a material that fulfils the needs in a design project. They also indicate the importance of placing the material in the right type of product so that the material's qualities are enhanced.

By studying how sensory and aesthetic dimensions of a material is related to its technical properties it is possible for the materials scientist and the designers to work together to create new bio based materials that appeal to the users and will succeed on the market.

Our results from perceptual evaluations of different materials demonstrate a challenge for the material design level in that quality/value and naturalness/environmental friendliness appear to be two separate and uncorrelated dimensions of materials perception. Which strategies should the materials scientist adopt in order to design these new materials to express e.g. a high degree of naturalness without compromising the quality impression?

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REFERENCES

1. Lindström, M., Gamstedt, E. K., Berthold, F., Varna, J., & Wickholm, K., *Hierarchical design as a tool in development of wood-based composite applications*, in *13th European Conference of Composite Materials*, L.E. Asp and E.K. Gamstedt, Editors. 2008: Stockholm.

2. Adelson, E.H. *On seeing stuff: the perception of materials by humans and machines*. in *SPIE*. 2001.

3. Krippendorff, K. and B. Butter, *Product semantics: Exploring the symbolic qualities of form in Innovation.* The Journal of the Industrial Designers Society of America, 1984. **3**(2): p. 4.

4. Petiot, J.-F. and B. Yannou, *Measuring consumer perceptions for a better comprehension, specification and assessment of product semantics.* International Journal of Industrial Ergonomics, 2004. **33**(6): p. 507-525.

5. Nagamachi, M., *Kansei Engineering: A new ergonomic consumer-oriented technology for product development.* International Journal of Industrial Ergonomics,, 1995. **15**: p. 3-11.

6. Jonsson, O., Lindberg, S., Roos, A., Hugosson, M., & Lindström, M., *Consumer perceptions and preferences on solid wood, wood-based panels and composites – A repertory grid study.* Wood and Fiber Science, 2008. **40**(4): p. 663-678.

7. Nyrud, A.Q., A. Roos, and M. Rødbotten, *Product attributes affecting consumer preference for residential deck materials. .* Canadian Journal of Forest Research, 2008. **38**: p. 1385-1396.

8. Karana, E., *Characterization of 'natural' and 'high-quality' materials to improve perception of bio-plastics.* Journal of Cleaner Production, 2012. **37**(0): p. 316-325.