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Consumer perception of wood surfaces: the relationship between stated preferences and visual homogeneity

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Abstract Information about people's preferences as to wood products is of relevance to several decision makers in the forest sector. Studies revealing consumer preference provide information that can be used for marketing and manufacturing of wood products, but these also provide information of relevance to designers and decision makers involved in building design and construction processes. Previous studies show that the overall harmony of the visual surface is correlated with preference. In this study, perceived visual homogeneity is modeled for five copper-impregnated and five organic biocide-impregnated decking materials with different visual quality. The models are based on visual variables. Homogeneity is a function of material-dependent variables (dry knots, knot shape, and splay knot), production-dependent variables (stain), and surplus color, which is a combination of both wood property and treatment. The results imply that homogeneity is influenced by both wood properties and treatment. Producers of decking should, while maintaining a focus on using high-quality raw material, also focus on producing a product with an unstained appearance.

Key words Sawnwood · Preservative treatment · Consumer preference · Sensory analysis · Homogeneity

Introduction

Studies that reveal consumers' preferences provide relevant information to decision makers in the forest sector, with respect both to the manufacturing and the marketing of wood products and to building design and construction. More knowledge about the appearance of wood can provide competitive advantages for the forest industry and will also, if applied to the development of new products in accordance with consumers' needs and requirements, improve consumer satisfaction and welfare. Preference studies are also relevant from a psychological point of view.

Results from previous preference studies indicate that people's preferences are affected by product attributes. Brandt and Shook[1] conducted a comprehensive review of previous attribute research on forest products and concluded that consumers' quality attributions with respect to forest products can usually be ascribed to the visual and tactile, i.e., tangible, properties of the wood. A few studies had also evaluated the importance of intangible attributes, such as service and environmental impact. Furthermore, Brandt and Shook[1] found only a few published articles that had studied end-consumers' preferences.

A few studies have investigated the relationship between preferences and physical wood properties. In general, these studies have concluded that homogeneous visual properties, for example, wood surfaces with few and evenly dispersed knots and an even growth ring pattern, are preferred by consumers.[2–5] Preference studies are relevant to the industry because they reveal consumers' taste and preferences, but results from analytical models are particularly important because these studies can be used to predict consumer preferences.

An important aspect with respect to consumer preference is the relationship between wood properties and the aesthetic properties of the material. There is evidence that architects and construction designers choose wooden building materials because wood is perceived as aesthetically appealing,[6] but there is little knowledge concerning which wood properties of the wood are related to aesthetic characteristics and how they are related. A model developed by Broman[3] provides insights into the formation of preference for solid wood products, but so far it has not been empirically validated. Broman claimed that there were three properties of wood that influenced consumer preference: *harmony*, *activity*, and *social status*. In this article, the rela-

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tionship between consumer preferences and perceived homogeneity is modeled.

The present study evaluates consumers' preferences for wooden decking products. Wooden decking and other outdoor wood applications are usually made from preservative-treated wood or naturally durable wood (e.g., heartwood from pine or oak). Preservative-treated wood is usually pressure-treated using water-based or petroleum-based preservatives, but in recent years modified wood products have also been commercially available, for example, heat-treated wood, acetylated wood, and furfurylated wood. In the present study, two pressure-treated decking materials were included: Cu-treated wood, for which a traditional copper treatment was used, and wood subjected to metal-free treatment, a new product without toxic metal preservatives.

Both wood properties and product properties affected by the manufacturing process are studied and modeled after the concept of *harmony*.[3] Thus, this study provides new information about how raw material properties relate to end products, how they affect consumer preferences, and how treatment and manufacturing processes influence consumer preferences. Results from the study can be used to improve products made from treated wood, and they also provide information of relevance to the product development and innovation processes.

Materials and methods

Ten material samples were evaluated by a sensory panel consisting of trained sensory assessors and approximately 120 potential consumers. Thus, two data sets were available for analysis: (1) descriptive sensory data and (2) stated preference from potential customers. Two wooden decking products, made of Scots pine (*Pinus sylvestris*), that had been subjected to two different pressure treatments, were used: copper treatment (Wolmanit) and organic biocide treatment (Metal Free). The material samples that were evaluated by the sensory profilers and customers were made to resemble outdoor residential decks. These sample decks were rectangular, measuring 1000 × 62 × 0 mm, and consisted of five parallel boards, each measuring 1000 × 120 × 28 mm, fastened to two perpendicular boards on the underside of the deck. The pith side of the boards faced up. Five material samples were made for each decking product.

Both decking products were from pressure-treated wood, but because of the treatment method the visual properties of the sample deckings differed. Treatment method affects wood properties such as color and wood density. The wood properties of the raw material used to produce preservative-treated products can influence the visual properties of the final products; hence, the boards selected for the sample deckings were sorted according to wood quality. Wood properties differ with the quality of the sawnwood used as raw material. Pressure-treated wood products are usually made from sawnwood with a large share of sapwood, which influences the quality. The ten material samples are described in Table 1. Figure 1 shows photographs of the different samples.

Sensory analysis

Sensory analysis is a method for identification and measurement of product attributes perceived by sight, sound, smell, taste, and touch.[7] Sensory methods are classified according to their primary use; usually a distinction is drawn between analytical methods, with the purpose of providing objective descriptions of products (analytical sensory profiling), and hedonic methods, in which the purpose is to retrieve information about consumers' preferences and attitudes toward products (hedonic profiling).[8] Previous experience indicates that sensory analysis can be applied to wood products.[5,9,10]

The sensory panel consisted of 11 assessors (judges) who were trained in defining, understanding, and evaluating product attributes in general. In a discussion with the assessors taking different Nordic visual grading rules into account, a list of 23 attributes was chosen. It was emphasized that the different attributes should be possible to judge by means of a scale from 1 to 9. The method was used by Nyrud et al.[5] Before the study, all the assessors were screened for their ability to discriminate between wood samples with small variations in the intensity of the given attribute. All members of the panel were allowed to evaluate the samples at individual speed, and the results were recorded on a 15-cm nonstructured scale. The left side of the nonstructured scale corresponded to the lowest intensity and had a score equal to 1. The rightmost side of the

Table 1. Description of material samples

Decking ID number	Treatment	Description of the quality
117	Copper	Few small-sized sound knots
285	Copper	Medium-sized sound knots
331	Copper	Large annual rings, board with pith
593	Copper	Many failures, dry medium-sized knots
939	Copper	Some rotten and dry knots
730	Organic biocide	Small-sized sound knots
480	Organic biocide	Medium-sized sound knots
174	Organic biocide	Large-sized sound knots
564	Organic biocide	Board with pith
42	Organic biocide	Many failures and dry knots

ID, identification
All deckings were made of Scots pine

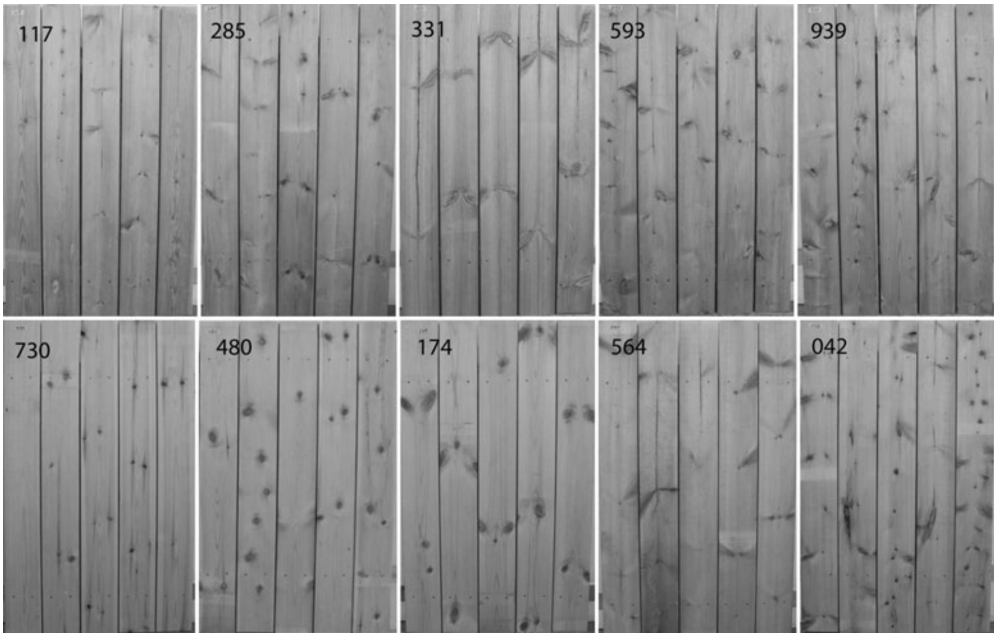

Fig. 1. Photographs of the deckings investigated, which are described by the *numbers* in Table 1

Table 2. Sensory attributes identified by the sensory panel

Sensory attributes	Definitions	Score 1	Score 9
Lightness	Degree of white/black in the color	Black	White
Hue	Green/yellow to yellow/red	Green/yellow	Yellow/red
Saturation	Color saturation	Indistinct	Saturated
Homogeneity	Overall homogeneity	Nonhomogeneous	Homogeneous
Stained	Stained/mottled	No stains/spots	Stained/spotted
Surplus color	Redundant color	No surplus color	Surplus color
Gloss		Matte	Glossy
Knot size	Diameter	Small	Large
Knot shape	Ovality	Round	Oval
Spike knot	Amount of spike knots	No spike knots	Spike knots
Dry knots	Amount of dry knots	No dry knots	Abundant dry knots
Knot groups	Amount of knot groups	No knot groups	Abundant knot groups
Knot homogeneity	Distribution of knots on the surface	Unevenly distributed	Evenly distributed
Knot checks		No knot checks	Abundant knot checks
Ring density	Growth ring density	Wide rings	Dense rings
Ring contrast	Growth ring contrast	No visible rings	Distinct rings
Ring pattern	Growth ring pattern	No pattern	Clearly visible pattern
Density	Wood density	Low	High
Hardness	Wood hardness	Soft	Hard
Smoothness	Smoothness when touched	Rough	Smooth
Pitchy		Dry	Pitchy
Checks	Checks along the board	No checks	Abundant checks
End checks		No end checks	Abundant end checks

scale had a score equal to 9. The samples were evaluated under identical lighting conditions (ISO 1988). The sensory panel identified 23 attributes for each of the ten decks. The different attributes are described in Table 2.

Hedonic study

Data for the hedonic study were collected during a house and garden fair in the Oslo region in Norway. Material samples were displayed on a stand, and visitors passing the stand were invited to participate in the study. One group of consumers evaluated five decking samples made from copper-treated wood (n = 102) and one group evaluated the decking samples made from wood treated with biocide (n = 119). The respondents were asked to rate their preference for the samples on a nine-point scale: from 1 ("dislike very much") to 9 ("like very much"). The respondents were allowed to complete the questionnaire at individual speed. Demographic information was also collected for all respondents, i.e., sex, age, living situation (one-family house/row house, apartment, cabin, owners, or renters), education, annual income, experience in woodwork, and plans for remodeling. Descriptive statistics for both groups of respondents are provided in Table 3.

Partial least squares regression (PLSR), using The Unscrambler,[11] and logistic regression, using JMP,[12] was

Table 3. Respondents and descriptive statistics

	Copper-treated material samples	Biocide-treated material samples
Number of respondents	102	119
Sex (% women/men)	54/47	64/55
Age (years) (% 16–35/36–55/>56)	34/49/16	13/42/45
Previous experience (professional or do-it-yourself projects) (%)	56	61

Table 4. Sensory attributes and mean scores for copper-treated sample deckings

Sensory attribute	Decking ID number				
	117	285	331	593	939
Lightness	4.42^{A}	4.47^{A}	**4.60^{A}**	*4.24^{A}*	4.41^{A}
Hue	1.70^{A}	1.51^{A}	*1.36^{A}*	1.45^{A}	**1.89^{A}**
Saturation	5.55^{A}	5.65^{A}	**6.75^{A}**	5.87^{A}	*5.45^{A}*
Homogeneity	5.23^{AB}	4.35^{BC}	**6.22^{A}**	*3.12^{C}*	3.69^{C}
Stains	*2.65^{A}*	**4.64^{A}**	2.82^{A}	4.25^{A}	4.56^{A}
Surplus color	6.03^{AB}	6.65^{A}	*4.41^{B}*	**7.43^{A}**	6.00^{AB}
Gloss	2.55^{A}	2.52^{A}	2.47^{A}	*2.15^{A}*	**2.93^{A}**
Knot homogeneity	5.65^{A}	5.51^{A}	*4.37^{A}*	**6.01^{A}**	4.85^{A}
Knot size	*2.55^{C}*	3.82^{BC}	**6.09^{A}**	4.23^{B}	3.95^{BC}
Knot shape	*2.59^{C}*	4.00^{BC}	**6.57^{A}**	5.35^{AB}	4.05^{B}
Spike knots	*2.06^{B}*	3.46^{AB}	4.45^{A}	**4.56^{A}**	3.20^{AB}
Ring density	*3.73^{C}*	4.86^{ABC}	4.03^{BC}	**5.84^{A}**	5.25^{AB}
Dry knots	2.75^{AB}	2.25^{B}	*1.44^{B}*	4.22^{A}	**4.46^{A}**
Knot groups	3.07^{B}	3.87^{AB}	**5.37^{A}**	4.34^{AB}	*2.98^{B}*
Knot checks	2.06^{A}	2.23^{A}	*1.66^{A}*	**2.64^{A}**	1.98^{A}
Ring contrast	5.57^{A}	4.63^{AB}	**5.72^{A}**	*3.83^{B}*	5.24^{AB}
Ring pattern	**5.51^{A}**	4.75^{A}	5.49^{A}	*3.89^{A}*	5.11^{A}
Wood density	4.61^{A}	4.77^{A}	*4.29^{A}*	4.57^{A}	**5.00^{A}**
Hardness	4.79^{A}	**4.93^{A}**	*4.31^{A}*	4.49^{A}	4.79^{A}
Smoothness	3.20^{A}	*3.05^{A}*	3.23^{A}	3.13^{A}	**3.32^{A}**
Pitch	2.80^{A}	*2.71^{A}*	2.82^{A}	**3.06^{A}**	2.80^{A}
Checks	2.74^{AB}	**3.01^{A}**	*1.51^{B}*	2.93^{A}	2.18^{AB}
End checks	2.06^{A}	1.66^{A}	*1.56^{A}*	1.78^{A}	**2.09^{A}**

Identical superscripts indicate no statistical difference in sensory score (Tukey–Kramer test, $P < 0.05$)
Maximum score in bold; minimum score in italic

Table 5. Sensory attributes and mean scores for biocide-treated sample deckings

Sensory attribute	Decking ID number				
	174	42	480	564	730
Lightness	**6.21^{A}**	*4.28^{B}*	5.86^{A}	4.71^{B}	5.88^{A}
Hue	*5.45^{B}*	**7.85^{A}**	6.06^{B}	7.38^{A}	6.07^{B}
Saturation	*3.91^{B}*	**5.77^{A}**	4.44^{AB}	5.13^{AB}	4.25^{AB}
Homogeneity	**6.42^{A}**	*3.61^{C}*	5.20^{ABC}	4.16^{BC}	5.94^{AB}
Stains	*1.61^{C}*	4.16^{AB}	2.93^{ABC}	**4.55^{A}**	1.96^{BC}
Surplus color	2.48^{A}	3.95^{A}	*1.94^{A}*	**3.59^{A}**	2.37^{A}
Gloss	2.85^{A}	2.25^{A}	**3.05^{A}**	*2.06^{A}*	3.00^{A}
Knot homogeneity	5.73^{A}	5.40^{A}	**5.94^{A}**	*4.58^{A}*	5.80^{A}
Knot size	**6.55^{A}**	4.66^{B}	4.47^{B}	5.33^{AB}	*2.88^{C}*
Knot shape	5.80^{AB}	4.27^{BC}	2.75^{CD}	**6.70^{A}**	*2.07^{D}*
Spike knots	2.06^{BC}	3.72^{AB}	1.35^{C}	**5.05^{A}**	*1.15^{C}*
Ring density	4.86^{A}	**5.75^{A}**	4.51^{AB}	4.39^{AB}	*3.23^{B}*
Dry knots	*1.45^{C}*	**5.51^{A}**	1.48^{C}	1.66^{C}	3.41^{B}
Knot groups	5.54^{AB}	**6.07^{A}**	*2.95^{C}*	3.69^{BC}	3.07^{C}
Knot checks	1.95^{B}	**5.48^{A}**	2.28^{B}	2.54^{B}	*1.74^{B}*
Ring contrast	**5.21^{A}**	*3.48^{B}*	4.10^{AB}	3.52^{B}	4.58^{AB}
Ring pattern	5.13^{A}	*2.91^{B}*	4.22^{AB}	3.15^{B}	**5.16^{A}**
Wood density	4.47^{A}	4.40^{A}	4.60^{A}	*4.18^{A}*	**4.80^{A}**
Hardness	**4.80^{A}**	4.59^{A}	4.95^{A}	*4.22^{A}*	4.78^{A}
Smoothness	4.16^{AB}	*3.07^{B}*	**4.48^{A}**	3.43^{AB}	4.27^{AB}
Pitch	3.04^{A}	*2.65^{A}*	**3.06^{A}**	2.79^{A}	3.24^{A}
Checks	*1.00^{B}*	**2.65^{A}**	*1.00^{B}*	1.40^{B}	1.05^{B}
End checks	*1.00^{A}*	1.12^{A}	1.22^{A}	**1.23^{A}**	*1.00^{A}*

Identical superscripts indicate no statistical difference in sensory score (Tukey–Kramer test, $P < 0.05$)
Maximum score in bold; minimum score in italic

used to analyze the sensory data and the data from the hedonic study. In addition, Tukey–Kramer tests, using JMP,[12] were used to test whether the different attributes differed between the different decks.

Results

Results from the sensory evaluation are presented below. Tukey–Kramer tests were applied to determine whether the sensory scores differed between the sample deckings and to provide information concerning which sensory scores are determined by wood quality. Identical superscripts in the tables indicate that there is no statistical difference between the sample deckings. Results for the five copper-treated material samples are reported in Table 4; results for the five biocide-treated material samples are reported in Table 5.

According to the Tukey–Kramer test, sample deckings made from copper-treated wood differed significantly for ten sensory attributes: homogeneity, surplus color, ring contrast, ring density, checks, knot groups, dry knots, spike knots, knot shape, and knot size (see Table 4).

According to the Tukey–Kramer test, sample deckings made from biocide-treated wood differed significantly for 16 sensory attributes: lightness, hue, saturation, homogeneity, stain, ring density, ring contrast, ring pattern, smoothness, checks, knot groups, dry knots, spike knots, knot shape, knot size, and knot checks (see Table 5).

Differences between the copper-treated sample deckings and the biocide-treated sample deckings were also evaluated using mean scores for each deck as the basis (Table 6). The copper-treated sample deckings had significantly lower scores for hue compared to the sample deckings from biocide-treated wood. The copper-treated sample deckings were somewhat more saturated, somewhat darker, and had more surplus color. The copper-treated sample deckings also had somewhat more checks. Knot properties did not differ significantly between the copper-treated and the biocide-treated sample deckings (see Table 6).

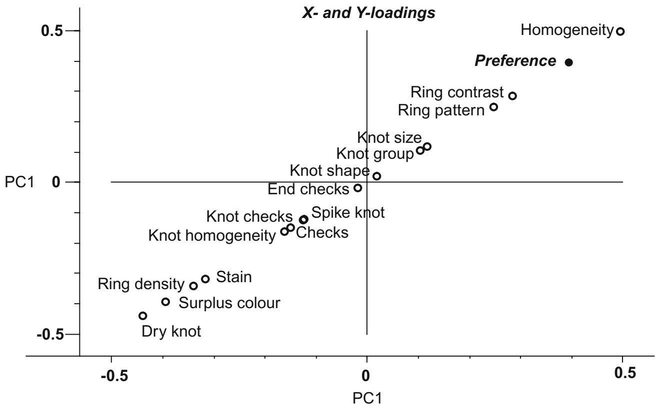

Fig. 2. Partial least squares (PLS)1 plot (one dimension, only one principal component, *PC1*). Loadings for the different sensory attributes (independent variables) for the ten decks and the consumer preference (dependent variable, ***italic bold***)

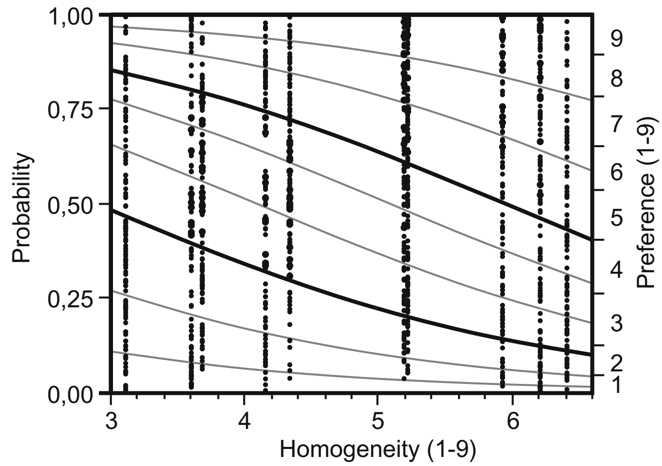

Fig. 3. Logistic regression between the dependent ordinal variable preference and overall homogeneity

Table 6. Comparison of mean scores for copper-treated sample deckings and biocide-treated sample deckings using *F* tests

Dependent variable	Mean score (copper/biocide)	DF	F	Probability > *F*
Lightness	4.43/5.39	1.8	6.39	0.035
Hue	1.58/6.57	1.8	117	<0.0001
Saturation	5.85/4.70	1.8	7.97	0.022
Homogeneity	4.52/5.07	1.8	0.51	0.49
Stains	3.78/3.04	1.8	1.04	0.34
Surplus color	6.10/2.87	1.8	26.6	0.0009
Gloss	2.52/2.64	1.8	0.26	0.62
Knot homogeneity	5.28/5.49	1.8	0.31	0.59
Knot size	4.13/4.78	1.8	0.63	0.45
Knot shape	4.51/4.32	1.8	0.032	0.86
Spike knots	3.55/2.67	1.8	1.01	0.34
Ring density	4.74/4.55	1.8	0.12	0.74
Dry knots	3.03/2.70	1.8	0.11	0.75
Knot groups	3.93/4.27	1.8	0.19	0.68
Knot checks	2.11/2.80	1.8	0.94	0.36
Ring contrast	5.00/4.18	1.8	2.93	0.13
Ring pattern	4.95/4.11	1.8	2.21	0.18
Wood density	4.65/4.49	1.8	1.03	0.34
Hardness	4.66/4.67	1.8	0.0018	0.95
Smoothness	3.19/3.88	1.8	6.5	0.034
Pitch	2.84/2.95	1.8	0.93	0.36
Checks	2.47/1.42	1.8	6.1	0.038
End checks	1.83/1.11	1.8	37.9	0.0003

Loadings from the PLS1 (partial least squares regression model to set a single dependent variable) analysis are plotted in Fig. 2. Both samples from copper-treated sample deckings and biocide-treated sample deckings are included. Visual inspection indicates that the loadings for homogeneity are close to the consumer preferences for PC1 (principal component 1, the only principal component in this analysis), compared with most of the other sensory attributes. The loadings in a PLS plot map the positional relationship of the different sensory attributes. The result indicates that the sensory attribute homogeneity (i.e., overall visual texture and evenness) is correlated with the respondent's preferences through the other sensory attributes important for homogeneity. Results from the sensory study concluded that the mean value for homogeneity varied between 3.12 and 6.22 for the copper-treated sample deckings (see Table 4) and between 3.61 and 6.42 for the biocide-treated sample deckings (see Table 5). The variables with loadings farthest away from the consumer preference (preference) were dry knots, surplus color, ring density, stains, and knot homogeneity (see Fig. 2).

Results from an ordinal logistic regression between stated consumer preferences and mean sensory homogeneity (mean score for the judgment of the 11 assessors) for each of the ten sample decking materials are presented in Fig. 3. The relationship between homogeneity (overall visual texture and evenness) and the stated preference was positive and statistically significant ($n = 221$, $DF = 1$, $\chi^2 = 28.9$, $P < 0.0001$) for both the copper- and the biocide-treated sample deckings. Probability for preference scores 1, 2, and 3 ("do not like") was high when the homogeneity score was low, and the probability for preference scores 7, 8, and 9 ("like the sample decking") increased with increasing overall homogeneity (Fig. 3).

The significant relationship between homogeneity and preference data indicates that consumer preferences can be predicted from the homogeneity of the surface of the samples. A model for homogeneity was estimated by the means of PLS1: homogeneity was the dependent variable and the remaining sensory attributes were independent variables. The PLS1 regression was performed on data for all sample deckings.

Departing from a full model, including all 22 sensory attributes, a recursive modeling procedure was used to achieve a parsimonious model. Irrelevant sensory variables were discarded based on the loading values and warnings given by the statistical software Unscrambler. The final model is presented in Fig. 4. The model included six explanatory variables (dry knots, splay knots, knot checks, knot shape, stains, and surplus color) and two principal components.

Surplus color and stains are related to the manufacturing process of the decking products. All remaining sensory attributes were related to knots, indicating that properties related to knots constitute the most important wood properties related to surface homogeneity of wooden decking materials. To model homogeneity based on wood properties only, a PLS1 model containing dry knots, splay knots, and knot shape was estimated (Fig. 5, Table 7). When analyzing the same relationship with a multiple regression, spike knot contributed significantly ($P = 0.008$), whereas dry knot and knot checks received P values of 0.06 and 0.05, respectively. The P value for knot shape was as low as 0.15.

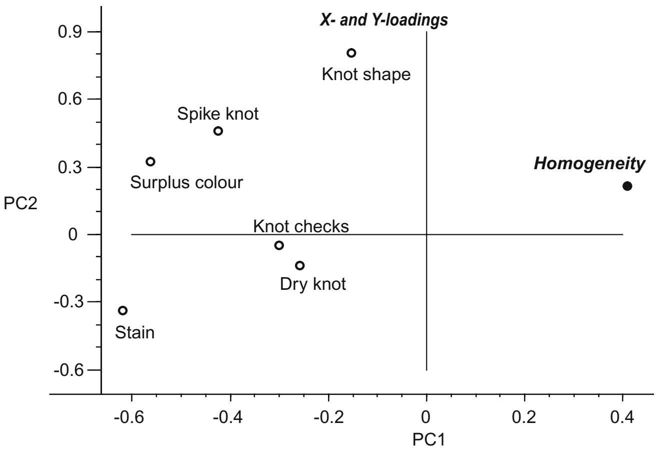

Fig. 4. PLS1 analysis: loadings from model 1 (dependent variable in *italic bold*)

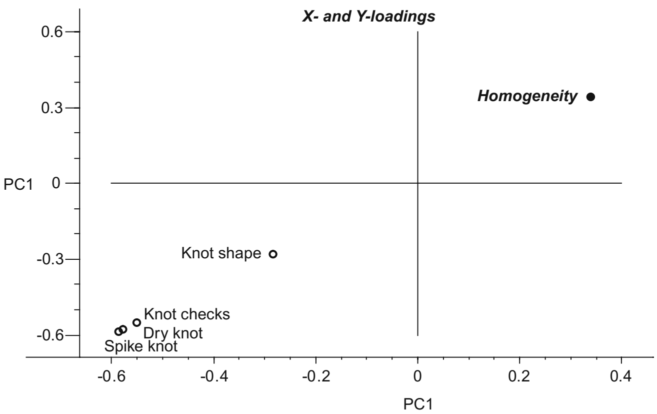

Fig. 5. PLS1 analysis: loadings from model 2 (dependent variable in *italic bold*)

Parameter estimates and loadings for both PLS1 models are reported in Table 7. All parameter estimates are negative, except knot shape in model 1, implying that increased intensity of the variables has a negative effect on homogeneity. The effect of knot shape is ambiguous because the parameter estimates have opposite signs in model 1 and model 2 (Table 7). Also, in model 2 the parameter estimate for knot shape is close to zero. Because all the independent variables have the same range (values from 1 to 9), the size of the regression coefficients implies the relative importance of the variables in the regression model. Furthermore, the loadings give information about the relative importance of each variable on the dependent variable. Independent variables with loadings that differ substantially from the loading of the dependent variable are of more importance than loadings close to the dependent variable. The r^2 values in Table 7 are the coefficients of determination from the cross-validation of the models (The Unscrambler).

Discussion

The study explores the concept of visual homogeneity, which has been identified in various previous studies but has not been subject to elaborate investigation. Furthermore, the study presents an empirical model for surface homogeneity of wood surfaces made from pressure-treated pine. Results from previous empirical studies indicate that there is a close relationship between the visual impression of wood surfaces and stated preference for wood products.[3–5] Broman[3] analyzed aesthetic features of wood and identified a set of key concepts that described respondents' attitudes toward wood products. According to his results, the most important feature of a wooden surface is the perceived harmony of the surface. Nyrud et al.[5] provided empirical evidence that Broman's concept of harmony is related to the degree of homogeneity in the surface of wood

Table 7. Partial least squares (PLS)1 models predicting surface homogeneity of sample deckings, loadings, and parameter estimates: model 1 refers to Fig. 4 and model 2 refers to Fig. 5

Model	r^2 (%), cross-validation[a]	Variable	Parameter estimates	Loading	
				PC1	PC2
1	43	Stains	–0.431	–0.617	–0.338
		Surplus color	–0.121	–0.563	0.320
		Knot shape	0.110	–0.153	0.809
		Spike knots	–0.024	–0.424	0.460
		Dry knots	–0.172	–0.258	–0.137
		Knot checks	–0.124	–0.301	–0.049
2	14	Knot shape	–0.013	–0.283	–
		Spike knots	–0.198	–0.586	–
		Dry knots	–0.197	–0.577	–
		Knot checks	–0.192	–0.551	–

PC, principal component
[a]The r^2 values are the coefficients of determination from the cross-validation of the models (The Unscrambler)

products. Therefore, harmony can be identified with homogeneous visual texture (homogeneity).

Results from multivariate statistics and logistic regression indicate that consumers' stated preference for wood products is closely related to the sensory attribute homogeneity. This attribute is subsequently modeled based on the remaining sensory attributes measured by the sensory panel. The results imply that measurements of visual wood properties can be used to model the visual homogeneity of a wooden surface and that the perceived harmony of a surface can successfully be modeled from data about wood features such as knot properties. The result corresponds to previous research and implies that subjective evaluation of wood surfaces, such as preference, can be modeled using wood properties.

The results demonstrate that surface homogeneity is influenced by visual wood properties. According to the results from the statistical model, surface homogeneity can be modeled as a function of knot shape and knot defects as well as residual color from the pressure treatment. It is concluded that homogeneity can be given as a parsimonious model with only six independent variables (stains, surplus color, knot shape, dry knots, spike knots, and knot checks). The results therefore indicate that surface homogeneity is determined by wood quality and by properties related to treatment method and the manufacturing process.

Focusing on wood quality, a second model was estimated using only wood properties (i.e., knot shape, dry knots, spike knots, and knot checks). The explanatory power of this second model is inferior to the previous model, but it still provides sufficient results for predicting surface homogeneity, and Broman's[3] concept of visual *harmony* can therefore be modeled using information about the wood quality of a given product. Thus, it is likely that surface homogeneity can be modeled using wood properties for all types of visual wood products.

From the models, it is evident that knot properties influence the visual homogeneity of, and thus the preference for, wood surfaces. The results coincide with previous research conducted in Japan. Nakamura and Kondo[13] examined why knots are perceived to be a poor visual characteristic of the wood surface; they compared the number of knots in wood panels with subjective perception of knots. The results revealed that there was a clear linear relationship between the number of knots in the wood and the subjective perception of the knots. Nakamura and Kondo concluded that clear wood leads to more relaxed eye patterns than knotty wood. This opinion corresponds with the results reached in the present study and in Broman's previous studies.[3]

Most consumers have no experience in evaluating wood products and are, in particular, less experienced with differentiating wood material samples according to quality compared to professional graders. In particular, persons with little or no experience can have difficulties detecting small variations in quality, as was the case in the present study; the quality difference between some of the sample decking materials was fairly small. Furthermore, discrete variables, such as the nine-point scale, usually exhibit larger measurement error than continuous variables. Because preference is a subjective matter, the dependent variable will exhibit considerable variation for all values of the independent variables. Because of this, the diagnostic statistics (P values and r^2 values) from PLS1 models and the multiple regressions were low (see Table 7). The models explaining product homogeneity had plausible parameter estimates.

In general, the results should be relevant for decision makers involved in forest product sales and marketing as well as architects and professionals in building design and construction. Raw material quality is important with respect to providing a harmonious surface property; wood qualities with few knots and an even knot structure should be preferred for visual products. However, the results indicate that it is equally important to avoid production defects. The wood processing industry should therefore take care to choose appropriate raw material quality as well as conduct manufacturing and treatment properly to avoid color stains.

Architects and professionals in building design and construction should take into account the results from the present study when using visual wood products. To exploit possible beneficial effects of wood surfaces and create a pleasant, harmonious visual atmosphere, the wood used should exhibit homogeneous surface properties. Results obtained from the model indicate that homogeneous surface properties are wood properties with few knots and/or even knot structure. Visual defects such as dry knots should be avoided. In addition, surface-treated wood should not exhibit visual defects from the manufacturing process such as stains or cracks.

Future research should evaluate the relationship between surface homogeneity and consumer preferences for other wood products. The results discussed here are probably relevant for other visual wood products, but this relationship should also be established through research. Furthermore, the relationship between surface homogeneity and Broman's concept of harmony should be elaborated. Previous research indicates that there is a relationship between the use of building materials from wood and the well-being of the building's inhabitants.[14,15] The present study is of relevance in this respect as the beneficial effects of wood will probably be strengthened by using wood surfaces that have advantageous visual characteristics, i.e., when the surface has a homogeneous, harmonious appearance. It is likely that the perceived harmony of a visual wood product has beneficial psychological effects on the consumer's environment, but there may also be a reverse effect of disharmonious wood surfaces. For visual wood products used in outdoor environments, the effects of weathering should also be investigated. Exposure to outdoor climate affects the appearance of wood products, and such weathering effects will probably influence people's preferences as well.

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References

1. Brandt JP, Shook SR (2005) Attribute elicitation: implications in the research context. Wood Fiber Sci 37:127–146
2. Bigsby H, Rai C, Ozanne L (2005) Determining consumer preference for furniture timber. J For Prod Bus Res 2(2)
3. Broman NO (2000) Means to measure the aesthetic properties of wood. Doctoral thesis 2000:26. Luleå University of Technology, Luleå
4. Marchal R, Mothe F (1994) Appreciation of oak wood for the French consumer and wood professionals. Ann Sci Forestières 51:213–232
5. Nyrud AQ, Roos A, Rødbotten M (2008) Product attributes affecting consumer preference for residential deck materials. Can J For Res 38:1385–1396
6. Masuda M (2004) Why wood is excellent for interior design? From vision physical point of view. In: Proceedings of the 8th World Conference on Timber Engineering, Lahti, Finland, pp 101–106
7. Lawless H, Heymann H (1998) Sensory evaluation of food: principles and practices. Chapman & Hall, New York
8. Evin E, Siekierski E (2002) Sensory evaluation of heating and air conditioning systems. Energy Build 34:647–651
9. Obata Y, Takeuchi K, Furuta Y, Kanayama K (2005) Research on better use of wood for sustainable development: quantitative evaluation of good tactile warmth of wood. Energy 30:1317–1328
10. Wang S-Y, Lin F-C, Lin M-Y (2001) Thermal properties of interior decorating material and the sensation of cold/warm by contact. II: The relations among heat flux, temperature change of material, and sensation of cold/warm by contact. J Wood Sci 47:109–114
11. The Unscrambler, Version 9.7 (1986–2007) CAMO Software ASA, Oslo, Norway
12. JMP, Version 7.02. SAS Institute Inc., Cary, NC
13. Nakamura M, Kondo T (2008) Quantification of visual inducement of knots by eye-tracking. J Wood Sci 54:22–27
14. Rice J, Kozak RA, Meitner MJ, Cohen DH (2006) Appearance wood products and psychological well-being. Wood Fiber Sci 38:644–659
15. Sakuragawa S, Miyazaki Y, Kaneko T, Makita T (2005) Influence of wood wall panels on physiological and psychological responses. J Wood Sci 51:136–140