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RESEARCH OF BAMBOO QUALITATIVE MATERIAL TACTILE CHARACTERISTICS

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ABSTRACT

In this study, the semantic differential method was employed for investigating the tactile properties of bamboo qualitative material, such as bamboo integrated timber (vertical splicing plate), bamboo integrated timber (transverse splice plates), bamboo parallel strand lumber, whole bamboo unfolding plate (outer of bamboo), whole bamboo unfolding plate (remove outer of bamboo), bamboo plastic composite plate, while *Liquidambar formosana* and *Abies fabri* (Mast) were selected as contrast. Respondents rated the samples by descriptive words, such as natural, exclusive, eco-friendly, rough, inexpensive, reliable, warm, modern, snug, and solid. Moreover, statistical analysis was employed for analyzing the data. The results showed that material and tactile characteristics exhibit significant correlation. Principal component analysis yielded four attributes based on tactile perceptions. Summing up the main points of the experiment, the tactile properties of different bamboo qualitative material were obtained.

KEYWORDS: Bamboo qualitative material, Tactile, SD method, psychological values of touching.

INTRODUCTION

Currently, studies related to wood-based composites are increasing. Several research studies have focused on broad topics, such as material structure, mechanical properties, and modification, while some others have focused on material and tactile properties or visual investigation. For example, Lindberg (Lindberg 2013) has reported on the tactile attributes of wood and wood-based composites, described the importance of tactile attributes of materials, and introduced these attributes to several types of woody materials. Product semantics involves the study of perceived meanings and impressions of man-made shapes (Krippendorff and Butter 1984). Theoretically, products are representative of the attributes, such as color, shape, form, texture, and gloss. Jonsson et al. (2008) have reported that solid wood is preferred over wood–polymer composites, and this material preference is associated with their properties, such as natural, pleasant, smooth, as well as good value. From these studies, they concluded that wood provides good tactile warmth, regardless of the season. Hence, when selecting the tactile properties of bamboo, the author of this study referenced wood-based composites. Previous studies have reported tactile perceptions, such as warmth (Obata et al. 2000, 2005), dryness (Kobayashi et al. 2002), or physiological and subjective reactions (Morikawa et al. 1998, Sakuragawa 2006). For example, the tactile attribute of roughness for wood-based composites refers to the humans feeling of smooth or rough when skin comes in contact with a wood-based composite surface (Qian 2006). It is a comprehensive physical and psychological reaction caused by surface morphology and texture features, which act on the skin and tactile organs of human body (Hu 2008).

In addition, the study of tactile attributes is not only applicable to wood material, but also is integral to the study of packaging materials, decoration materials, and common materials. For instance, Yang Yan (Tsinghua University) has investigated the visual and tactile properties of interior decoration materials and summarized the perception of materials. Qun Zhao (Donghua University) has experimentally investigated the relationship between the fabric surface properties and tactile perception. Meanwhile, summarizes the tactile properties of weave. In daily life, people frequently touch wooden surfaces and substitute materials; hence, it is particularly important to investigate tactile properties for materials research (Huaqiang 2003).

Nowadays, several products of bamboo qualitative material appear in the market, primarily because it exhibits advantages of bright color, clear natural veins, finest ductility, high intensity, and wear resistance (Ahmad and Kamke 2005). Several types of bamboo-based materials are available, such as raw bamboo, bamboo plywood, bamboo-integrated timber, bamboo reorganization, and bamboo tablet (Nugroho and Ando 2000, 2001, Nugroho and Bahtiar 2012); they have been widely used in construction, furniture, as well as the packaging industry. However, not much research has been conducted on bamboo qualitative material. Most researchers focus on the material properties, while few scholars focus on the tactile properties of materials. Hence, this study aims to investigate the tactile properties of various bamboo-based materials and understand how the tactile properties meet the demand of a person's tactile sensation with respect to the physiological and psychological aspects (Osgood et al. 1957). In addition, in the design process, bamboo-based materials can be selected according to the tactile attributes, thereby making people comfortable, pleasurable, and leaving a good impression.

In this paper, the tactile characteristics of bamboo-based materials are investigated by subjective evaluation via the semantic differential method, where the aim is to study tactile perceptions and associations of different bamboo-based materials, as well as to select descriptive words that have significant correlations. Hsu et al. (2000) set up evaluation systems for predicting the tactile properties of bamboo-based materials. The study expects that tactile perception will be subjectively and comprehensively, as well as the evaluation will be more scientific; thus, it can provide some guidelines for the choice of appropriate bamboo-based materials in furniture design (Petiot and Yannou 2004).

MATERIAL AND METHODS

Nine solid wood and bamboo-based material samples were used. The wood samples included *Liquidambar formosana* and *Abies fabri* (Mast). The composite samples included bamboo integrated timber (vertical splicing plate), bamboo integrated timber (transverse splice plates), bamboo parallel strand lumber, whole bamboo unfolding plate (outer of bamboo), whole bamboo unfolding plate (remove outer of bamboo) and bamboo plastic composite plate. The samples were freed from knots in order. The samples were cut into pieces of 100 × 60 × 10 mm, as shown in Fig. 1.

Fig. 1: Wood and composites used in the tactile study.

Fig. 2: Test situation during the tactile study.

The bamboo-based materials were selected for representing the varying types of panels and composites with respect to their applications, structures, and production processes.

Descriptive words

In this article, the choice of descriptive words was based on previous studies as well as experimental-specific contents. The descriptive words used herein are in part based on previous elicitation studies on wood, eliminating not commonly used words but also antonyms (Chen and Li 2004). The final set of words included two categories: perceptual (rough, warm, solid) and cognitive (natural, exclusive, eco-friendly, inexpensive, reliable, modern, and snug) (Jonsson et al. 2008; Broman 2000; Nyrud et al. 2008; Obata et al. 2000).

Assessment grade

Respondents rated samples with an integer between 1 and 7, with 1 and 7 denoting that the word was not associated at all with the sample and that the word was strongly associated with the sample, respectively (Xiaojuan 2009a, b).

Respondents

For the experiment, 30 respondents were selected-6 women and 24 men with the distribution of ages between 20 and 25 years.

Methods

In this paper, the SD method was conducted. In 1957, C. E Osgood developed the SD method for psychological measurement. Literally, the SD method refers to "the semantics of an analytical method," where psychological experiments use semantics in "speech" as the scale and then analyze the scale for quantitatively describing the concept and structure of the object under study (Krippendorff and Butter 1984).

Experimental set up

A desk, a chair, a mask, a headset, and a soft mat is required in this experiment. This experiment must be conducted under comfortable conditions, e.g., in the office, and the temperature should be suitable for both hands, neither hot nor too cold. Several factors affect experiments. Hence, when conducting experiments, the impact of visual and auditory senses should be avoided while conducting experiments; hence, eyes and ears of the respondents should be covered using dark glasses and a headset, respectively, while simultaneously for controlling the temperature and humidity of the test facility.

Experimental design

For this experiment, 30 subjects were chosen, and they extracted one material at random from nine materials, one at a time. The respondents were allowed to freely touch the sample; however, their vision and hearing were blocked as they had black painted goggles (UVEX) and noise-cancelling headphones (PELTOR Optime III headset with audio input). A soft pad was used on the table for preventing sound by knocking or vibrations from materials against the wooden table, as shown in Fig. 2. Ten words were sounded out, one at a time, in random order, by a test leader via a telephone connected to the hearing protection. The respondent rated the sample by an integer between 1 and 7, where 1 and 7 denoted that the word was not associated at all with the sample and that the word was strongly associated with the sample, respectively.

Analysis

Mean attribute ratings for each material, as well as analysis of variance (ANOVA statistics), including Tukey's (separation) tests, were calculated. Pearson's correlation tables were computed across all observations (subject, sample), and principal component factor analysis (PCA) was conducted (Wu et al. 2006; Jinshan et al. 2010). Cluster analysis generated groups of wood species with similar properties. These outcomes were presented in a multidimensional scaling (MDS) graph (Hair et al. 2010), and discriminant analysis was used for identifying the most important differentiating concepts between the groups.

RESULTS

Correlations

Tab. 1 shows the Pearson's correlations between the properties. The coefficient values were divided into two categories: positive and negative. Eleven correlations were greater than (0.25); five were greater than or equal to (0.3); one correlation coefficient (reliable/solid) was greater than (0.68).

The correlation coefficient between reliable and solid was 0.683, reflecting a high positive correlation. The correlation coefficients for eco-friendly–natural, warm–natural, eco-friendly–warm, and warm–snug were 0.529, 0.4, 0.334, and 0.357, respectively. These values indicated that significant correlation exists between these attributes. In addition, the correlation coefficients between rough and snug, rough and modern, inexpensive and solid were -0.229, -0.205, and -0.266, respectively. These values indicated that there is a significantly negative relationship between rough and sung, rough and modern, as well as inexpensive and solid.

Tab. 1: Correlations.

Natural	Exclusive	Eco-friendly	Rough	Inexpensive	Reliable	Warm	Modern	Snug	Solid	Natural
Natural	1									
Exclusive	0.191**	1								
Eco-friendly	0.529**	0.139*	1							
Rough	0.224**	0.200**	0.236**	1						
Inexpensive	-0.01	-0.178**	0.01	-0.01	1					
Reliable	0.252**	0.173**	0.263**	0.181**	-0.19	1				
Warm	0.400**	-0.04	0.334**	0.01	0.02	0.150*	1			
Modern	-0.12	0.160**	-0.10	-0.21	-0.05	0.05	0.00	1		
Snug	0.292**	-0.01	0.261**	-0.23	-0.11	0.233**	0.357**	0.169**	1	
Solid	0.166**	0.140*	0.159**	0.164**	-0.27	0.683**	0.06	0.09	0.258**	1

Note:*: significant at level $p < 0.05$.

Ratings

Tab. 2 shows the tactile psychological scores of 30 groups of different bamboo qualitative materials, mean ratings, ANOVA statistics, and Tukey's significance tests for investigating the relationship between descriptive words and material. F-values, in Tab. 3, indicate significantly different ratings for every characteristic.

Tab. 2: ANOVA statistics.

	Natural	Exclusive	Eco-friendly	Rough	Inexpensive	Reliable	Warm	Modern	Snug	Solid
Side-pressing plates of bamboo	↑4.7	↓3.9	↑4.8	4.7	3.8	↑5.2	4.1	4.0	↑4.5	5.4
Flat cable clamp of bamboo	4.5	4.3	4.6	↑5.0	3.8	4.7	3.9	↓3.9	4.4	5.0
Bamboo parallel strand lumber	3.8	↑4.7	4.3	4.8	↓3.0	↑5.5	3.2	4.2	4.2	↑6.0
Bamboo plywood	↓3.5	4.5	↓3.7	3.7	3.8	4.6	↓3.2	↑4.8	↓4.0	4.9
Whole bamboo nfolding plate (outer of bamboo)	4.5	↑4.6	4.3	↑5.1	↑4.2	4.1	3.7	↓3.7	↓3.6	4.0
Whole bamboo unfolding plate remove (outer of bamboo)	4.4	3.9	4.3	4.3	↑4.2	↓4.1	4.1	3.7	4.0	↓4.0
Bamboo plastic composite plate	↓2.5	4.0	↓3.0	↓1.4	↓3.6	↓4.0	↓3.0	↑5.0	4.4	4.5
Liquidambar formosana	4.6	↓3.7	↑4.7	4.0	3.7	5.1	↑4.4	3.7	4.4	↑5.3
Abies fabri (Mast)	↑4.9	4.0	4.7	↓2.3	4.1	4.3	↑4.8	4.2	↑5.3	↓4.2
F-value	10.08	2.61	7.30	33.39	2.58	5.95	9.30	4.65	4.52	12.47
p>F	0.0000	0.0090	0.0000	0.0000	0.0100	0.0000	0.0000	0.0000	0.0000	0.0000

↑: Top two values in column, ↓: two lowest values in column.

From the ANONA of the psychologists scores for tactile attributes, the F-value for tactile roughness was 33.389 and P = 0.0000 < 0.05; the value of tactile solid, F=12.467, P = 0.0000 < 0.05; the value of tactile natural, F=10.079, P=0.0000 < 0.05. The results indicated that the most significant differences between the samples are tactile perceptions of roughness, followed natural and solid. In addition, from the average shown in Tab. 3, the average marks for the tactile attribute of being natural for the bamboo material of side-pressing plates, flat cable clamp of bamboo, whole bamboo unfolding plate (outer of bamboo), and whole bamboo unfolding plate (remove outer of bamboo) were greater than (4.4), while the average marks for *Liquidambar formosana* and *Abies fabri* (Mast) were 4.6 and 4.9, respectively. This result indicates that four materials have a similar tactile attribute of being natural, distinguishing them from the remaining samples. The average marks for the tactile attribute of being exclusive of the nine materials were greater than (3.7). The F-value for the tactile attribute of being exclusive was 2.61, and P = 0.009 < 0.05; hence, nine materials exhibit better tactile attribute of being exclusive, and tactile attribute of being exclusive exhibits significant difference between materials.

Tab. 2 summarizes the rough characterization of all materials based on their mean rates, as well as in relation to the other samples examined:

1. Side-pressing plates of bamboo: natural, eco-friendly, reliable, snug, and solid
2. Flat cable clamp of bamboo: rough, not modern
3. Bamboo parallel strand lumber: exclusive, rough, not inexpensive, reliable, not warm, and solid
4. Bamboo plywood: not natural, not eco-friendly, not warm, and not snug
5. Whole bamboo unfolding plate (outer of bamboo): exclusive, not inexpensive, not reliable, not modern, not snug, and not solid
6. Whole bamboo unfolding plate (remove outer of bamboo): not exclusive, not inexensive, not reliable, not modern, snug, and not solid
7. Bamboo plastic composite plate: not natural, not eco-friendly, not rough, not modern
8. *Liquidambar formosana*: not exclusive, eco-friendly, warm, and not modern
9. *Abies fabri* (Mast): natural, eco-friendly, not rough, not exclusive, warm, snug, and not solid

Principal component analysis

Tab. 3: Principal component factor loadings.

	Factor 1 Reliable	Factor 2 Solid	Factor 3 Rough	Factor 4 Modern	Communality
Natural	0.383	-0.081	0.097	0.101	0.695
Exclusive	0.033	-0.064	0.070	0.748	0.807
Eco-friendly	0.360	-0.064	0.119	0.066	0.634
Rough	0.038	0.045	0.517	0.129	0.688
Inexpensive	0.133	-0.285	0.059	-0.140	0.340
Reliable	0.002	0.457	0.061	-0.113	0.754
Warm	0.372	-0.095	-0.155	-0.105	0.590
Modern	-0.043	-0.021	-0.438	0.475	0.677
Snug	0.240	0.101	-0.401	-0.094	0.700
Solid	-0.073	0.514	0.022	-0.126	0.812
Eigenvalue	2.62	1.56	1.47	1.05	
Percent explained	0.2617	0.1561	0.1473	0.1049	

The overall Kaiser measure of sampling adequacy (MSA) was 0.654, and all individual variable MSAs exceeded 0.34. This result demonstrates that the data set is acceptable for PCA. PCA yielded four factors based on the criterion that the eigenvalue should exceed 1. The first factor explained 26.17, the second factor explained 15.61, the third factor explained 14.73, and the fourth factor explained 10.49 %. Together, the four factors explained 67 % of the total variance.

Tab. 3 shows factor loadings (unrotated) and communalities. Factor loadings exceeding 0.3 are highlighted. The first factor involves high loadings on natural, eco-friendly, inexpensive, as well as warm and snug, whereas factor 2 reflects the attributes of tactility of reliable and solid, corresponding to the attributes that have a positive impact on Factor 2. Factor 3 negatively affects modern and snug and positively affects the degree of roughness and eco-friendly tactile attributes. Finally, Factor 4 reflects the attributes of tactility of modern and exclusive, corresponding to the attributes that have a positive impact on Factor 4. Hereafter, Factors 1–4 correspond to reliable, solid, rough, and modern, respectively. Tab. 4 shows the mean factor scores for the different samples.

As shown in Tab. 4, the side-pressing plate of bamboo, flat cable clamp of bamboo, bamboo parallel strand lumber, and bamboo parallel strand lumber exhibited positive scores for Factor 1 (Reliable). Nevertheless, the side-pressing plate of bamboo exhibited a high value of 0.536, indicating that this material is better for the tactile attributes of reliability. On the other hand, the whole bamboo unfolding plate (outer of bamboo) and whole bamboo unfolding plate (remove outer of bamboo) exhibited negative factor scores for the same attribute, indicating that these two materials exhibit poor tactile reliability. High negative scores of -0.954 and -0.633 were observed for bamboo parallel strand lumber for Factor 2 (solid) and Factor 3 (rough), respectively, indicating that the material exhibits relatively bad tactile roughness, as well as tactile attribute of being modern and solid. In addition, the highest negative score of -0.739 and the highest positive score of 0.494 were observed for whole bamboo unfolding plate (outer of bamboo) for Factor 3 (rough) and Factor 4 (modern), respectively. These results imply that the whole bamboo unfolding plate (outer of bamboo) exhibits better attribute of being modern and exclusive. On the other hand, the highest negative score of -0.918 was observed for bamboo plastic composite plate for Factor 2 (solid), while the highest positive score of 0.982 was observed for Factor 3 (rough), implying that this material exhibits bad tactile attributes of being rough and solid.

Tab. 4: Mean factor scores.

	Factor 1 Reliable	**Factor 2 Solid**	**Factor 3 Rough**	**Factor 4 Modern**
Side-pressing plates of bamboo	↑0.536	0.115	-0.156	↓-0.370
Flat cable clamp of bamboo	0.304	0.191	-0.404	-0.041
Bamboo parallel strand lumber	0.415	↓-0.954	↓-0.633	-0.214
Bamboo plywood	↓-0.342	-0.633	-0.041	↑0.302
Whole bamboo unfolding plate (outer of bamboo)	-0.263	0.543	↓-0.739	↑0.494
Whole bamboo unfolding plate (remove outer of bamboo)	-0.239	↑0.693	-0.141	0.036
Bamboo plastic composite plate	↓-1.008	↓-0.918	↑0.982	0.121
Liquidambar formosana	↑0.424	0.241	0.021	↓-0.565
Abies fabri (Mast)	0.172	↑0.722	↑1.111	0.236

Note:↑: Top two values, ↓: two lowest values.

Superscripts: Outcome of Tukey multiple comparison test.

Cluster analysis

Clustering analysis refers to the analysis of the collection of a physical or abstract objects grouped into multiple similar objects Lindberg et al. (2013). This article employs McQuitty's similarity analysis and the complete linkage method.

Fig. 3 shows the clustering tree for the complete linkage method. The clustering results from the synthesis two methods are Cluster 1 consisting of *Abies fabri* (Mast); Cluster 2 consisting of bamboo plywood and bamboo plastic composite plate; Cluster 3 consisting of side-pressing plates of bamboo, *Liquidambar formosana*, flat cable clamp of bamboo, and bamboo parallel strand lumber; Cluster 4 consisting of a whole bamboo unfolding plate (outer of bamboo) and whole bamboo unfolding plate (remove outer of bamboo).

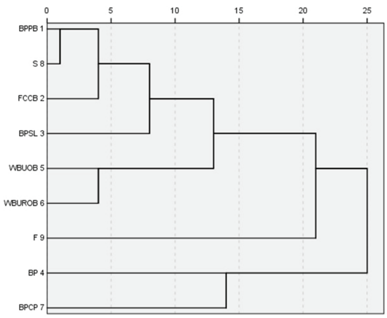

Fig. 3: Cluster tree. BPPB: Side-pressing plates of bamboo, FCCB: Flat cable clamp of bamboo, BPSL: Bamboo parallel strand lumber, BP: Bamboo plywood, WBUOB: Whole bamboo unfolding plate (outer of bamboo), WBUROB: Whole bamboo unfolding plate (remove outer of bamboo), BPCP: Bamboo plastic composite plate, S: Liquidambar formosana, F: Abies fabri (Mast).

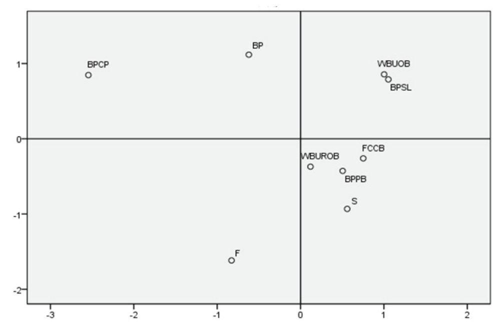

Fig. 4: Two-dimensional cluster results. (Dito).

Fig. 3 shows the outcomes from cluster analysis, which is based on multidimensional scaling (MDS) in two dimensions (Hair et al. 2010). MDS is employed to graphically present perceived differences and similarities between objects (Hair et al. 2010). The input data consisted of the mean ratings of the samples (aggregate, decompositional approach). Fig. 4 shows the two-dimensional configuration, where the circles illustrate the results obtained from hierarchical cluster analysis. The distance of two circles reflects similarities or differences. As shown in Fig. 4, the distance between whole bamboo unfolding plate (outer of bamboo) and bamboo parallel strand lumber was the smallest, implying that the two materials have similar tactile perceptions. In addition, the distances of *Abies fabri* (Mast), side-pressing plates of bamboo, flat cable clamp of bamboo, and bamboo parallel strand lumber are close to each other, indicating that they also have similar tactile perceptions.

After cluster analysis, the materials should be subjected to ANOVA for understanding that the clustering result is reasonable and for analyzing the characterization of the cluster in the ANONA of tactile psychologists score.

Tab. 5 shows the result obtained from the mono factor analysis of variance used for analysis for the tactile psychological of the material after the cluster.

In the ANOVA of tactile attributes, eight F-values of descriptive words were greater than (10); three F-value exceeded (20), the F-value for tactile roughness was 53.07, and $p = 0.000 < 0.05$, indicating that four clusters exhibit significantly different behavior with respect to tactile roughness. The F-value for the tactile attribute of being exclusive was 0.49, $p = 0.688 > 0.05$, indicating that a small probability event occurs; hence, all clusters are not significantly different with respect to the tactile attribute of being exclusive.

Tab. 5: ANOVA for cluster means.

	Natural	Exclusive	Eco-friendly	Rough	Inexpensive	Reliable	Warm	Modern	Snug	Solid
Abies fabri(Mast)	4.93	3.97	4.67	2.3	4.13	4.27	4.83	4.23	5.27	4.17
Bamboo plywood, Bamboo plastic composite plate	3	4.28	3.38	2.53	3.68	4.3	3.1	4.92	4.18	4.72
Side-pressing plates of bamboo, Flat cable clamp of bamboo, Bamboo parallel strand lumber, *Liquidambar formosana*	4.39	4.15	4.61	4.65	3.59	5.13	3.92	3.97	4.37	5.45
Whole bamboo unfolding plate (outer of bamboo), Whole bamboo unfolding plate (remove outer of bamboo)	4.45	4.23	4.3	4.68	4.18	4.08	3.92	3.73	3.82	4
F-value	20.29	0.49	16.45	53.07	3.76	12.74	15.85	11.25	10.41	26.92
p>F	0.000	0.688	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000

Step wise discriminant analysis

For further distinguishing the clusters and to confirm the earlier outcomes, a step wise discriminant analysis was conducted, which involves the constant extraction of important variables and elimination of the variables not important in the process of identification, finally leaving behind the best.

Tab. 6 shows the screening procedure of stepwise discriminant analysis. The first step involves the introduction of rough, while the fifth step involves the introduction of all variables. Searching for p-values, having no variables was excluded from stepwise discriminant analysis, and five variables significantly affect the material classification.

Tab. 6: Step wise selection summary.

Step	Entered	F-value	Pr>F	Wilks' Lambda	Pr<F
1	Rough	53.07	0.000	0.626	0.0000
2	Solid	26.92	0.000	0.767	0.0000
3	Natural	20.29	0.000	0.814	0.0000
4	Warm	15.85	0.000	0.848	0.0000
5	Modern	11.25	0.000	0.890	0.0000

Tab. 7: Linear discriminant function.

	Abies fabri (Mast)	Bamboo plywood, Bamboo plastic composite plate	Side-pressing plates of bamboo, Flat cable clamp of bamboo, Bamboo parallel strand lumber, *Liquidambar formosana*	Whole bamboo unfolding plate (outer of bamboo), Whole bamboo unfolding plate (remove outer of bamboo)
Rough	1.493	0.538	0.975	1.210
Solid	1.087	1.252	2.315	2.400
Natural	2.690	1.597	2.141	2.200
Warm	2.435	2.934	2.250	2.215
Modern	2.198	2.937	3.305	2.076
(constant)	-22.552	-20.392	-26.572	-22.293

Wilks' Lambda: F-value 39.86, Pr > F < 0.0001 Pillai's Trace: F-value 39.99, Pr > F < 0.0001.

Tab. 8: Number of observations and percent classified into clusters.

Material	Predicted group membership				Total
	Abies fabri (Mast)	Bamboo plywood, Bamboo plastic composite plate	Side-pressing plates of bamboo, Flat cable clamp of bamboo, Bamboo parallel strand lumber, *Liquidambar formosana*	Whole bamboo unfolding plate (outer of bamboo), Whole bamboo unfolding plate (remove outer of bamboo)	
Abies fabri (Mast)	25 83.3	2 6.7	0 0	3 10.0	30 100.0
Bamboo plywood, Bamboo plastic composite plate	8 13.3	41 68.3	7 11.7	4 6.7	60 100.0
Side-pressing plates of bamboo, Flat cable clamp of bamboo, Bamboo parallel strand lumber, *Liquidambar formosana*	9 7.5	12 10.0	79 65.8	20 16.7	120 100.0
Whole bamboo unfolding plate (outer of bamboo), Whole bamboo unfolding plate (remove outer of bamboo)	9 15.0	2 3.3	10 16.7	39 65.0	60 100.0

Up: number of observations, down: percent classified. Based on estimation on all other observations.

Tab. 7 shows the coefficient matrix of four variables that occur in the discriminant function of materials. Tab. 8 shows the coefficient of the Fisher discriminant equation.

The coefficient indicates that cluster 1 exhibits good tactile attribute of being warm and modern; cluster 2 exhibits good tactile attribute of being modern and solid; and cluster 3 exhibits the largest coefficient in tactile attribute of being solid, implying that it has good solid tactile attributes; cluster 4 exhibits better tactile property with respect to roughness, but it exhibits poor tactile attributes of being modern and solid. This conclusion is consistent with the previous conclusion that tactile properties of four clusters are correct.

Tab. 8 shows the predictive properties. The remaining variables were plugged into the Fisher discriminant equation for comparing discriminant results to reach classification results. Summing the total number of correct classifications yielded a precise percentage of 68.1 %. This model performed best for fir, where 83.3 % was correctly classified. The accuracies for clustering 2, 3, and 4 are 68.3, 65.8, and 65 %, respectively, and it shows that this model can be used to represent the relationship between variables and the dependent variable.

Validate conclusion

For further distinguishing our clusters and confirming the earlier outcomes, we consequently conducted multinomial logistic regression. Cluster 1 is set to the comparison case.

The fitting information of the logistic regression model included the situation of intercept and the final model. P = 0.00 < 0.05 implies that the significance of this model is better.

Tab. 9 shows the results of multinomial logistic regression. Cluster 1 was set to a control group. The result obtained from Tab. 9 was made up by comparing cluster 1 in terms of tactile attribute.

Tab. 9: Multinomial logistic regression results.

	Bamboo plywood, Bamboo plastic composite plate	**Side-pressing plates of bamboo, Flat cable clamp of bamboo, Bamboo parallel strand lumber, *Liquidambar formosana***	**Whole bamboo unfolding plate (outer of bamboo), Whole bamboo unfolding plate (remove outer of bamboo)**
Natural	-0.847	-0.576	-0.211
Exclusive	0.495	-0.101	0.201
Eco-friendly	-0.440	0.208	-0.209
Rough	0.334	1.285	1.310
Inexpensive	-0.137	-0.248	-0.091
Reliable	-0.016	-0.012	-0.116
Warm	-0.663	-0.307	-0.072
Modern	0.720	0.111	-0.022
Snug	-1.174	-1.084	-1.131
Solid	1.183	1.663	0.572
Intercept	3.476	-1.367	1.652
N	60	120	60

Likelihood ratio: 250.73, p = 0.000. Wald statistic: 92.60, p = 0.000.

Pseudo-R 2 (Cox and Snell): 0.605. Pseudo-R 2 (Nagelkerke): 0.715.

From Tab. 9, bamboo plywood and bamboo plastic composite plate were perceived to be less natural, eco-friendly, inexpensive, reliable, warm, and snug, as well as rougher than *Abies fabri* (Mast). However, as compared to *Abies fabri* (Mast), they exhibit better performance with respect to the tactile attributes of being solid, modern, and exclusive. As compared to *Abies fabri* (Mast), side-pressing plates of bamboo, flat cable clamp of bamboo, bamboo parallel strand lumber, and *Liquidambar formosana* were also less natural, inexpensive, reliable, warm and snug, and less exclusive. However, as compared to the fir, the material was differentiated from the other samples as being more rough, more eco-friendly, and more solid. In addition, as compared to *Abies fabri* (Mast), whole bamboo unfolding plate (outer of bamboo), and whole bamboo unfolding plate (remove outer of bamboo) were perceived to be less natural, eco-friendly, inexpensive, reliable, warm, snug and modern, and as compared to the *Abies fabri* (Mast), the material was rougher and more snug.

DISCUSSION

In this paper, the results obtained from the unimodal tactile exploration of solid bamboo-based material samples are explained. This study investigated the tactile attributes of bamboo-based material that are perceived and interpreted semantically by possible customers. *Liquidambar formosana* and *Abies fabri* (Mast) are selected as the contrast. The scores obtained through experiments of the SD method were analyzed and subjected to correlation analysis, variance analysis, factor analysis, discriminant analysis, cluster analysis, and regression analysis. This study also reported the tactile properties of different bamboo qualitative material for providing some advice on choosing proper bamboo-based materials in furniture design.

The samples were mainly differentiated by pronounced tactile perception, such as roughness. However, descriptors, exclusive, modern, and inexpensive, were also used for distinguishing the samples. Four factors condensed perceived differences: reliable, solid, rough, and modern. Solid woods, *Liquidambar formosana*, and *Abies fabri* (Mast) were considered as natural and eco-friendly. The association of warmth with, above all, solid wood is in agreement with previously reported results by Obata et al. (2000). Notably, the association between wood and the impression of being natural and eco-friendly was pronounced, even when only tactile inspection was allowed. In a previous study, Broman (2000) has conducted a visual study and reported distinguishing descriptors such as exclusivity and modern appearance.

In this study, bamboo-based and wood materials were categorized in four types: cluster 1, *Abies fabri* (Mast); cluster 2, bamboo plywood and bamboo plastic composite plate; cluster 3, side-pressing plates of bamboo, *Liquidambar formosana*, flat cable clamp of bamboo and bamboo parallel strand lumber; cluster 4, whole bamboo unfolding plate (outer of bamboo) and whole bamboo unfolding plate (remove outer of bamboo). Cluster 1 exhibited good values for the tactile attribute of being warm and modern; cluster 2 exhibited good tactile attributes of being modern and solid; cluster 3 exhibited the highest coefficient in tactile attribute of being solid, implying that it exhibits good tactile attributes of being solid; the tactile property of cluster 4 was better in roughness, albeit it exhibited poor tactile attributes of being modern and solid.

The results in this study can indicate appropriate materials for specific design intentions. Hence, the bamboo plastic composite plate is poor with respect to tactile attribute of being eco-friendly, albeit its tactile attributed of perception is the smoothest. On the other hand, *Abies fabri* (Mast) and *Liquidambar formosana* exhibit better performance with respect to the tactile attributed of roughness, as well as eco-friendly and solid. Side-pressing plates of bamboo appear to be the preferred material for conveying a natural, eco-friendly impression; it is also preferred for objects that are normally touched, such as furniture and joinery. These descriptions can also aid in the creation of the most suitable verbal-marketing descriptors for wood-based materials.

The results are in agreement with those reported previously: product semantic approaches can be employed for designing products (Krippendorff and Butter 1984). Furthermore, this approach should be combined with sensory studies (Petiot and Yannou 2004). By the results obtained herein, this procedure can also rely on tactile impressions.

CONCLUSIONS

1. High positive correlations by correlation analysis were noted for eco-friendly–natural, natural–warm, and reliable–solid, while significant negative correlation was observed between rough and modern, rough and snug, as well as inexpensive and solid.
2. Correlation analysis indicated that the most significant differences between the samples

were tactile perceptions of roughness, followed by tactile perceptions of being natural and solid.

3. Four primary dimensions of perceived attributes and impressions, reliable, solid, rough, and modern, were obtained from principal component analysis. Together, the four factors explained 66.985 % of the total variance; hence, it can replace the original variable.
4. Whole bamboo-based materials can be divided into four categories. Cluster 1 consists of *Abies fabri* (Mast); cluster 2 includes of Bamboo plywood and the bamboo plastic composite plate; cluster 3 consists of side-pressing plates of bamboo, *Liquidambar formosana*, flat cable clamp of bamboo, and bamboo parallel strand lumber; cluster 4 consists of the whole bamboo unfolding plate (outer of bamboo) and whole bamboo unfolding plate (remove outer of bamboo).
5. Regression analysis shows that the analysis of the material tactile attributes is accurate. Bamboo plywood and bamboo plastic composite plate exhibited better performance with respect to tactile attributes of being solid, exclusive, and modern, and they were perceived to be less natural, eco-friendly, inexpensive, reliable, warm and snug, as well as rougher than *Abies fabri* (Mast). Side-pressing plates of bamboo, *Liquidambar formosana*, flat cable clamp of bamboo, and bamboo parallel strand lumber all exhibited better performance with respect to tactile attributes of roughness, as well as being eco-friendly and solid. Whole bamboo unfolding plate (outer of bamboo) and whole bamboo unfolding plate (remove outer of bamboo) exhibited good tactile attributes of being modern and snug.

The semantic differential method provided the tactile properties of bamboo qualitative material. By this study, we have a more comprehensive understanding of the performance of bamboo qualitative material and reference to interrelated field for product design. The results also confirm the role of tactile aspects in material design, especially when interior details and furniture are considered. Hence, when it comes to tactile design, designers can choose suitable material according to the tactile properties of different bamboo qualitative materials.

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