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The Importance and Necessity of New Bio-Based Materials in Industrial Design

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Abstract: *Main goals like technical innovation, costs and respect for the environment urge us to discover finer, lighter, biodegradable, and more «intelligent» materials in their functionality. The development of industrial design is motivated by criteria such as the environment, sustainability, the need for lightweight products, manufactured with fewer components and integrating various functions. As experts in new materials and technologies for the development of innovative products, we work closely with international research institutes as part of our projects. We want to create materials that combine such properties in the most efficient way, interacting with their close environment and the environment in general and, based on their features, to be transformed through various processes in completely different materials. The goal of our work is to compare different existing materials with a new bio-based material using quantifiable measurement indicators and sensory measurement indicators. The purpose of this article is to provide a few elements that can be used as a guide in establishing a quantitative impact assessment strategy based on the use of sensory evaluation techniques. In the framework of our presentation, we will focus mostly on comparing the materials via a metrological tool for quantifying tactile characteristics likely to be correlated to the "ground truth" that constitutes a sensory profile.*

Keywords*: Design, environment, bio-sourced materials, eco-design*

1. Introduction

First, we know that the design is not limited to appearance or to the decorative aspect that catches the eye. It is also about knowing how to design, develop and manufacture intelligent products [1, 2]. By "intelligent" we mean products that combine functionality, sensible manufacturing methods, use of environmentally friendly materials and, of course, an interface that is both attractive and useful [3, 4]. All these skills are needed in order to design good products. Designers, who are also observers, engineers and "poets", are the pioneers in this field.

Another important factor is the competition between manufacturers, leading to the development of industrial design. In an increasingly competitive market, design is seen as a "plus", like the added value or "the angle" that allows manufacturers to sell good products with high quality standards in terms of use, functionality and aesthetics [4-6]. Finally, consumers are increasingly aware of the concept of design and its importance in the overall quality of a product, and therefore they increasingly demand products that offer a good design [4, 6].

By giving priority to features such as safety, stress and abrasion resistance, flexibility and resistance to extreme temperatures and by striving to reduce weight, cost and density, we are able to apply some of the criteria that play an important role in the development of new materials. Materials that have one or more of these "optimal" properties are welcomed on new markets and provide products with added functionality. At the same time, new technologies allow for faster implementation, reduced waste and pollution and lower costs in terms of machines and tools [7]. However, designers, driven by ever-reduced time constraints, must set priorities for the functions, aspects and perceived quality of the products. Indeed, one of the current problems for manufacturers activating in this field is to be able to design environmentally friendly products based on new ecological materials in order to provide items having at least the same quality as the conventional synthetic ones.

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However, even if service quality (measured objectively) is paramount, it is also important for the designer to be able to anticipate/predict as best as possible the perceived quality (or value) of the product (subjective measurement) [8-10]. The human factors, in particular knowing the consumer's sensory preferences, are therefore fundamental. In this context, the integration of human factors at the heart of an approach to sensory evaluation of the products becomes a priority in the eco-design process.

In this paper, the focus is on the composite materials having plant fiber reinforcement. These are currently the subject of much research because of their environmental strengths and their ability to replace glass fiber reinforced composites. This raises the operational need for sensory evaluation of the products from bio-based materials, and then their comparison with products from conventional materials. In order to achieve this goal, we first propose to focus on the sensory characterization of *materials*, presented in the form of samples, whether bio-based or conventional.

Then, as a second step, we extend this sensory characterization to *products* obtained from these materials [8, 11, 12]. The introduction of the environmental dimension into development, design, manufacturing, and evaluation activities is a delicate and very complex process. The consuming patterns, the industrial development and the evolution of societies resulted in a significant degradation of our environment [13]. The respect for the environment in designing the products is a very advantageous perspective, both for the protection of the mentioned environment and for the manufacturer (resulting in improved brand image, shareholder confidence, improved customer satisfaction, etc.).

2. Materials and methods

2.1. An eco-design approach and bio-based materials

Eco-design is really an abbreviation for “green design”. It’s a way to design products with environmental considerations in mind. A so-called 'environmentally-friendly' concept requires taking into account the environment as a new factor in the product development process. The notion of “bio-based” materials is not a trend or a fashion. It is a necessity [1-3, 11, 14, 15].

The concept of “bio-based” materials usually refers to materials of plant or animal origin such as wood, straw, hemp, feather, etc. Companies are increasingly taking into consideration the environmental factors as opportunities to increase business efficiency, stimulate innovation, reduce costs, improve brand positioning, and improve communication [12, 13, 16-18]. There is a growing interest for a more sustainable lifestyle and different urban forms.

2.2. The samples

For our study we have chosen to compare bio-based materials composed of linen fibers with a synthetic material composed of glass fibers (Figure 1).

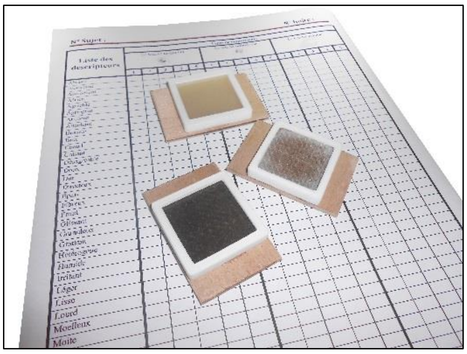

Figure 1. Samples

During the manufacturing process, a bio-based composite material results from a mixture of fibers (20% flax and 21% glass) and a matrix (80% resin for the bio-based material and 79% resin for the synthetic material). The orientation of the fiber is a decisive factor, establishing the performance properties of the composite [16, 19-21]. As a result, two groups of semi-products can be distinguished: a unidirectional composite bio-based material and a twill composite bio-based material.

Epoxy resin is a thermosetting material widely used in the composites industry. It obtains its definitive characteristics following a chemical reaction. The application of these resins can be done by stratification. This implementation technique consists of applying successive layers of stratification resin and reinforcing materials (fibreglass material, linen fiber material). It is perfect for work requiring increased performance, as well as superior durability.

Table 1. Types of samples

Type of material	Number of surface variations	Abbreviations			Total number of samples
Twill bio-based material (S)	3	T_11	T_12	T_13	9
Unidirectional bio-based material (U)	3	U_11	U_12	U_13	
Synthetic fiberglass material (G)	3	S_11	S_12	S_13	

In order to carry out the tests of our experiment, we manufactured 9 samples of 6 cm x 4 cm (see Figure 1). The thickness of each samples is 3 mm. Each sample of 3 cm x 3 cm was glued to a piece of wood having a plastic frame in order to loosen the edges and to facilitate its use in blind test boxes. Therefore, we built test boxes (30 cm x 11.5 cm x 9.5 cm), as seen in Figure 2. These boxes are used to test samples in batches of 5 (Figure 2). The subject has access to the sample either through a lateral opening or an opening on the top of the box. All material types were provided by the Department of Université de Technologie Belfort Montbéliard.

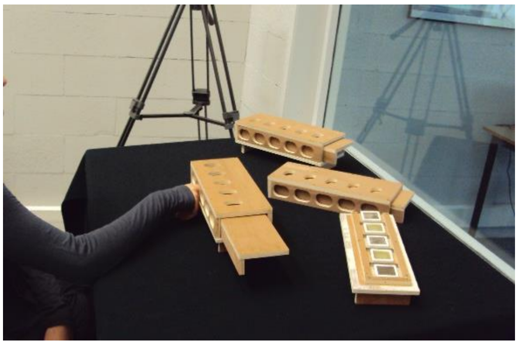

Figure 2. Test boxes

2.3. The subjects

For the experiments, we selected a group of 18 people, of which 7 were women and 11 men. It was important to be ordinary people, recruited among the students at the EDIM Department (Ergonomie Design et Ingénierie Mécanique) of the UTBM (Université de Technologie Belfort Montbéliard). This type of recruitment guaranteed the homogeneity of the sample in terms of age, socio-cultural background, education, and sensory design knowledge [1, 5, 22-25].

2.4. Experimental protocol and procedure

We used a sensory scale that we created based on the literature [1, 2, 5]. This scale contains only adjectives and represents the list of descriptors for bio-based materials (10 descriptors), as presented in Figure 3.

The samples are presented blindly, upon an experience plan defined according to the results to be achieved. The subjects submit their answers by filling a questionnaire specific to each test in order to highlight the differences between the materials they have tested.

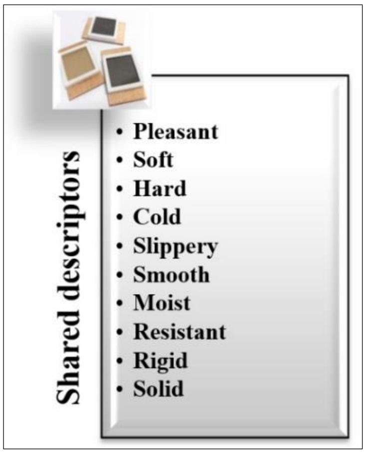

Figure 3. Lists of shared descriptors for all types of materials

The objective of a sensory study is to qualify and/or quantify one or more perceived characteristics of one or more materials. In this case, the focus is on describing and evaluating the intensity and the quality of the sensory features of the materials tested: description of the material, evaluating the sensory profile, highlighting differences between materials based on different descriptors, assessing the evolution of quality over time. The descriptive quantitative study uses descriptive terms to assess and measure the intensity of the sensory properties of a sample.

3. Results and discussions

The goal of this series of experiments is to measure and then compare the subjective perception of each descriptor selected for every type of material. It is an experimental series documenting the consumer's perception about two types of raw surface materials. This experimental study is taking place in two steps. In order to get the results, we are using a multivariable analysis for all the data collected.

3.1. Results

The first step is to focus on identifying the shared descriptors both for the subjective sensation when touching a bio-based material, be it unidirectional or twill, and the subjective sensation when touching a synthetic one.

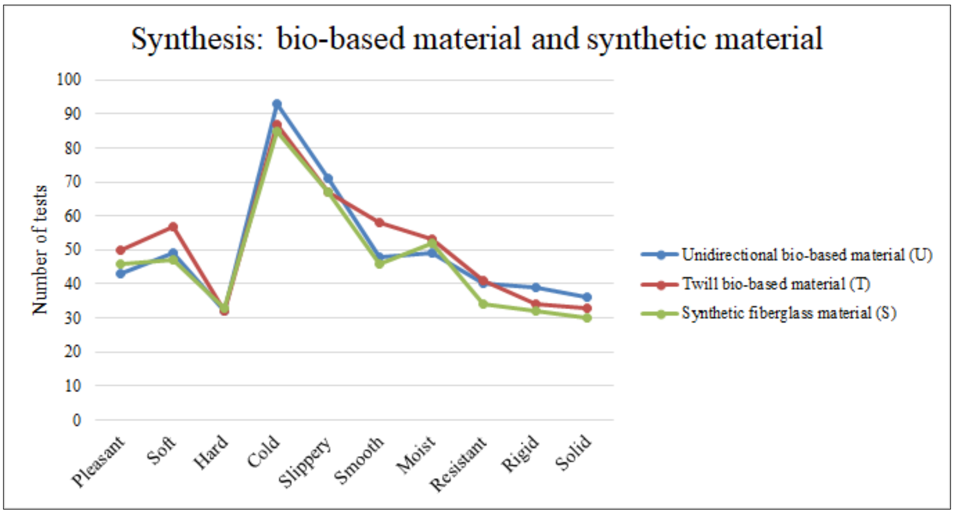

Figure 4. Product results – bio-based vs. synthetic materials

The next step is to create two complementary scores: one for the subjective sensation when touching the unidirectional bio-based material and another one for the subjective sensation when touching the bio-based twill material. These two scores are the result of collecting the values assigned to each descriptor used in evaluating the different bio-based materials.

Therefore, for each subject, we have two different scores for each descriptor: one score connecting the subjective sensation when touching unidirectional and twill bio-based materials and one score connecting the subjective sensation when touching synthetic materials. For each subject, for each descriptor, we obtained two different scores (Figure 4). In fact, we analyzed the scores assigned to each descriptor for every type of material (bio-based materials vs synthetic materials), no longer taking into account other variables (such surface variation or standardized touching). As a result, the score for biosafety materials was then contracted to a scale similar to that of synthetic materials.

In cases where the perceptions were not similar, we focused on two subcategories of the bio-based materials, comparing them to the synthetic material. It became possible to check whether these different perceptions were the same for all the types of bio-based materials, or specific to one or another type of material. Therefore, based on these two experimental series, we were able to identify two shared lists of descriptors for bio-based and synthetic materials.

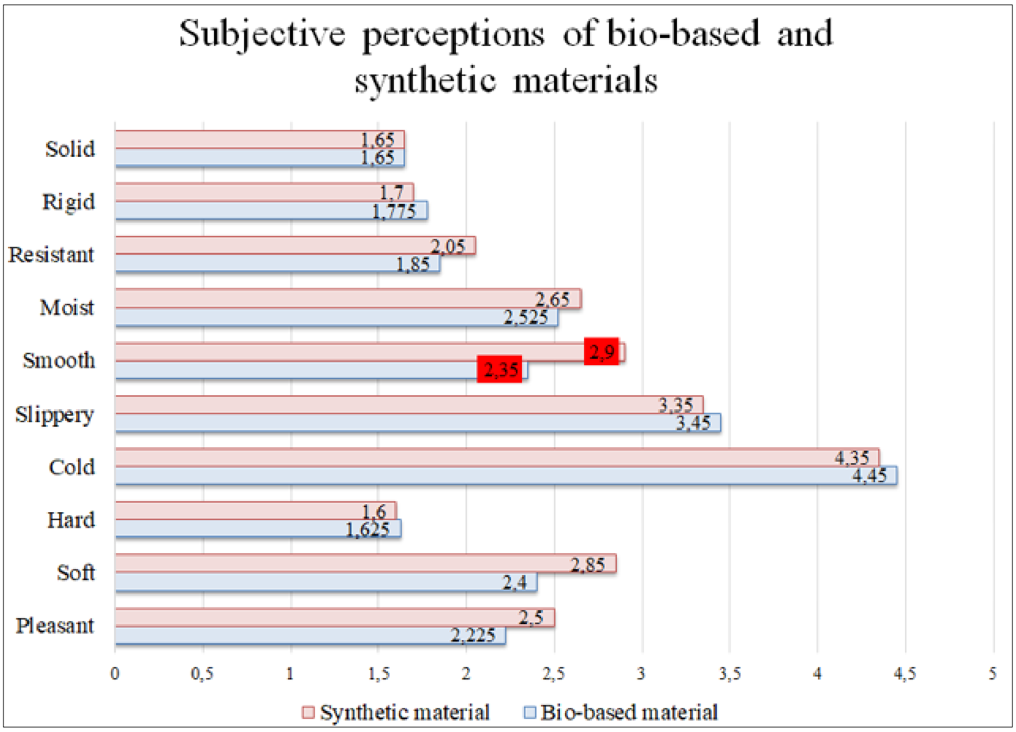

Figure 5. Results: bio-based material vs. synthetic material

As we already explained, the results of the experiment enabled us to identify every descriptor for which the subjective sensation when touching a bio-based material is different than the subjective sensation when touching a synthetic material. Figure 5 presents a review of all the results. The descriptor for which the perceptions are different is indicated in red. When considering descriptors like “Pleasant”, “Soft”, “Hard”, “Cold”, “Slippery”, “Moist”, “Resistant”, “Rigid” and “Solid”, there is no difference in perception when touching bio-based or synthetic materials. Only the scores for the “Smooth” descriptor indicated that the subjective sensation was different. We hope to have demonstrated a similarity of perception when touching the two types of material, bio-based and synthetic. We can therefore conclude by saying how relevant is to apply evaluation methodologies in order to demonstrate the similarity of the products manufactured with bio-based materials.

3.2. Discussions

In the various experiments we conducted, we achieved a number of particularly interesting results.

Our choice not to call for connoisseur subjects had a direct consequence on the list of descriptors [2, 4, 5]. Indeed, for a sensory evaluation is mandatory either to have a list defined by successive iterations of the subjects in a connoisseur panel, or using a pre-existing list of descriptors. We would like to underline that the choice of descriptors is a crucial step on which the quality of the results depends [5]. Based on not having a sample of connoisseur subjects and the fact that in the literature there is no such specific preexisting list of descriptors, we had to create our own list of descriptors by adapting the lists identified in the literature and combining this approach with an experimental one. The results have nevertheless allowed us to characterize precisely the subjective perception when touching bio-based material and synthetic materials and to conclude on their similarities and differences.

4. Conclusions

The limitation mentioned above in creating the list of descriptors became in fact a major result of our research. Indeed, this first study enabled us to advance a first list of descriptors for a bio-based material from flax fibers, taking also into account their specific type of surface. Our study thus provides a basis for further studies that could refer to our already validated list. This proposed list of descriptors makes it possible to promote a democratization of sensory evaluation in order to save time when conducting future studies on bio-based materials, particularly those from flax fiber.

The new method of implementation, created precisely to replace the synthetic materials with bio-based materials, grants the designers and manufacturers so many different options for developing and manufacturing new products. Such methods enable us to completely rethink the concepts of form, particularity and manifestation of objects. It seems that it is not a fantasy for the future, but a reality already happening in laboratories and research institutes around the world: biodegradable and bio-mimetic intelligent materials are replacing the existing less environmentally friendly materials.

The new perspective shows how to improve the experimental studies, for example in sampling and exploring other sensory modalities. Our study raises new questions in current research and provides positive and promising answers. For the future, we hope to be able to link sensory data with complementary data (from physics and chemistry).

Our study, a forerunner in the field of bio-based materials, needs to be taken even further, because there are still so many perspectives for research. For the moment, we identified two areas of reflection. The first is a short term one that focuses on the completion and optimization of experiments and data collection. The second is for the longer-term and pertains to the integration of this type of result in the process of product design.

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