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# Identifying the Purposes of Biological Materials in Everyday Designs

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**Abstract**
The exploration of new materials has provided new insights into the progressive use of living biological materials in everyday designs. Living biological materials are expected to have the potential to overcome the depletion of non-renewable resources. Through bio-design and biophilic design in the urban environment, designers apply living systems as appropriate solutions to everyday designs. This paper aims to classify the biological materials and the sense of ownership towards biological materials embedded in products in terms of a) Function, b) Aesthetic and Semantic, and c) Emotion and Experience. A survey was conducted from 173 respondents through an online questionnaire.

Keywords: biological materials; biophilic design; product designs; purposes and ownership


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## 1.0 Introduction

Significant threats towards the environment are caused by the vast usage and overconsumption of natural resources. A growing awareness of these problems has led to design movements which aim to alleviate the problems of non-renewable resources exhaustion. In this context, designers, architects, engineers, and scientists are experimenting and exploring future applications of living biological materials, which are known to have many beneficial properties in human-nature relation as well as the potential of drastically improving the quality of daily life (www.gsa.gov (2015); Montana-Hoyos, 2010). Biophilia, biophilic design and bio-design are the latest examples of the bio-related genre which led to the introduction of natural elements in built environments, highlighting their positive impact on the human-nature relationship. Moreover, the apparent decrease of interaction between human beings and nature – especially in the urban environment – affects the human life, emotion, behaviour, thinking, learning process, as well as the daily survival (Tischner, 1997; Thorpe, 2007; Proctor, 2009; Montana-Hoyos, 2010).

This research project elaborates upon the use of biological materials in everyday products. Various studies are trying to cultivate new alternatives to replace the depleted conservative resources by incorporating biological materials. This publication is part of a larger study on emotional design and perception (Sayuti and Ahmed-Kristensen, 2020) which were executed to gain feedback on positive and negative emotions, purposes, the application of biological materials in everyday design, as well as the ownership of designs that incorporate biological materials.

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### 1.1. Research Aim

This research project aims to understand the valid purposes of biological materials and consumer's ownership towards everyday products incorporating biological materials. More specifically, this study firstly investigates the practical purposes of biological materials which could be embedded in future everyday designs. Then secondly, this study elaborates the acceptance and ownership of these particular products which could be incorporated in the development of future daily consumer products. Finally, this study will further clarify the user perception towards biophilia, biophilic design, bio-design and emotional design.

## 2. Literature Review

To understand everyday products incorporating biological materials or living organisms, it is important to situate these products within bio-design, biophilia theory and biophilic design followed by other related topics, such as living organisms and product semantics.

### 2.1 Biophilia, biophilic design and bio-design,

Biophilia describes the association of human beings with nature and living organisms. Wilson (1984, page 1) who developed biophilia theory, defined it as "the innate tendency to focus on life and lifelike processes." Arvay (2018) suggested biophilia can be applied in home context and enhance the wilderness experience through the correlation of scientific and spiritual experiences with nature – also supported by Wilson and Kellert et al. (2008). The practical applications of biophilic design in built environments was introduced by Kellert et al. in 2008, which identifies the roles of nature to the human mind, emotion, and physical well-being. Nowadays, many urban built environments and designs consider the integration of biophilic elements as it helps to elevate and enhance the way of living, especially to the spaces which are lacking contact with natural elements. Biophilic design studies were conducted in the disciplines of the built environment, health, employees' productivity, employee well-being, among others. Among the initial studies on biophilic design – addressing the benefits of natural elements to human nearby or indoors – include Grinde and Patil (2009), Simaika and Samways (2010), Howell et al. (2011), Bartczak et al. (2013), Johnson (2014), as well as Terrapin Bright Green (2012 and 2014). More recent studies on biophilic designs have been published by Sayuti et al (2015 and 2018), Gunawardena and Steemers (2018), Rosenbaum et al. (2018), Yin et al. (2018), Parsaee et al. (2019), among others.

Myers (2018) defined bio-design as the application of living ecosystems which allow designed products to be more sustainable. Myers (2018) focus more on the application of radical materials, especially living ecosystem in the development of bio-design products, such as *The Seed of Narcissus* by Tomáš Libertíny and *Lung-on-a-chip* by Donald E. Ingber and Dongeun Huh, among others. Magnan (2018) uses images to explore perception and cognitive psychology to elevate creative thinking abilities and emphasise bio-design thinking. Resulted from the previous studies above, the application of natural elements in everyday products has shown potential to be further explored, and disciplines like industrial design can help to develop more innovative and productive designs which can serve end users by promoting the interaction, communication, empathy, emotional connection and awareness towards natural elements. The main concern of this study is the exploration of emotional responses, perception and the functionality of living materials.

### 2.2 Biological materials/ Living organisms

A living organism can be defined as a living condition of an individual form or a living body (which is not dead), including animals, plants, bacteria, fungi, algae, and others (Dictionary of the English Language, Fifth Edition, 2011). Biological materials also defined by Dictionary of the English Language (Fifth Edition, 2011) is relating to the biology of living things or natural organic matters including biomass, chemical substance, tissue or cellular component.

For this research, we have identified eleven materials which are commonly – directly or indirectly – used in everyday products. These biological materials were then subdivided into four categories: 1) *Artificial natural elements* which consist of a) *nature images*, such as in photographs, graphics, painting, drawing and others and b)*artificial plants*, e.g. plastic flowers or grass, 2) *Real natural elements: plants,* such as moss, edible plants, flowers, decorative plants, cacti or succulents, 3) *Real natural elements: animals* including fishes, insects and others, and 4) *Real natural elements: microorganisms,* such as fungi, algae and beneficial bacteria.

### 2.3 Product purposes, appearance, semantics, experience and ownership

Radford and Bloch (2011) stated that consumers are strongly drawn to new innovative products, where bio-design and biophilic design can be considered as a newly emerging design genre. They add to a product's functionality and semantics, enhance them towards a more pleasing appearance, and promotes near-natural experiences to consumers. Bio-design and biophilic design are new design disciplines which enable consumers to perceive, communicate, and interact with living materials directly or indirectly, depending on how the living materials are applied in the designs. Usually, these materials provide specific functionality or are part of a specific nature-related product. Products for a specific purpose or usage and enhanced product aesthetics are highly valued and chosen by consumers (Veryzer, 1993; Yamamoto and Lambert, 1994; Bloch, 1995; Creusen and Schoormans, 2005). Another example of studies about product appearances in product design are provided by Govers and Schoormans (2005), Mugge, Govers and Schoormans (2008) and Blijlevens et al. (2009), among others.

The term "semantics" is widely used in design to define the meaning of a product, visually and physically. Product semantics (as defined by Krippendorff, 1989) should enable consumers to make sense of things with a special focus on understanding the consumers' attitude toward the product, its functionality and interfaces. Other relevant studies on product aesthetics, semantics, and styling in design are Crilly et al. (2004), Zuo and Jones (2007), Boess (2008), Krippendorff (2008), Lawson and Storer (2008), Bonollo (2010), Demirbilek and Sener (2010), and Hagtvedt and Patrick (2014).

These previously-described studies have been useful to understand emotional design, perception, purposes, ownership of product design, and its relation towards biophilia theory, biophilic design and bio-design.

## 3.0 Methodology

This work builds on the study by Sayuti and Ahmed-Kristensen (2020). A survey comprising of six main sections was designed mainly to gather the respondent's perceptions and emotions towards biological elements. This survey extends the previously-published results and focuses on *the purpose of biological elements and the sense of ownership in everyday designs*. Images of biological materials in specific contexts were shown to the participant. Please refer to Sayuti and Ahmed-Kristensen (2020) for detailed information on the study on perception, which is the first part of the survey and was disseminated through social media and emails. This current work focusses on those 173 respondents who actually completed the survey up to the section covering purposes and ownership of biological materials. Eleven questions on the purposes and logic questions on ownership had the intention to investigate the opinion of potential consumers (as shown in Figure 1 below). An example page of the survey can be seen in Figure 1.

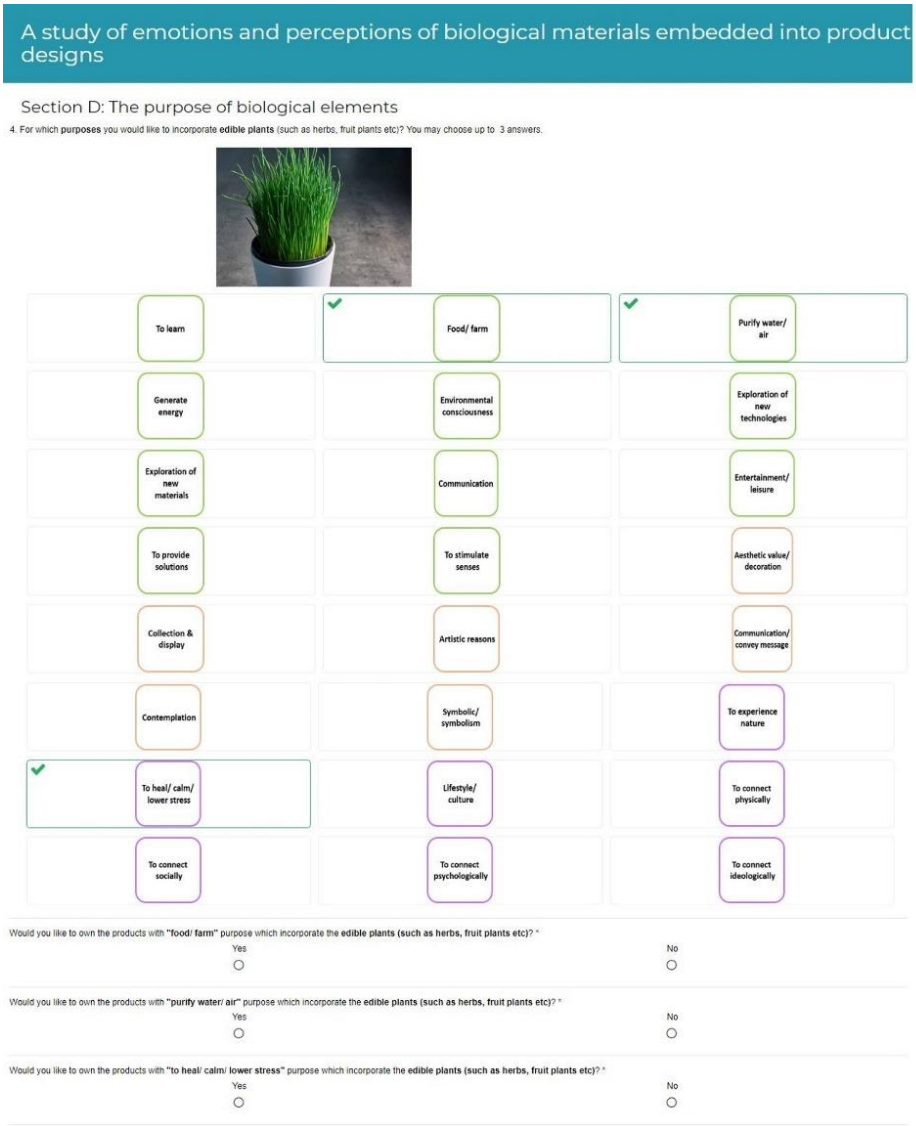


Figure 1: The example of Section D: the purpose and ownership in the survey
*(Source:* Authors*)*

### 3.1 The conceptual model development

The conceptual model built upon previous research (Sayuti et al 2015 and 2018) and was revised and tested in the context of this study. Previously, the original conceptual model was developed with four main categories and six subcategories each. The subcategories were revised rearranged and renamed accordingly to the suitability of the purposes within the conceptual model. The latest model consists of three main categories which are; *A: Function and Practicality*, *B: Aesthetic and Semantic*, *C: Emotion* and *Experience.* The subcategories under *A: Function and Practicality* are comprised of eleven purposes including five new subcategories (whereas the original model

consisted of six subcategories for A). The subcategories are *A1: To learn, A2: Food/ farm, A3: Purify water/air, A4: Generate energy, A5: Environmental consciousness, A6: Exploration of new technologies, A7: Exploration of new materials, A8: Communication, A9: Entertainment/Leisure, A10: To provide solution, A11: to stimulate senses*. The subcategories under *B: Aesthetic and Semantic* are, *B1: Aesthetic value/decoration, B2: Collection & display, B3: Artistic reasons, B4: Communication/convey message, B5: Contemplation, B6: Symbolic/symbolism*. Finally, the subcategories under *C: Emotion* and *Experience* consisted of seven (with five newly added) which are *C1: To experience nature, C2: To heal/calm/lower stress, C3: Lifestyle/culture, C4: To connect physically, C5: To connect socially, C6: To connect psychologically, C7: To connect ideologically*.

Table 1: The conceptual model of the purpose of biological materials in everyday designs

| The purpose of biological materials in everyday designs | | | | | |
|---|---|---|---|---|---|
| **Function and practicality** | | | | | |
| **A1 To learn** | **A2 Food/ farm** | **A3 Purify water/ air** | **A4 Generate energy** | **A5 Environmental consciousness** | **A6 Exploration of new technologies** |
| **A7 Exploration of new materials** | **A8 Communication** | **A9 Entertainment/ leisure** | **A10 To provide solution** | **A11 to stimulate senses** | |
| **Aesthetic & Semantic** | | | | | |
| **B1 Aesthetic value/ decoration** | **B2 Collection & display** | **B3 Artistic reasons** | **B4 Communication/ convey message** | **B5 Contemplation** | **B6 Symbolic/ symbolism** |
| **Experience & Emotion** | | | | | |
| **C1 To experience nature** | **C2 To heal/calm/ lower stress** | **C3 Lifestyle/ culture** | **C4 To connect physically** | **C5 To connect socially** | **C6 To connect psychologically** |
| **C7 To connect ideologically** | | | | | |

(Source: Authors)

## 4. Results

### 4.1 Respondent background

A total of 173 responses were received and analysed for this section. Background data were collected on *gender* (67% of female, 32.4% of male while 0.6% preferred not to answer), *age* (ranging from 18 to 25 with 11.6%, 26 to 30 with 11.6%, 31 to 40 with 41.3%, 41 to 50 with 26.2% of, 51 to 60 with 7.6% of, and 1.7% from 61 or older). The respondents are from a *design or non-design background* with 39.3% (68 respondents) and 60.7% (105 respondents) respectively. Their *cultural background* (88.4% Asian, 7.5% White, 1.7% Mixed, 1.7% Other, 0.6% preferred not to answer and 0% Black/African- American). Almost all respondents have *access to nature* with 88.4%.

The results can be seen in Table 2 and 3 below, representing the descriptive analysis in terms of (number of responses) counts and their overall summary regarding the overall purposes of biological materials and the sense of ownership of products embedded with biological materials. For this section, respondents were allowed to select a maximum of 3 purposes which they deemed suitable for each material. Results were computed by using IBM SPSS version 25 and compiled in Excel. It is worth noting that there are percentages which do not have 100% frequency due to the usage 0- point decimal in the SPSS, and show either 100.1% or 99.9% frequencies.

### 4.2 The purposes of products with biological materials

Table 2 below shows the results regarding the different types of biological materials in the context of the purposes introduced in Table 1. These results can be seen in Table 2 below highlighted in either blue, green or pink (according to the conceptual model colour coding in Table 1). The four (4) highest counts received for biological materials are edible plants with 100 counts, followed by decorative plants with 94 counts, images of nature with 82 counts and bacteria with 82 counts as well. In terms of biological materials, the highest combined count for the three main categories (A, B and C) was achieved by images of nature with 462 counts, while the lowest overall count is received by bacteria and insects with 358 and 359 counts respectively.

For brevity, only the highest purposes will be highlighted. The *A: Function and Practicality* categories received the overall responses counts of 2360. Edibles plants received the highest of 100 counts for "*A2: Food/ farm"*, followed by bacteria, algae and insects or other animals with 82, 60 and 56 counts for "*A1: To learn"* and the next highest received by artificial plants with 58 counts for "*A11: to stimulate senses"*. Other purposes received lower responses.

The results obtained for *"B: Aesthetic and Semantic"* categories with the overall responses counts of 1096. The purpose of "*B1: Aesthetic value/decoration"* received 94, 82 and 63 counts for decorative plants and images of nature, succulents and cacti respectively

while the purposes of "*B3: Artistic reasons"* and "*B2: Collection & display"* received 45 counts and 42 counts respectively for decorative plants and succulent and cacti. Lower responses received by other purposes.

Finally, for *C: Emotion* and *Experience,* the categories received the overall responses counts of 977. Moss and insects or other animals received 62 and 52 counts respectively for *"C1: To experience nature"*. Fishes received the highest response counts of 41 for "C2: *To heal/calm/lower stress".* The next highest purpose is *"C3: Lifestyle/culture"* with 34 counts. Other purposes received lower responses.

Moreover, the biological materials which received the highest responses within the purposes are bacteria (*A1: To learn* with 82 counts, *A6: Exploration of new technologies* with 41 counts, *A7: Exploration of new materials* with 37 counts, *A10: To provide solution* with 34 counts and *C5: To connect socially* with 7 counts) and artificial plants (*A4: Generate energy* with 45 counts*, A8: Communication* with 10 counts, *A11: to stimulate senses* with 58 counts, *B5: Contemplation* and *B6: Symbolic/symbolism* with 11 and 39 counts respectively) with 5 purposes, followed by insects and other animal with 4 purposes (*A1: To learn* with 56 counts, *C1: To experience nature* with 52 counts, *C6: To connect psychologically* and *C7: To connect ideologically* with 9 and 5 counts respectively) and moss (*A3: Purify water/air* with 41 counts, *A5: Environmental consciousness* with 55 counts, *C1: To experience nature* with 62 counts and *, C4: To connect physically* with 7 counts).

A radar graph in Figure 2 below depicts the highest and lowest responses towards the overall sum of the purposes regarding biological materials.

Table 2: The overall sum and responses counts of the purposes of biological materials

| The overall purposes of biological materials | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Function and Practicality** | | | | | | | | | | | | |
| **The purposes**<br>**Biological materials** | **A1** | **A2** | **A3** | **A4** | **A5** | **A6** | **A7** | **A8** | **A9** | **A10** | **A11** | **Overall counts A** |
| Images of nature | 21 | 15 | 23 | 12 | 46 | 13 | 14 | 8 | 19 | 0 | 38 | |
| Artificial plants | 33 | 23 | 18 | 45 | 11 | 19 | 3 | 10 | 10 | 20 | 58 | |
| Moss | 23 | 20 | 41 | 15 | 55 | 10 | 17 | 4 | 8 | 7 | 32 | |
| Edible plants | 23 | 100 | 18 | 10 | 44 | 5 | 7 | 2 | 4 | 9 | 30 | |
| Decorative plants | 9 | 5 | 23 | 5 | 33 | 3 | 8 | 5 | 21 | 3 | 35 | |
| Succulent/ cacti | 28 | 7 | 17 | 4 | 28 | 7 | 13 | 2 | 10 | 6 | 32 | |
| Fishes | 26 | 20 | 21 | 10 | 24 | 7 | 5 | 8 | 28 | 2 | 32 | |
| Insects or other animals | 56 | 6 | 2 | 3 | 26 | 8 | 9 | 4 | 12 | 9 | 30 | |
| Fungi | 52 | 68 | 9 | 7 | 34 | 15 | 25 | 4 | 1 | 9 | 11 | |
| Algae | 60 | 24 | 24 | 22 | 40 | 26 | 32 | 2 | 1 | 17 | 11 | |
| Bacteria | 82 | 23 | 16 | 11 | 16 | 41 | 35 | 5 | 1 | 34 | 7 | |
| Counts of each subcategory | **413** | **311** | **212** | **144** | **357** | **154** | **168** | **54** | **115** | **116** | **316** | **2360** |
| **Aesthetic and Semantic** | | | | | | | | | | | | |
| **The purposes**<br>**Biological materials** | **B1** | | **B2** | | **B3** | | **B4** | | **B5** | | **B6** | **Overall counts B** |
| Images of nature | 82 | | 12 | | 39 | | 3 | | 4 | | 14 | |
| Artificial plants | 24 | | 17 | | 1 | | 5 | | 11 | | 39 | |
| Moss | 30 | | 5 | | 17 | | 5 | | 2 | | 7 | |
| Edible plants | 28 | | 11 | | 12 | | 1 | | 2 | | 6 | |
| Decorative plants | 94 | | 27 | | 45 | | 0 | | 1 | | 14 | |
| Succulent/ cacti | 63 | | 42 | | 41 | | 5 | | 2 | | 12 | |
| Fishes | 34 | | 35 | | 21 | | 2 | | 8 | | 12 | |
| Insects or other animals | 12 | | 26 | | 15 | | 5 | | 8 | | 28 | |
| Fungi | 19 | | 19 | | 17 | | 2 | | 5 | | 6 | |
| Algae | 14 | | 10 | | 9 | | 6 | | 5 | | 9 | |
| Bacteria | 5 | | 8 | | 11 | | 3 | | 5 | | 14 | |
| Counts of each subcategory | **405** | | **212** | | **228** | | **37** | | **53** | | **161** | **1096** |
| **Experience and Emotion** | | | | | | | | | | | | |
| **The purposes**<br>**Biological materials** | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | | **Overall counts C** | | **Overall counts of all categories for each material (A+B+C)** | |
| Images of nature | 26 | 36 | 21 | 3 | 4 | 8 | 1 | | | | **462** | |
| Artificial plants | 22 | 20 | 4 | 0 | 2 | 3 | 0 | | | | **398** | |
| Moss | 62 | 38 | 3 | 7 | 1 | 7 | 1 | | | | **417** | |
| Edible plants | 28 | 34 | 34 | 4 | 2 | 7 | 0 | | | | **421** | |
| Decorative plants | 37 | 40 | 18 | 4 | 3 | 8 | 3 | | | | **444** | |
| Succulent/ cacti | 41 | 31 | 18 | 2 | 2 | 4 | 4 | | | | **421** | |
| Fishes | 41 | 41 | 14 | 3 | 2 | 9 | 3 | | | | **408** | |
| Insects or other animals | 52 | 14 | 11 | 6 | 3 | 9 | 5 | | | | **359** | |
| Fungi | 45 | 5 | 11 | 2 | 3 | 4 | 3 | | | | **376** | |
| Algae | 31 | 3 | 8 | 3 | 5 | 3 | 4 | | | | **369** | |
| Bacteria | 14 | 6 | 7 | 1 | 7 | 2 | 4 | | | | **358** | |
| Counts of each subcategory | **399** | **268** | **149** | **35** | **34** | **64** | **28** | | **977** | | | |

(Source: Authors)

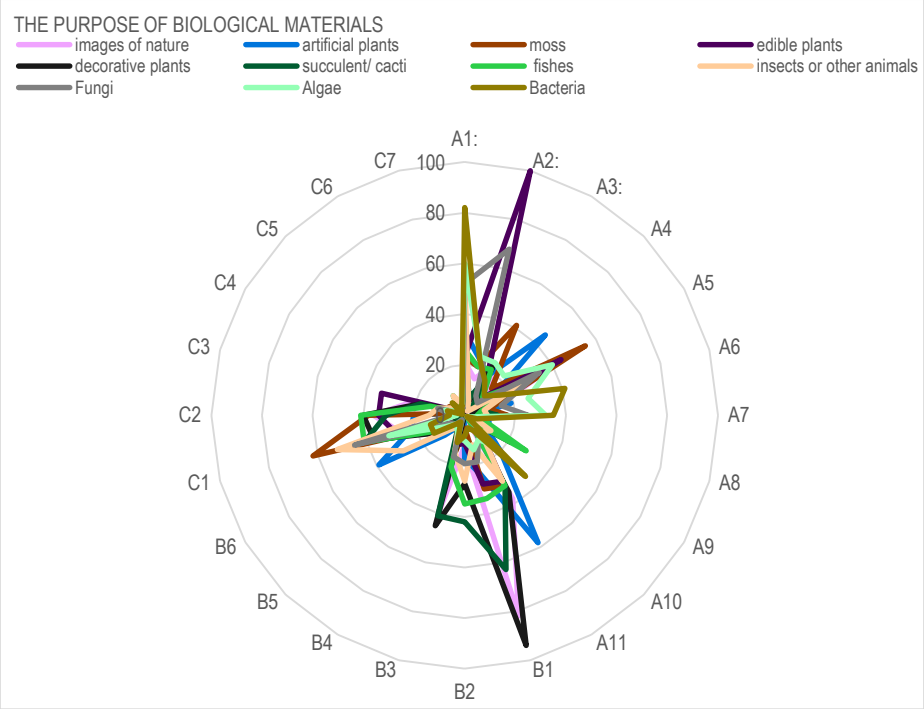


Figure 2: The radar graphs depicting the highest and lowest responses towards the overall purposes of different biological materials.
*(Source: Authors)*

### 4.3 The ownership of products embedded with biological materials

For brevity, this section will only discuss the highest purpose-related counts regarding ownership of products embedded with biological materials. Table 3 below shows the overall sum and counts of the ownership of products incorporated in biological materials. Results are highlighted in either blue, green or pink. The highest overall count of each subcategory in this context received the purpose of *"B1: aesthetic value/decoration*" with 359 counts followed by *"C1: to experience nature"* purpose with 326 counts while the lowest overall count is received by *"C7: To connect ideologically"*. The highest overall count of main categories (A, B and C) in terms of biological material's ownership was received by images of nature with 406 and closely followed by edible plants with 405 counts while the lowest overall count is received by insects with 185 counts.

For the ownership of products embedded with biological materials under the category *"A: Function and Practicality"*, the overall response counts received is 1884, which shows that this main category of purpose received the highest responses in terms of ownership. Edible plants received the highest count for the ownership with 99 for the different purposes of *"A2: Farm/food"*. Fungi also received a high response for *"A2: Farm/food" with 57counts.* Bacteria received 51 counts of ownership *"A1:to learn"*. Next highest is *"A5: Environmental consciousness"* received by moss *with 48 counts.* Other purposes received lower responses.

The main category of purpose *"B: Aesthetic and Semantic",* received overall responses counts of 842, decorative plants, images of nature and succulent and cacti with 85, 70 and 57 counts respectively for *"B1: aesthetic value/decoration"*. "*B2: Collection & display" and "B3: Artistic* reasons" are the next highest in this category with 36 and 35 counts respectively *for* decorative plants and succulent and cacti. Lower responses received by other purposes.

*"C: Emotion* and *Experience"* received the lowest overall responses counts of 811. *"C1: to experience nature"* is the highest in this category with 52 counts for moss, which also received *35 for* "*C2: To heal/calm/lower stress". "C3: Lifestyle/culture"* is the next highest purpose with 33 counts for edible plants. Other purposes received lower responses of ownership.

Moreover, the biological materials which received the highest responses within the purposes on ownership are moss with 5 purposes (*A3: Purify water/air*, *A5: Environmental consciousness*, *C1: To experience nature, C2: To heal/calm/lower stress* and *C4: To connect physically*), followed by bacteria with 4 purposes (*A1: To learn*, *A6: Exploration of new technologies*, *A7: Exploration of new materials* and *A10: To provide solution*) and succulent and cacti (*B1: aesthetic value/decoration*, *B2: Collection & display, B4: Communication/convey message* and *C7: To connect ideologically*).

The radar graph in Figure 3 below depicts the highest and lowest responses towards the overall sum of the sense of ownership regarding biological materials.

Table 3: The overall sum and counts of the ownership of products embedded with biological materials

| The ownership of products embedded with biological materials | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Function and Practicality | | | | | | | | | | | |
| **The purposes** / **Biological materials** | **A1** | **A2** | **A3** | **A4** | **A5** | **A6** | **A7** | **A8** | **A9** | **A10** | **A11** | **Overall counts A** |
| Images of nature | 21 | 14 | 21 | 11 | 42 | 11 | 13 | 7 | 15 | 0 | 38 | |
| Artificial plants | 10 | 28 | 18 | 15 | 39 | 11 | 13 | 2 | 5 | 8 | 16 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moss | 17 | 14 | 37 | 14 | 48 | 9 | 16 | 3 | 8 | 6 | 29 | |
| Edible plants | 21 | 99 | 17 | 10 | 42 | 5 | 7 | 1 | 4 | 9 | 30 | |
| Decorative plants | 9 | 5 | 20 | 5 | 28 | 3 | 5 | 4 | 15 | 3 | 33 | |
| Succulent/ cacti | 28 | 6 | 16 | 3 | 27 | 6 | 12 | 2 | 10 | 5 | 29 | |
| Fishes | 20 | 17 | 17 | 8 | 20 | 6 | 5 | 5 | 24 | 0 | 26 | |
| Insects or other animals | 31 | 3 | 1 | 2 | 13 | 5 | 5 | 2 | 8 | 4 | 16 | |
| Fungi | 29 | 57 | 7 | 6 | 28 | 15 | 18 | 1 | 0 | 6 | 9 | |
| Algae | 41 | 19 | 20 | 19 | 31 | 21 | 24 | 2 | 0 | 15 | 9 | |
| Bacteria | 51 | 20 | 12 | 6 | 13 | 28 | 27 | 5 | 2 | 23 | 4 | |
| Counts of each subcategory | **278** | **282** | **186** | **99** | **331** | **120** | **145** | **34** | **91** | **79** | **239** | **1884** |

**Aesthetic and Semantic**

| **The purposes**<br>**Biological materials** | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **Overall counts B** |
|---|---|---|---|---|---|---|---|
| Images of nature | 70 | 8 | 32 | 2 | 3 | 10 | |
| Artificial plants | 43 | 16 | 10 | 0 | 4 | 8 | |
| Moss | 28 | 3 | 16 | 3 | 1 | 5 | |
| Edible plants | 26 | 10 | 9 | 1 | 2 | 6 | |
| Decorative plants | 85 | 25 | 36 | 0 | 1 | 11 | |
| Succulent/ cacti | 57 | 35 | 33 | 4 | 2 | 10 | |
| Fishes | 26 | 25 | 16 | 2 | 6 | 10 | |
| Insects or other animals | 5 | 14 | 5 | 2 | 2 | 17 | |
| Fungi | 10 | 12 | 11 | 1 | 2 | 5 | |
| Algae | 7 | 5 | 6 | 4 | 4 | 4 | |
| Bacteria | 2 | 5 | 5 | 2 | 2 | 10 | |
| Counts of each subcategory | **359** | **158** | **179** | **21** | **29** | **96** | **842** |

**Experience and Emotion**

| **The purposes**<br>**Biological materials** | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **Overall counts C** | **Overall counts of all categories for each material (A+B+C)** |
|---|---|---|---|---|---|---|---|---|---|
| Images of nature | 25 | 32 | 18 | 3 | 3 | 6 | 1 | | **406** |
| Artificial plants | 34 | 20 | 13 | 3 | 0 | 2 | 1 | | **319** |
| Moss | 52 | 35 | 3 | 7 | 1 | 7 | 1 | | **363** |
| Edible plants | 27 | 33 | 33 | 4 | 2 | 7 | 0 | | **405** |
| Decorative plants | 34 | 34 | 15 | 4 | 2 | 7 | 0 | | **384** |
| Succulent/ cacti | 37 | 29 | 11 | 1 | 2 | 4 | 4 | | **373** |
| Fishes | 32 | 34 | 13 | 1 | 2 | 9 | 2 | | **326** |
| Insects or other animals | 25 | 7 | 3 | 1 | 2 | 9 | 3 | | **185** |
| Fungi | 32 | 3 | 7 | 2 | 1 | 3 | 1 | | **266** |
| Algae | 19 | 3 | 5 | 2 | 3 | 2 | 1 | | **266** |
| Bacteria | 9 | 6 | 4 | 0 | 4 | 2 | 2 | | **244** |
| Counts of each subcategory | **326** | **236** | **125** | **28** | **22** | **58** | **16** | **811** | |

(Source: Authors)

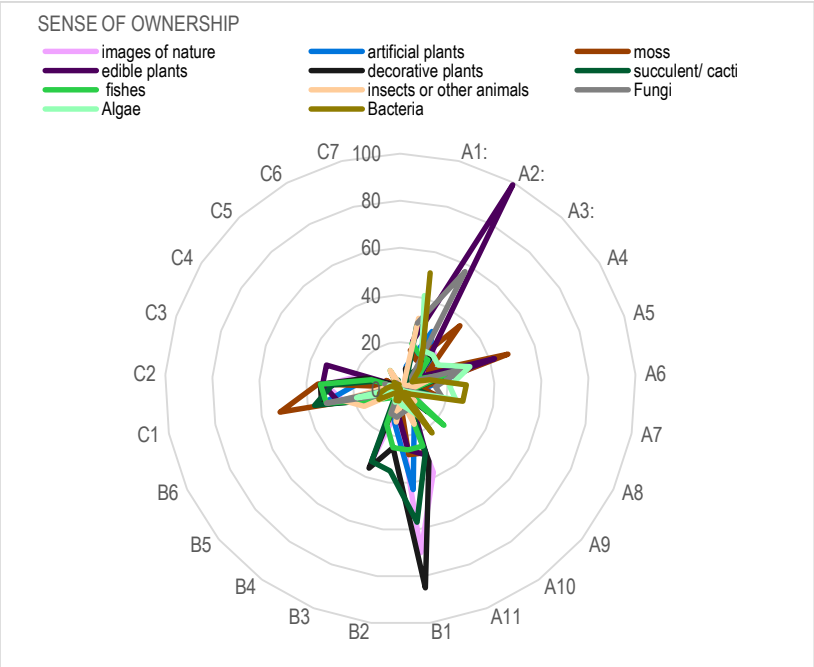


Figure 3: The radar graph depicting the highest and lowest responses towards the overall sum of the sense of ownership of the biological materials.
*(Source: Authors)*

## 6. Conclusion

This study was examining and classifying responses of consumers when exposed to new nature-near materials and products. More specifically, responses regarding purposes and ownership of everyday products embedded with biological materials were explored. A conceptual model was tested to evaluate the respondents' opinion on the relevant purposes of biological materials. From the overall results, it can be concluded that the respondents have chosen the main category "*A: Function and Practicality"* where six materials were identified to have the highest responses, i.e. artificial plants, edible plants, insects or other animals, fungi, algae and bacteria. The related subcategories are *"A1: to learn"*, *"A2: farm/food"*, "*A11: to stimulate senses"*. Other materials such as images of nature, decorative plants and succulent/cacti are viewed as *"B: Aesthetic and Semantic"* with the subcategories of *"B1: aesthetic value/decoration"*. Moss and fishes are viewed as materials compatible to purposes *"C1: to experience nature"* and *"C2: to heal/calm/lower stress"* under the category of *"C: Experience and Emotion"*. Each question regarding the sense of ownership was linked to each material and purpose question.
In addition, participants were asked to either confirm or decline the answer if they want to own a product embedded with biological materials. Based on the overall counts, the results on the ownership have declined almost to half as some respondents might consider not to buy a specific nature-related product. The reason of purchasing or to own the product are leaning towards two main categories, which are *"A: Function and Practicality"* and *"B: Aesthetic and Semantic"* where the respondents might be in favour of products which can support the learning process or fulfil decorative purposes. Surprisingly bacteria received the highest responses within the 4 to 5 purposes and ownership, as the responses view this material for learning, exploration of technologies and new materials purposes. Bacteria, as found in the studies discussed by Myers (2018), are currently used in textiles – more precisely for bacteria-grown clothes/ 'biocouture' – with the purpose to grow biomaterial, create and enhance the natural colours of clothing. Moreover, modified bacteria (e.g. Escherichia coli and Serratia marcescens) could also be used to create digital system storage, growing letters in typeface design and be used for other aesthetic reasons. Other materials such as moss, artificial plants, succulent and cacti and insect or other materials also viewed within 4 to 5 categories as well.

We are hoping that these findings can be used to identify and categorise the appropriate functional use of biological materials. These findings also could support the future development of alternative materials or new material explorations which can be integrated into products of daily use.

## Paper Contribution to Related Field of Study

The contribution of this paper in relation to the field of study Industrial Design, Product Design, Emotional Design, Biophilic Design and Bio-design

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