

# Bio-related Design Genres: A Survey on Familiarity and Potential Applications

Nurul 'Ayn Ahmad Sayuti<sup>1,2(✉)</sup>, Bjorn Sommer<sup>1</sup>, and Saeema Ahmed-Kristensen<sup>3</sup>

<sup>1</sup> School of Design, Royal College of Art, London, UK  
ayn.sayuti@network.rca.ac.uk

<sup>2</sup> Faculty of Art and Design, Universiti Teknologi MARA, Shah Alam, Malaysia

<sup>3</sup> University of Exeter, London, UK

**Abstract.** Biophilia, biophilic design, bio-inspired and bio-design are design genres that adopted nature and biological elements as part of design processes. With the spread use of natural elements in design nowadays, from the analogical approach to the application of the biological materials in design brought up a different connotation towards the diverse use of nature in everyday life. This paper discusses the background knowledge of Biophilia, biophilic design, bio-inspired and bio-design and the application of biological materials in urban environments, especially for home. As part of a larger project on the application of biological materials in everyday products, this study investigates the emotional design and perception, while identifying the purposes of biological materials which incorporated into designs or systems. Data from 158 potential consumers were collected in an online survey specifically designed for this study, differentiating between design and non-design participants. Interesting findings are that more than 65% of non-design respondents are not aware of the terms biophilia and biophilic design, but they are familiar with the terms *bio-inspired* and *bio-design*. On the other hand, the potential consumers which are from non-design and design background as well agreed that having biological materials indoors, can a) help to release stress, b) create awareness of nature and ecological impact, c) can foster a sense of care, and d) can be educational.

**Keywords:** Biophilia · Biophilic design · Bio-inspired · Bio-design

## 1 Introduction

### 1.1 The Background of Biophilia, Biophilic Design, Bio-inspired and Bio-design

Referring to the Dictionary of Environment and Ecology (Colin 2004), the prefix “bio” means “referring to living organisms” and the suffix “philia” means “attraction towards or liking for something”. As such, biophilia describes the innate feeling of human beings

to be associated with nature and living organisms. Introduced by Fromm in 1973, and mentioned by Eckardt (1996), biophilia proposes benefits to human vitality and well-being as nature offers a conducive environment for human development and growth.

Moreover, Wilson (1984, page 1) developed the biophilia theory and defined it as “the innate tendency to focus on life and lifelike processes.” Arvai (2018) supports Wilson by suggesting the effect of biophilia through the exploration and reconnection of scientific and spiritual process with nature in the wilderness and from the comfort of home.

Biophilia theory has evolved into practical applications of biophilic design, by Kellert et al. in 2008. Kellert et al. (2008, page 3) defined biophilic design as:

*“The deliberate attempt to translate an understanding of the inherent human affinity to affiliate with natural systems and processes – known as biophilia, into the design of the built environment.”*

Biophilic design are divided into six design elements based on Kellert et al. (2008, page 7–15), which are (1) *Environmental features* which involve colour, water, air, sun-light, plants, animals, natural materials, views and vistas, facade greening, geology and landscape, habitats and ecosystems and fire in nature, (2) *Natural shapes and forms in man-made designs* that include the natural traits, motifs, forms or structures, (3) *Natural patterns and processes* which comprise the integration of natural elements and cycles that are compatible to be adapted to the built environment, (4) *Light and space*, involving the function of lights and spaces outdoors and indoors of built environments, (5) *Place-based relationship*, as the merging of ecology into culture, and finally (6) *Evolved human-nature relationships*, where the affiliation between human beings and nature is elaborated and the way nature has influenced human beings.

Studies which addressed the benefits of natural elements to human nearby or indoors include Mehrabian and Russell (1974), Ulrich (1981), Balling and Falk (1982), Kaplan (1995), Frumkin (2001), Huelat et al. (2008), Hoffman et al. (2009), Grinde and Patil (2009), O’haire (2010), Simaika and Samways (2010), Howell et al. (2011), Bartzak et al. (2013), Johnson (2014), as well as Terrapin Bright Green (2012 and 2014). 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. These studies were conducted in the disciplines of the built environment, health, employees’ productivity, and employee well-being among others.

Bio-inspired design approaches adapt or mimic the natural elements and incorporate them into designs or technologies to solve problems (Thorpe 2007; Montana-Hoyos 2010; Gruber et al. 2011). Bio-inspired design was proposed by Massimo et al. (2017) as: (1) Nature as inspiration where designs are inspired by a systematic ecological or natural process, and (2) Nature as a design constraint; as nature is very resourceful, many aspects can be learned in terms of new designs and applications.

Myers (2018) defined bio-design as the incorporation of living biological materials or ecosystems that enable the systems designed to be more renewable and sustainable. The use of living biological elements are no longer restricted to the scientific field, but it has gone beyond engineering and design with the incorporation of these living materials into structures, objects and processes (Myers 2018). Myers (2018) also provided examples of developed bio-design products, such as *Local River* by Matthieu Lehanneur, *Moss Table* by Alex Driver and Carlos Peralta, *Bacterioptica* by the MADLAB, among others. Moreover, Magnan (2018) emphasized on the bio-design thinking through the use on visual images towards the perception and cognitive psychology to elevate creative thinking abilities in order to help enhancing scientific and technical innovations. This

literature review shows parallels to our study, as a series of biological images was used to gain feedback on emotional reactions, perceptions, and opinions on the use of biological materials in everyday designs.

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 and the application of biological materials in everyday design, as well as the ownership of designs that incorporate biological materials.

## **1.2 Research Aim**

This study investigates the emotional responses and perception of users with design and non-design background towards biological materials. The emotional responses and perceptions which affected the consumers when the materials are embedded in a product are also reviewed. Moreover, the sense of ownership towards this type of product is also analysed. In this way, this paper focuses on the clarification of user perception and knowledge regarding biophilia, biophilic design, bio-inspired and bio-design.

## **1.3 Structure**

This paper is divided into four sections which are: 1) the introduction of the bio-related design theories involved in this study – this section, 2) the methodology used to perform the research followed by 3) the results and discussion of the selected section from the survey, and finally 4) conclusions and outlook.

# **2 Methodology**

## **2.1 Research Project Structure**

This research project was developed in eight stages, namely: 1) structuring the question-naire by identifying the online platform to be used and subdividing the questionnaire into six sections, 2) an initial compilation and classification of biological materials and related products, 3) setting up the online survey in correspondence to the chosen online survey platform, 4) testing the online survey, 5) obtaining ethical approval for the survey from the ethic commission of the Royal College of Art 6) dissemination of the online survey through social media and emails, 7) further development of the conceptual model based on results of a previous study (Sayuti et al. 2015 and 2018) and finally 8) analysis and discussion of the results gathered from the survey to understand the emotional responses and perception of potential consumers towards the biological elements.

This paper addresses theoretical aspects of this study in stage 8, as well as the questionnaire design as part of stage 3. It mainly focuses on those results of the overarching research project related to the theory, knowledge, and familiarity of bio-related design genres, as well as the application of biological materials in everyday designs and indoor spaces. As previously mentioned, the publication of this project will be divided into sections because it covers different topics and would be wise to discuss in sequences.

## 2.2 Questionnaire Design

A survey was designed to gather the respondent's perceptions and their emotions towards biological elements. As previously mentioned in the research aims, this survey gathered data on how potential consumers perceived biological elements in existing products, and also might experience it in future product designs. The study also surveys consumer's emotional response through the purpose of materials, functionality, sense of ownership and also the general knowledge on Biophilia, biophilic design, bio-inspired and bio-design.

The online questionnaire was designed using SurveyGizmo.com consisted of six main sections which are: A) respondent background, B) artificial and real biological materials, C) emotional design: biological materials, D) the purpose of biological elements, E) existing Biophilic Design/Bio-design by designer (product designs which currently available in the market or still in the conceptual development stage), and F) Biophilia, biophilic design, bio-inspired design and bio-design. The SurveyGizmo.com was chosen as the platform for this project because of its specific feature allowing to use images and custom designed buttons with the 'logic' connection of each question (question within question feature with ratings – which was used for section C, D and E to rate the emotions). The questionnaire was designed by providing illustrative images of biological materials in each section. A total of 234 responses were collected and analysed for this project. However, this paper only discusses Section F – Biophilia, bio-philic design, bio-inspired design and bio-design – which was only completed by 158 participants, because they were allowed to withdraw at any point during the survey. This project received an ethical clearance from the ethical committee of the Royal College of Art before the online survey circulated for six months. Participants were recruited through social media and the survey was also disseminated through emails.

In Section F, 13 questions, as shown in Table 1, were asked to investigate the understanding of respondents' and their personal preferences with nature and biological materials/elements in terms of their interaction, awareness and behaviour. This section was designed using a 5-point Likert scale (Matell and Jacoby 1972; Albaum 1997; Johns 2010), Yes/No and finally an open-ended format. A mean score uses the scale of (-)2; Strongly Disagree, (-)1; Disagree, 0; Neither Agree or Disagree, 1; Agree and 2; Strongly Agree. The findings from this section were analysed using SPSS.

**Table 1.** The list of questions for Section F: biophilia, biophilic design, bio-inspired and bio-design

The list of questions	Format
Q1: I like to have biological elements (such as plants or animals) inside my house	Likert scale
Q2: It is important to have biological elements indoors?	Likert scale
Q3: Having natural and biological elements indoor can: A. release stress/calm	Likert scale
Q4: Having natural and biological elements indoor can: B. create awareness of nature and ecological impact	Likert scale
Q5: Having natural and biological elements indoor can: C. foster a sense of care (as living organisms need to be watered or fed)	Likert scale
Q6: Having natural and biological elements indoor can: D. be educational (especially for children)	Likert scale
Q7: Having natural and biological elements indoor can: E. be dangerous and inconvenient, as in the case of allergies	Likert scale
Q8: Having natural and biological elements indoor can: F. Not desirable, as they are usually messy, dirty, or require much of my time	Likert scale
Q9: Do you know what is Biophilia?	Yes/No format
Q10: Do you know what Biophilic design is?	Yes/No format
Q11: Do you know what Bio-inspired design is?	Yes/No format
Q12: Do you know what Bio-design is?	Yes/No format
Q13: Your opinion on biological materials embedded in product design	Open-ended format

### 3 Results and Discussion

#### 3.1 Respondents Background

A total of 158 responses were received and analysed for this section. Background data were collected on gender (67.1% of female, 32.3% of male while 0.6% preferred not to answer), age (ranging from 18 to 25 with 12.1%, 26 to 30 with 12.1%, 31 to 40 with 42.0%, 41 to 50 with, 51 to 60 with 7.0%, and 61 or older with 1.9%). The respondents are from design and non-design background with 39.2% (62 respondents) and 60.8% (96 respondents) respectively. Their Cultural Background (88.6% Asian, 7.6% White, 1.7% Mixed, 1.3% Other, 1.9% preferred not to answer and 0% Black/African - American).

Almost all respondents have access to nature with 89.9%. Fifty-five-point-seven percent (55.7%) of the respondents prefer to experience nature outdoor while 42.4% preferred to experience both (outdoor and indoor) and only 1.9% preferred to experience it indoor. 24.1% of the respondents preferred to spend time in nature 2–3 times a week. Another 24.1% also preferred to spend once a month in nature, followed by 20.3% on daily basis, 19.6% experience nature once a week, only 10.1% spend twice a month in nature and 1.9% has no access to nature at all.

The results can be seen in Table 2 until Table 6 below. They are presented with the mean value and a nonparametric (Mann-Whitney U Test) analysis from the SPSS test. A mean score uses the scale of (-)2; Strongly Disagree, (-)1; Disagree, 0; Neither Agree or Disagree, 1; Agree and 2; Strongly Agree. The mean value and Mann-Whitney U Test was used to analysed Questions 1 to 8. The value used for Question 9 to 12 is 0 for No and 1 for Yes. Question 13 is using an open-ended format which allow the respondents to answer according to their opinion and it is recorded in a categorization table.

### 3.2 The Knowledge on Biophilia, Biophilic Design, Bio-inspired and Bio-design was Analysed

The Table 2 below shows the mean for responses regarding the level of agreement on having the natural and biological elements indoor. Responses close to a mean value more than 1.000 would indicate the level of agreement by respondents. Question 1 to 6 is designed to have an agreement response while 7 and 8 a disagreement response. Question 1 to 6 shown a level of agreement as the mean value is more than 1.000 respectively. However, Question 7 indicates of 0.500 to 1.000 value which is close to neither Agree nor Disagree. Also, the disagreement level tends towards the negative side for the opinion that having natural/biological elements indoors might be dangerous and inconvenient. The respondents disagree with Question 8 on having the natural biologicals indoor is dirty or time consuming with a -0.100 Mean value.

**Table 2.** The analysis of Mean value on the level of agreement on having the natural and biological elements indoor

Working Background		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Non design	Mean	1.1915	1.2447	1.3750	1.2421	1.2000	1.2917	0.6526	-0.1667
	N	94	94	96	95	95	96	95	96
	Std. Dev	0.85856	0.71371	0.66886	0.72517	0.76631	0.76663	0.93135	1.13013
Design	Mean	1.0806	1.2787	1.5082	1.1639	1.1613	1.2258	0.3226	-0.1774
	N	62	61	61	61	62	62	62	62
	Std. Dev	1.10585	0.91526	0.53613	0.77847	0.70580	0.66331	0.86412	1.01665
Total	Mean	1.1474	1.2581	1.4268	1.2115	1.1847	1.2658	0.5223	-0.1709
	N	156	155	157	156	157	158	157	158
	Std. Dev	0.96255	0.79641	0.62228	0.74496	0.74094	0.72637	0.91698	1.08371

The Mann-Whitney test has verified the significance value Question 7 (Having natural and biological elements indoor can: E. be dangerous and inconvenient, as in the case of allergies) which has significantly different responses, i.e. Sig. Value (below 0.05) with 0.015Asymp. Sig. (2-tailed) value as highlighted in yellow in Table 3 below.

**Table 3.** The Non-Parametric test for the level of agreement on having the natural and biological elements indoor

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
<b>Mann-Whitney U</b>	2908.00	2617.00	2655.50	2752.50	2807.00	2737.50	2309.50	2966.50
	0	0	0	0	0	0	0	0
<b>Wilcoxon W</b>	4861.00	7082.00	7311.50	4643.50	4760.00	4690.50	4262.50	4919.50
	0	0	0	0	0	0	0	0
<b>Z</b>	-0.024	-1.014	-1.120	-0.591	-0.561	-0.947	-2.444	-0.035
<b>Asymp. Sig. (2-tailed)</b>	0.981	0.311	0.263	0.555	0.575	0.344	0.015	0.972

**a. Grouping Variable: Working Background**

Relating to the question in the respondent background section on nature experience, 42.4% of participants preferred to experience both – outdoor and indoor – and this information can be used to support these findings on how natural elements or biological materials affected them in daily life. Moreover, the connections of the Q1 to Q8 with the preferences of respondents regarding spending their time in nature, shows the ANNOVA test has a significant value for *Question 6. Having natural and biological elements indoor can: D. be educational (especially for children)* with 0.022 Sig. Value (below 0.05) in Table 4 below.

**Table 4.** The analysis of ANNOVA relating to experience nature (outdoor and indoor) with preferences of biological elements indoor.

ANOVA		Sum of Squares	df	Mean square	F	Sig.
Q6. Having natural and biological elements indoor can: D. be educational (especially for children)	Between Groups	3.977	2	1.988	3.908	.022
	Within Groups	78.859	155	.509		
	Total	82.835	157			

The Mann-Whitney test was done for the preferences on nature experience (comparing outdoor and both – indoor and outdoor – experiences), to see the connection of having the biological elements indoors. The test has verified the significance value for *Question 2 (It is important to have biological elements indoors?)*, *Question 3 (Having natural and biological elements indoor can: A. release stress/calm)*, *Question 4 (Having natural and biological elements indoor can: B. create awareness of nature and ecological impact)*, *Question 5 (Having natural and biological elements indoor can: C. foster a sense of care (as living organisms need to be watered or fed))*, and *Question 6 (Having natural and biological elements indoor can: D. be educational (especially for children))*

which have significant responses, i.e. Sig. Value (below 0.05) with 0.041, 0,017, 0.005, 0.47 and 0.007, asymp. Sig. (2-tailed) value respectively, as highlighted in yellow in Table 5 below.

**Table 5.** The Non-Parametric test for the level of agreement on having the natural and biological elements indoor within the preferences on nature experience

	Test Statistics <sup>a</sup>							
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Mann-Whitney U	2763.500	2333.000	2342.000	2193.500	2423.500	2276.000	2846.500	2485.500
Wilcoxon W	6504.500	6161.000	6170.000	6021.500	6339.500	6192.000	6674.500	4763.500
Z	-.471	-2.042	-2.380	-2.797	-1.990	-2.703	-.265	-1.730
Asymp. Sig. (2-tailed)	.638	.041	.017	.005	.047	.007	.791	.084

a. Grouping Variable: Experience nature

This part of the question is using a Yes/No format represented by the values 1/0. Table 6 below shows the mean values regarding the knowledge on biophilia, biophilic design, bio-inspired and bio-design. The overall responses for biophilia, biophilic design are ranging around a value of 0.4 which is closer to No, whereas the overall responses for Bio-inspired and Bio-design are around 0.7 which is closer to Yes. In this way, Question 9 and 8 indicate that half of the respondents may not have any knowledge on biophilia and biophilic design.

**Table 6.** The analysis of Mean value on the knowledge on biophilia, biophilic design, bio-inspired and bio-design

Working background		Q9: Do you know what Biophilia is?	Q10: Do you know what Biophilic design is?	Q11: Do you know what Bio-inspired design is?	Q12: Do you know what Bio-design is?
Non design	Mean	0.3438	0.3333	0.6979	0.6170
	N	96	96	96	94
	Std. Dev	0.47745	0.47388	0.46157	0.48872
Design	Mean	0.5484	0.6129	0.7903	0.7581
	N	62	62	62	62
	Std. Dev	0.50172	0.49106	0.41040	0.43175
Total	Mean	0.4241	0.4430	0.7342	0.6731
	N	158	158	158	156
	Std. Dev	0.49577	0.49832	0.44318	0.47060



Table 7 below shows the descriptive and frequency analysis. The non-design group has negated the question on biophilia and biophilic design with a percentage of 65.5% and 66.7%. However, the design group seems to be familiar with the terms biophilia and biophilic design where 54.8% and 61.3% answered with Yes. Both groups confirmed the questions on bio-inspired design and bio-design with a minimal percentage of more than 61%.

**Table 7.** The descriptive and frequency analysis of the knowledge on biophilia, biophilic design, bio-inspired and bio-design

Working background			Q9: Do you know what Biophilia is?		Q10: Do you know what Biophilic design is?		Q11: Do you know what Bio-inspired design is?		Q12: Do you know what Bio-design is?	
			Freq	Valid %	Freq	Valid %	Freq	Valid %	Freq	Valid %
Non design	Valid	No	63	65.6	64	66.7	29	30.2	36	38.3
		Yes	33	34.4	32	33.3	67	69.8	58	61.7
		Total	96	100.0	96	100.0	96	100.0	94	100.0
Design	Valid	No	28	45.2	24	38.7	13	21.0	15	24.2
		Yes	34	54.8	38	61.3	49	79.0	47	75.8
		Total	62	100.0	62	100.0	62	100.0	62	100.0

The Mann-Whitney test has verified the significance value of the questions regarding knowledge on biophilia and biophilic design with a Sig. Value (below 0.05) with 0.011 and 0.001 Asymp. Sig. (2-tailed) value as highlighted in yellow in Table 8 below.

**Table 8.** The Non-Parametric test for the knowledge of on biophilia, biophilic design, bio-inspired and bio-design

	Q9: Do you know what Biophilia is?	Q10: Do you know what Biophilic design is?	Q11: Do you know what Bio-inspired design is?	Q12: Do you know what Bio-design is?
<b>Mann-Whitney U</b>	2367.000	2144.000	2701.000	2503.000
<b>Wilcoxon W</b>	7023.000	6800.000	7357.000	6968.000
<b>Z</b>	-2.533	-3.443	-1.280	-1.832
<b>Asymp. Sig. (2-tailed)</b>	0.011	0.001	0.201	0.067
<b>a. Grouping Variable: Working Background</b>				

Finally, Question 13 was designed in open-ended format, allowing respondents to share their opinion on biological materials embedded in product design. Listed in Table 9 are the corresponding answers. The comments received by the potential consumers were divided into four sections which are a) Positive responses, b) Neutral responses, c) Negative responses, and d) Other selected responses. Positive responses are relating to the potential consumer emotions concerning products embedding biological materials. Obviously, positive reactions are associated with terms such as 'love', 'good', 'really

**Table 9.** The opinion on biological materials embedded in product design

Q13: Your opinion on biological materials embedded in product design	
<b>Positive responses – relating to emotions etc.</b>	
• I love it	• Good
• Really good	• Excellent
• Good	• Fantastic!
• Good idea	• Good
• Ok	• Interesting
• Interesting	
<b>Neutral responses</b>	
• No preference	• Neutral but I won't buy it
<b>Negative responses</b>	
• No	
<b>Other selected responses – relating to products etc.</b>	
I think it's the future	
It is good for people nowadays living in an apartment or for indoor worker	
Good innovation where the natures and lifestyle meet	
Very artistic like Batik design	
I think using biological materials embedded in product design shows creativity, gives value-added to the product and as a symbol of therapy	
I'd only purchase them if it were valuable to the product	
I love the idea; nature knows a lot more than we do. But it makes me nervous	
I think the most important aspect is context of the product that we design for. If it suits the space aesthetic, yea why not. Like indoor garden office or restaurant. But product for common home seems impractical	
They are usually aesthetically appealing and have the ability to biodegrade without use of any external energy	
(I) hope that sharing your experience will help teachers and senior researchers disseminate useful concepts and real examples of biomimetic principles and tools for the development of new materials, new/improved design and fabrication strategies, and innovation methodologies	
A positive way to utilise and research on other purposes of the vast biological materials available in nature. A very interesting subject particularly involving the material properties in finished products	
Desirable as nowadays more and more people living in a small place and yet still need for biological material which are convenient and easy to be taken care of inside their house/room- to balance their emotion/stress & to relax	
It can be one way of creating awareness of nature conservation and its benefits to our living	
Needs to be more commonplace, without being intrusive	
I think it's important to explore the intersection of the natural world with the man-made world and how we can live a more environmentally conscious life to be more connected with ourselves and with nature. It is important for humans physical and mental health, as well as being important for the preservation of our natural world	
Sense of connection with the nature	
An excellent way to appreciate nature and reduce stress at home and the work place	
The incorporation of biological materials in product design is for environmentally-conscious people. It has appeal to educated people, but not for people who prioritize practicality over aesthetic functions	

good', 'ok,' 'excellent', 'fantastic!', and 'interesting'. The neutral responses consist of reactions such as 'No preference' and 'Neutral but I won't buy it'. Negative responses tend towards the 'No' answer.

Other selected responses are relating to products which are associated with positive opinions regarding products embedded with biological materials. Related opinions are for example, that those products are positive in terms of lifestyle, supporting creativity and sustainability, for therapeutic purposes and stress reduction, improving the atmosphere in an apartment (also in terms of limited space availability) or office environments. An interesting opinion is also that these approaches might be primary appealing to educated people, but not for people who prioritize practicality over aesthetics. ~~Acting participants~~ conclusion of this section are the following two comments:

- ‘(I) hope that sharing your experience will help teachers and senior researchers disseminate useful concepts and real examples of biomimetic principles and tools for the development of new materials, new/improved design and fabrication strategies, and innovation methodologies.’
- ‘A positive way to utilise and research on other purposes of the vast biological materials available in nature.’

The respondent feedback on the incorporation of biological materials with their knowledge on the bio-related design genres was identified and a cross-comparison analysis was performed. Table 10 below shows the analysis of the findings gathered based on the working background (design and non-design). The results have shown that some of the respondents know at least one bio-related design genre. For positive design responses, two respondents do not know any of the bio-related design genres. Others at least responded to one genre, for example, bio-inspired design. For neutral responses, one respondent knows all bio-related topics, and the other one does not know any of these terms. Respondents with negative response only knew about bio-inspired design. Other selected responses – relating to products etc. – also responded to at least one design genre. These findings show that – although some people are not familiar with bio-related design genres – they can relate to the advantages of incorporating biological elements into everyday products or merely integrating biological elements into indoor living spaces. These results also show a strong, affecting outcome in terms of those who were aware of biophilia and also the acceptance of having biological elements as standard part to be included in everyday living. It is also interesting to find that some respondents from design background do not have any knowledge on the bio-related design genre, and people from non-design are more aware of the “environmental” topic.

**Table 10.** The Cross-comparison analysis on the opinion on biological materials embedded in product design with the knowledge on bio-related design genres

Cross-comparison analysis between the opinion and knowledge on bio-related design genres					
Responses or opinion received	Q9	Q10	Q11	Q12	Working background
<b>Positive responses – relating to emotions etc.</b>					
I love it	Yes	Yes	Yes	Yes	Design
Really good	No	No	Yes	No	Non-design
Good	No	No	No	No	Design
Ok	Yes	Yes	Yes	Yes	Non-design
Good	No	No	Yes	Yes	Non-design
Excellent	Yes	Yes	Yes	Yes	Non-design
Fantastic!	No	No	Yes	Yes	Design
Good idea	No	No	Yes	Yes	Non-design
Good	No	No	No	No	Non-design
Interesting	Yes	Yes	Yes	Yes	Design
Interesting	No	No	No	No	Non-design
<b>Neutral responses</b>					
No preference	Yes	Yes	Yes	Yes	Non-design
Neutral but I won't buy it	No	No	No	No	Non-design
<b>Negative responses</b>					
No	No	No	Yes	No	Non-design
<b>Other selected responses – relating to products etc.</b>					
I think it's the future	No	Yes	Yes	Yes	Design
It is good for people nowadays living in an apartment or for indoor worker	Yes	No	Yes	Yes	Design
Good innovation where the natures and lifestyle meet	Yes	Yes	Yes	Yes	Non-design
Very artistic like Batik design	No	No	Yes	Yes	Non-design
I think using biological materials embedded in product design shows creativity, gives value-added to the product and as a symbol of therapy	Yes	Yes	Yes	Yes	Non-design
I'd only purchase them if it were valuable to the product	No	Yes	Yes	Yes	Design
I love the idea, nature knows a lot more than we do, but it makes me nervous	No	No	Yes	No	Design
I think the most important aspect is context of the product that we design for. If it suits the space aesthetic, yea why not. Like indoor garden office or restaurant. But product for common home seems impractical	Yes	Yes	Yes	Yes	Design
They are usually aesthetically appealing and have the ability to biodegrade without use of any external energy	Yes	Yes	Yes	Yes	Design
(I) hope that sharing your experience will help teachers and senior researchers disseminate useful concepts and real examples of biomimetic principles and tools for the development of new materials, new/improved design and fabrication strategies, and innovation methodologies	Yes	Yes	No	No	Design
A positive way to utilise and research on other purposes of the vast biological materials available in nature. A very interesting subject particularly involving the material properties in finished products	Yes	No	Yes	Yes	Non-design
Desirable as nowadays more and more people living in a small place and yet still need for biological material which are convenient and easy to be taken care of inside their house/room- to balance their emotion/stress & to relax	Yes	Yes	Yes	Yes	Non-design
It can be one way of creating awareness of nature conservation and its benefits to our living	Yes	Yes	Yes	Yes	Design
Needs to be more commonplace, without being intrusive	Yes	No	Yes	No	Non-design

(continued)

**Table 10.** (continued)

Cross-comparison analysis between the opinion and knowledge on bio-related design genres					
Responses or opinion received	Q9	Q10	Q11	Q12	Working background
I think it's important to explore the intersection of the natural world with the man-made world and how we can live a more environmentally conscious life to be more connected with ourselves and with nature. It is important for humans physical and mental health, as well as being important for the preservation of our natural world	No	No	No	Yes	Design
Sense of connection with the nature	Yes	Yes	Yes	Yes	Non-design
An excellent way to appreciate nature and reduce stress at home and the work place	No	Yes	Yes	Yes	Design
The incorporation of biological materials in product design is for environmentally-conscious people. It has appeal to educated people, but not for people who prioritize practicality over aesthetic functions	Yes	Yes	Yes	Yes	Non-design

## 4 Conclusions and Outlook

The exploration and usage of biological materials allow the consumers to understand the basic needs regarding the interaction with/emotions and behaviour towards natural surroundings and their elements. The study was conducted using an online survey to investigate the knowledge towards biophilia, biophilic design, bio-inspired and bio-design.

From the findings, the background of the participants was analysed to investigate the difference between design or non-design background. Thirteen questions were asked for this section. The respondents agreed with Questions 1 to 6 which means that they like to have biological materials in the house, they think it is important to have biological elements indoors, that natural elements can release stress/calm, create awareness of nature and ecological impact, can foster a sense of care, and can be educational (especially for children). However, Question 7 – if it is dangerous and inconvenient to have biological elements in the house – could not be decided. The respondents disagree to Question 8 asking if natural and biological elements indoors are dirty or time-consuming. Moreover, the connection of the preferences of experiencing nature (whether outdoor or both, indoor and outdoor) towards the preferences on having the biological elements indoors was proven to be significant based on our survey. This could be the reason why participants seem to favour or agree in integrating biological materials into indoor environments.

For the knowledge on biophilia, biophilic design, bio-inspired and bio-design questions, the non-design group has knowledge on biophilia and biophilic design with a percentage of 65.5% and 66.7% respectively, whereas most of the design and non-design group claim to be familiar with the term bio-inspired and bio-design. Based on the cross-comparison analysis, there is also an interesting finding that participants (with design as well as non-design background) are widely affirmative regarding incorporating biological elements in everyday products and living spaces.

This study is part of an ongoing larger research project on emotional design and perception toward biological materials in everyday products (Sayuti and Ahmed-Kristensen 2020). Therefore, future work on, e.g., the study of emotional responses, identification of purposes, as well as ownership regarding biological products will be presented in upcoming publications (Sayuti et al. 2020). This project can also be explored further with the use of real living biological materials and embedded into existing products to

investigate the direct experience of living materials to gather results that provide more emotional layers while also enhancing the consumers' experience. The application of natural or biological elements in everyday products shows strong potential to be further explored in design disciplines, such as industrial design and product design engineering. These disciplines can help to develop and open up new market opportunities for more innovative and productive bio- or nature-inspired designs which promote and encourage interaction, communication, empathy, emotional connection and awareness towards the importance of human-nature-symbiotic relationship for future nature preservation.

Moreover, the significant threats of the vast usage and overconsumption of natural resources are encouraging the growing awareness to alleviate the problems of non-renewable resources exhaustion by incorporating biological materials as alternate options.

## References

- Albaum, G.: The Likert scale revisited: an alternate version. *J. Mark. Res. Soc.* **39**(2), 331–332 (1997)
- Arvay, C.G.: The biophilia effect: a scientific and spiritual exploration of the healing bond between humans and nature. Sounds True, Canada (2018)
- Balling, J.D., Falk, J.H.: Development of visual preference for natural environments. *Environ. Behav.* **14**(1), 5–28 (1982)
- Bartczak, C., Dunbar, B., Bohren, L.: Incorporating biophilic design through living walls: the decision-making process. *Construct. Green. Soc. Struct. Sustain.* **307** (2013)
- Collin, P.: *Dictionary of Environment & Ecology*, 5th edn. Bloomsbury Publishing Plc (2004)
- Eckardt, M.H.: Fromm's humanistic ethics and the role of the prophet. *A Prophetic Analyst: Erich Fromm's Contributions to Psychoanalysis*, pp. 151–165 (1996)
- Frumkin, H.: Beyond toxicity: human health and the natural environment. *Am. J. Prev. Med.* **20**(3), 234–240 (2001)
- Grinde, B., Patil, G.G.: Biophilia: does visual contact with nature impact on health and well-being? *Int. J. Environ. Res. Public Health* **6**(9), 2332–2343 (2009)
- Gunawardena, K., Steemers, K.: Living walls in indoor environments. *Building and Environment* (2018)
- Gruber, P., Bruckner, D., Hellmich, C., Schmiedmayer, H.-B., Stachelberger, H., Gebeshuber, I.C.: *Biomimetics- Materials, Structures and Processes: Examples, Ideas and Case Studies*. Springer, Heidelberg (2011)
- Hoffman, W.D.: Major depression and integrative medicine. *Integr. Med. Clin. J.* **14**(6) (2009)
- Howell, A., Dopko, R., Passmore, Holli-Anne., Buro, K.: Nature connectedness: associations with well-being and mindfulness. *Pers. Ind. Differ.* **51**(2), 166–171 (2011). <https://doi.org/10.1016/j.paid.2011.03.037>
- Huelat, B.J.: The wisdom of biophilia-nature in healing environments. *J. Green Build.* **3**(3), 23–35 (2008)
- Johns, R.: Likert items and scales. Survey question bank: methods fact sheet **1** (2010)
- Johnson, N.: Biophilic design benefits (2014). [https://www.architectureanddesign.com.au/features/features-articles/why-biophilic-architecture-works-five-reasons-and?mid=7603c81e3d&utm\\_source=Cirrus+Media+Newsletters&utm\\_campaign=9a3dbdbe88-Architecture+and+Design+Newsletter+-+201&utm\\_medium=email&utm\\_term=0\\_fe913f1856-9a3dbdbe88-59078485](https://www.architectureanddesign.com.au/features/features-articles/why-biophilic-architecture-works-five-reasons-and?mid=7603c81e3d&utm_source=Cirrus+Media+Newsletters&utm_campaign=9a3dbdbe88-Architecture+and+Design+Newsletter+-+201&utm_medium=email&utm_term=0_fe913f1856-9a3dbdbe88-59078485). Accessed 2014

- Kaplan, S.: The restorative benefits of nature: toward an integrative framework. *J. Environ. Psychol.* **15**(3), 169–182 (1995)
- Kellert, S.R., Heerwagen, J., Mador, M.: *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life*. Wiley, Hoboken (2008)
- Magnan, R.A.: *Discover Bio-design Thinking: Adopting Visual Images to Transform Our Information Processing Abilities*. Xlibris Corporation (2018)
- Matell, M.S., Jacoby, J.: Is there an optimal number of alternatives for Likert-Scale items? Effects of testing time and scale properties. *J. Appl. Psychol.* **56**(6), 506 (1972)
- Montana-Hoyos, C.: *BIO-ID4S: Biomimicry in industrial design for sustainability*. VDM-Germany (2010)
- Mehrabian, A., Russell, J.A.: The basic emotional impact of environments. *Percept. Mot. Skills* **38**(1), 283–301 (1974)
- Myers, W.: *Bio design: nature, science creativity*. Revised and expanded version. Thames and Hudson (2018)
- O’Haire, M.: Companion animals and human health: benefits, challenges, and the road ahead. *J. Vet. Behav. Clin. Appl. Res.* **5**(5), 226–234 (2010)
- Parsaee, M., Demers, C.M., Hébert, M., Lalonde, J.F., Potvin, A.: A photobiological approach to biophilic design in extreme climates. *Build. Environ.* **154**, 211–226 (2019)
- Rosenbaum, M.S., Ramirez, G.C., Camino, J.R.: A dose of nature and shopping: the restorative potential of biophilic lifestyle center designs. *J. Retail. Consum. Serv.* **40**, 66–73 (2018)
- Sayuti, N.A.A., Montana-Hoyos, C., Bonollo, E.: A study of furniture design incorporating living organisms with particular reference to biophilic and emotional design criteria. *Acad. J. Sci.* **4**(1), 75–106 (2015)
- Sayuti, N.A.A., Ahmed-Kristensen, S.: *Biological Understanding, Emotional Responses and the Fifth International Conference on Design Creativity (ICDC2020)*. University of Oulu, Finland (2020)
- Sayuti, N.A.A., Sommer, B., Ahmed-Kristensen, S.: Identifying the purposes of biological materials in everyday designs. *Environ.-Behav. Proc. J.* **5**(15). Accepted. Conference on AMEABRA International Virtual Conference on Environment-Behaviour Studies, 2nd Series (2020). <https://amerabra.org/aivce-bs-2-2020shahalam/>
- Sayuti, N.A.A., Montana-Hoyos, C., Bonollo, E.: Biophilic design: why do designers incorporate living organisms in furniture design? In: *Conference Proceeding, the Fifth International Conference on Design Creativity (ICDC2018)*. University of Bath, UK (2018)
- Simaika, J.P., Samways, M.J.: Biophilia as a universal ethic for conserving biodiversity. *Conserv. Biol.* **24**(3), 903–906 (2010)
- Terrapin Bright Green: *14 Patterns of biophilic design: Improving health & well-being in the built environment*. New York, USA (2012)
- Terrapin Bright Green: *The Economic of biophilia: why designing with nature in mind makes financial sense*. New York, USA (2014)
- Thorpe, A.: *The Designer’s Atlas of Sustainability*. Island Press (2007)
- Ulrich, R.S.: Natural versus urban scenes some psychophysiological effects. *Environ. Behav.* **13**(5), 523–556 (1981)
- Wilson, E.O.: *Biophilia*. Harvard University Press (1984)
- Yin, J., Zhu, S., MacNaughton, P., Allen, J.G., Spengler, J.D.: Physiological and cognitive performance of exposure to biophilic indoor environment. *Build. Environ.* **132**, 255–262 (2018)