BIOMIMICRY FOR SUSTAINABILITY:
AN EDUCATIONAL PROJECT IN SUSTAINABLE PRODUCT DESIGN

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ABSTRACT

BIOMIMICRY FOR SUSTAINABILITY: AN EDUCATIONAL PROJECT IN SUSTAINABLE PRODUCT DESIGN

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The notion of sustainability has become an extensive area of research ever since the term emerged in the late 1980s, due to the negative effects of unsustainable production and consumption patterns on environmental stewardship, social equity and economic development. There have been various approaches developed for product design and education within the context sustainability. Biomimicry is one of those approaches, and its implications for product design education have recently started to be explored. In this study, an educational tool - Biomimicry Sketch Analysis (BSA) - was developed and integrated into the idea-generation phase of an educational design project at the undergraduate level in the Department of Industrial Design at the Middle East Technical University (METU). This integration is analyzed throughout the graduate thesis study, to understand and explore the implications of the biomimicry approach for sustainability in product design education. The educational tool within this approach was found as influential among the third year industrial design students for the idea-generation phase, yet the results of this study included both pros and cons for the incorporation of the BSA exercise.

Keywords: biomimicry, sustainable production and consumption, product design and development process, design education, idea-generation tool

ÖZ

SÜRDÜRÜLEBİLİRLİK İÇİN BİYOMİMİKRİ:
SÜRDÜRLEBİLİR ÜRÜN TASARIMI EĞİTİMİNDE BİR EĞİTİM PROJESİ

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Sürdürülebilir olmayan üretim ve tüketim şekillerinin çevresel yönetim, sosyal eşitlik ve ekonomik gelişme üzerindeki olumsuz etkileri nedeniyle, sürdürülebilirlik kavramı, oluştuğu 1980'li yılların sonundan itibaren kapsamlı bir araştırma alanı haline geldi. Sürdürülebilirlik anlayışı içinde ürün tasarımı ve eğitimi için birçok yaklaşım geliştirildi. Biyomimikri, sürdürülebilirlik kapsamında yer alan ürün tasarımı yaklaşımlarından biri olarak tasarım eğitimine dahil edilmesi yeni incelenmeye başlanmıştır. Bu çalışmada, Biyomimikri Skeç Analizi (BSA) olarak adlandırılan eğitim aracı Orta Doğu Teknik Üniversitesi (ODTÜ), Endüstri Ürünleri Tasarımı Bölümü'nde geliştirilmiş ve lisans düzeyinde bir tasarım eğitim projesinin fikir geliştirme aşamasına dahil edilmiştir. Sürdürülebilirlik için biyomimikri yaklaşımının ürün tasarımı eğitimindeki etkilerini anlamak ve incelemek amacıyla bu süreç lisansüstü tez çalışması boyunca analiz edilmiştir. Üçüncü yıl endüstri ürünleri tasarımı öğrencileri için, çalışmaya konu olan eğitim aracının fikir geliştirme aşamasında etkili olduğu gözlenmiştir ve aynı zamanda bu çalışmanın sonuçları, BSA'nın sürece dahil edilmesinin hem olumlu hem de olumsuz yönlerini içermektedir.

Anahtar kelimeler: biyomimikri, sürdürülebilir üretim ve tüketim, ürün tasarım ve geliştirme süreci, tasarım eğitimi, eğitim aracı

To nature, offering everything it can regardless of how we treat it

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CHAPTER I

INTRODUCTION

The ways humans produce and consume have been affecting the world dramatically ever since the industrial revolution. The mass-produced goods along with the mass-consumption of those goods have been depleting and contaminating the planet's resources.

With the industrial revolution, the mass-production was introduced to the world as a way to increase both efficiency and profit. This revolution based on time and material optimization of producing goods, eventually led towards a societal change transformed by the mass-consumption. People, currently to a greater extent, not being able produce things for themselves, yet purchase what they need, created a system of mass-production accompanied by mass-consumption, mutually benefiting from this coupling. The expanding need of production for ever-growing consumption led towards styling, competitive marketing, and rapid aesthetic and technical obsolescence of mass-produced products, while on the other hand, it demanded speed-in-producing over all of them (i.e. styling, marketing and obsolescence).

The system has seemed to be working perfectly, until its impacts on the environment have become visible such as climate change and the depletion of the resources. Nature, taught to be endless until then, proved to be limited as a resource and this also proved to have life-threatening consequences (e.g. carbon emission, contamination of soil, water and air, depletion of non-renewable resources) for all life on the planet. As Carson points out, "Given time - time not in years but in millennia - life adjusts, and a balance has been reached. For time is the essential ingredient; but in the modern world there is no time" (1962, p. 6). The system, up until then relied on speed and efficiency, was suddenly challenged by other aspects, such as ecological impacts. That is how the term eco-design has surfaced, to create environmental efficiency (i.e. eco-efficiency) in producing goods.

Eco-design was an attempt to preserve the resources (i.e. renewable or non-renewable) in nature through addressing the current system of production and consumption. It was not long until the eco-efficiency proved to be insufficient to prevent ecological impacts by itself, since there appeared to be other aspects affecting our environmental stewardship: social wellbeing and economic feasibility. With the realization of these aspects, it has become possible to think of a world with a sustained environment, an economical balance and a socially-equitable global community. This is how the term sustainable development surfaced, to create a balance among these aspects, so people are able to live in this world, as well as the next generations.

Within the practice of industrial design, sustainable development has proved to be an important responsibility, so as to be emphasized as a task of industrial designer on the website of International Council of Societies of Industrial Design (ICSID): "Enhancing global sustainability and environmental protection." With respect to that, there have been many approaches towards sustainable production and consumption considering the design profession. Biomimicry has become one of them with the motto of "innovation inspired by nature" (Benyus, 1998).

Biomimicry, a term emerged approximately fourteen years ago, proved to have the potential as an approach leading towards sustainability. Looking at nature, beyond being merely a resource source, as a model, measure and mentor for the production of people's needs, was an idea towards sustainable development, and a reasonable one as nature has been a sustainable system for over 3.8 billions of years.

As an idea-generation approach, biomimicry has the potential to be influential towards environmental stewardship, as well as sustainability as a whole. Incorporating this approach within the realm of industrial design is a newly emerging area yet to be discovered further. There are a few practical successes in product design practice (i.e. i2 carpet by Interface explained in Section 2.3.3), supporting the biomimicry's application for product innovation regarding environmental stewardship that needs to be further explored in the realm of product design for sustainability.

1.1. Problem Definition

As an approach for sustainability, biomimicry constitutes the potential to help achieve sustainable development. Taking nature, an established sustainable system, as a mentor and a rich source of inspiration through observing its models, systems, and processes, could help in

the pursuit of sustainable development, not only in environmental stewardship, but also in economical and social aspects as well. Yet, the implications of biomimicry approach for sustainable product design education have not been fully explored.

There are pros and cons for integrating biomimicry into the idea generation phase of the product design and development process, such as the interdisciplinary nature, the lack of biology knowledge and the inability of analyzing that knowledge, etc. The interdisciplinary nature of biomimicry, which adds up biology (i.e. knowledge about nature) to an already saturated interdisciplinary nature of industrial design, is an issue to be further explored. The observation and analysis of nature requires skills that industrial design students lack, since the processes behind the sustainable system of nature has been examined either under the microscope or through long-term observation phase of the living organisms. The newly-developing interdisciplinary methodologies (e.g. biomimicry spirals, biologists at design table, etc.) have not been currently incorporated into the industrial design (ID) education.

In addition to these, product design for sustainability highlights alternative paths for production and consumption which needs to be solved through reconsidering existing social and economical systems within the context of the ecological system regarding nature as a limited resource. Thus, sustainable development requires solutions affecting our social and economical system for which nature may have solutions, yet cannot be achieved just by mimicking its models and systems. Biomimicry has to be re-evaluated and integrated into product design education, keeping these aspects of sustainability in mind.

1.2. Aim and Objectives of the Study

Considering the implications of biomimicry for sustainable product design education, this research aims to incorporate this approach into the idea generation phase of the product design and development process within the context of design education. In order to achieve that, the research examines an educational industrial design project carried out in the Department of Industrial Design at the Middle East Technical University (METU). The project was developed by the studio team of ID301 Industrial Design III course. In this study, a tool called Biomimicry Sketch Analysis (BSA) exercise was developed and integrated into an educational design project to understand and explore the implications of the biomimicry approach for design education to achieve sustainable design considerations.

Based on this education project, the research has been conducted with a focus on the integration of the biomimicry approach into the idea-generation phase of the design process includes the following purposes:

- To examine the emerging and evolving biomimicry approach, and its methods and tools for product design education for sustainability.
- To examine the outcomes of a biomimicry application - in the form of the Biomimicry Sketch Analysis exercise and its implications for the idea generation phase of an educational design project for sustainability from the students' and instructors' points of view.
- To provide suggestions for theoretical-yet-applicable improvements in terms of the integration of biomimicry into the product design education for sustainability.

1.3. Research Questions

The main research question is:

- What are the implications of integrating biomimicry into the idea generation phase of the product design and development based on a design education case for sustainability?

The secondary research questions are:

- What are the challenges that industrial design students face during the incorporation of a biomimicry analysis and idea generation tool into a design project?
- What are the pros and cons of this integration in terms of the design process and design concepts?
- What are the instructors' points of view on the integration of biomimicry into an educational design project?

1.4. Structure of Thesis

This thesis includes five chapters:

Chapter 1 constitutes a brief introduction, the problem definition, the aim and objectives of the study, and presents the research questions.

Chapter 2 includes the literature review that starts with exploring the area of sustainability, and presents literature review findings on sustainable development, approaches towards sustainable production and consumption, and approaches on product design for sustainability. It continues with presenting the biomimicry approach, its place among the approaches on product design for sustainability, and the methods and tools it offers for product design. This chapter concludes with an exploration of the biomimicry approaches for sustainable design education.

Chapter 3 summarizes the research methods and tools used for this study, focusing on qualitative research methods - i.e. semi-structured interviews, content analysis, and thematic coding and analysis. In this chapter, the development the Biomimicry Sketch Analysis (BSA) exercise and the integration of it into an educational design project are explained in detail. It continues with the methods and tools used for exploring this integration, such as the analysis of the BSA outcomes in project phases and the semi-structured interviews with students and instructors.

Chapter 4 starts with the pilot study findings, and mainly focuses on the integration of the BSA exercise into the third year educational design project carried out in the Department of Industrial Design at METU. In particular, the structure of the project and the educational tools at the idea-generation phase -i.e. BSA exercise, Matrix exercise and Task exercise - are explained, the results of semi-structured interviews and the analysis of the BSA outcomes in project phases are presented. The chapter continues with various student cases to understand and present the implications of the biomimicry approach for sustainable product design education, afterwards, presents the interview results for the instructors. This chapter concludes with overall findings and conclusions from the primary research.

Chapter 5 presents and summarizes the overall conclusions and findings of the study by revisiting the research questions and discusses the implications for further research.

CHAPTER 2

LITERATURE REVIEW

Considering the main area of this research, which is the biomimicry approach and its implications for sustainable product design and education, the necessity of taking into consideration a holistic approach and exploring the relationships between the three aspects - i.e. sustainability, biomimicry, product design and education- arises. Thus, this chapter presents the findings from the literature review starting with the exploration of sustainable development along with its context, and various approaches for product design and education within the area of sustainability. Later, the biomimicry approach in relation to product design for sustainability, along with various approaches in education that utilizes the biomimicry approach, will be explained.

2.1. Introduction

During the early periods, humans had the ability to have an impact on their surroundings, nature, mainly for their existence. Firstly, their needs were for food, shelter, security, etc. and their impact to some extent was minimal, yet later on they proved their intelligence by inventing means of reshaping their environments for their well-being. This reshaping of the environment was done by considering and utilizing nature as a rich source of raw materials (both renewable and non–renewable), and after the industrial revolution this process has became a rapid extraction of raw materials from nature, causing urging problems from the environmental pollution to the depletion of natural resources.

In 1962, Rachel Carson addressed the issue of contamination and pollution of the environment in her book Silent Spring, through an example of an imaginary town in the United States, and the changes it went through in the modern world. Her book focused on the use of pesticides and its inevitable effects on nature, and she pointed out that humans' desire to control their

surroundings has reached beyond what their minds could perceive. In her words (Carson, 1962, p.8):

> Future historians may well be amazed by our distorted sense of proportion. How could intelligent beings seek to control a few unwanted species by a method that contaminated the entire environment and brought threat of disease and death even to their own kind?

The environmental pollution is not the only issue lying behind our mistreatment of nature, let alone usage of pesticides. The issue is much more dramatic, hidden in the way humankind is depleting these resources. We have been exceeding reproductive capabilities of the planet Earth since 1970. In the Ecological Footprint Atlas 2010, it has been stated that the humanity as a whole is consuming double the amount of the Earth's reproductive capacity by the year 2007 (Edwig et al, 2010). This data is highly concerning in the fact that, authors, scientists, academicians, etc. have been trying to attract attention to a global exploitation of nature, yet it is still prevailing. The basic fact is, humankind is using double the amount of Earth is reproducing as well as contaminating the resources through turning these into waste. This is why the humankind is on a quest towards a sustainable world,

Today, there are various approaches towards sustainable development around the world, approaching these concerns from different perspectives. Biomimicry is one of them, introducing the motto of "innovation inspired by nature" (Benyus, 1997). Following its emergence as a term, biomimicry has been adopted for various applications in product design and engineering, to find solutions to a wide-range of human problems. Considering its potential for sustainable product design, this research aims to explore its implications for design education for sustainability.

2.2. Sustainable Development

In 1987, the World Commission on Environment and Development (WCED) released a report on the issue of humankind's coexistence with nature, affecting the Planet Earth's way of working, thus creating life-threatening situations in the long run (e.g. contamination of renewable resources, depletion of non-renewable resources, climate change, etc.), whose affects have already started to be seen. The report, commonly known as Our Common Future, defined the term of 'sustainability' as "...meeting our needs without jeopardizing the potential of future generations" explaining all the concerning situations the Planet Earth is in

(p.43). In the past 25 years, many authors have been defining sustainability using three key aspects: environmental, economic and social, as Walker (2008, p.26): "a type of development that simultaneously takes into consideration three key sets of issues: economic development, ethical and social concerns, and environmental stewardship."

In 1992, as a result of the United Nations Conference on Environment and Development, the Rio Declaration on environment and development was published consisting of 27 principles on the notion of sustainable development. Addressing various concerns on global level, some of those principles on three key aspects were:

- 4. In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.
- 8. To achieve sustainable development and a higher quality of life for all people, states should reduce and eliminate unsustainable patterns of production and consumption, and promote appropriate demographic policies.
- 12. States should cooperate to promote a supportive and open international economic system to better address the problems of environmental degradation.
- 23. The environment and natural resources of people under oppression, domination and occupation shall be protected.

(Rio Declaration on environment and development, 1992)

As stated in the declaration, the environmental protection is at the centre of sustainable development, yet economic development of developing countries and social equity between countries are also crucial for sustainable development. According to the Climate Research Unit in the UK, the 2001-2012 decade has been the warmest one since 1850, containing nine years (all years of the decade except 2008) in the warmest ten years list (Jones, 2012). In 2007, the biocapacity of the planet has been consumed and exceeded by nearly double the amount (18 billion gha[1] against 11.9 gha) and the United States and China are responsible for consuming 21 and 24 percent of the Earth's biocapacity respectively, and only 10 countries in total are consuming more than half of it (Edwig et al, 2010). These numbers support the fact that, in twenty years following Rio Declaration, the progress towards the achievement of sustainable development with respect to environmental stewardship and social equity is still further away, and this is also acknowledged in the outcome document of the United Nations Conference on

1." The Ecological Footprint calculates the combined demand for ecological resources wherever they are located and presents them as the global average area needed to support a specific human activity. This quantity is expressed in units of global hectares (gha), defined as hectares of bioproductive area with world average bioproductivity" (Edwig *et al*., 2010, p. 11).

Sustainable Development in 2012, namely "The Future We Want":

> "We acknowledge that since 1992 there have been areas of insufficient progress and setbacks in the integration of the three dimensions of sustainable development, aggravated by multiple financial, economic, food and energy crises, which have threatened the ability of all countries, in particular developing countries, to achieve sustainable development" (The Future We Want, 2012, p.4) .

Unsustainable patterns of production and consumption posing critical issues need to be rethought in achieving sustainable development. They should be reconsidered and transformed properly, considering the three key aspects of sustainable development (Rio Declaration, 1992). Unsustainable means of production and consumption have been fueled by the industrial revolution as a direct result of the global industrial economy: "The ability to over-exploit the Earth's stoned-up supply of resources is what we call economic progress" (Hawken, 1993, p.21). Humankind has adopted a linear approach on nature and its resources: "They extract, convert and throw away" (Ternaux, 2011, p.52).

Within the current industrial system, relying on mass-production as an efficient way of reshaping and serving goods to humanity, and a resultant occurring of mass-consumption of those goods, have been considered as a development in humans' quest on shaping their environment. However, as Hawken suggests, the outcomes and the implications of this development have not been visible as "we do not realize what a powerful and destructive impact our demanding capacity is having" (1993, p.26). That fact still prevails as the prerequisite of mass-production, the division of labor, is still predominantly supporting mass-consumption. Mass-production still has the potential in creating a more efficient way of production, yet what we are facing right now is humans' detachment from the consequences of their doings - e.g. externalized production and consumption, and its environmental and social impacts (Walker, 2008, p.27).

The current system of production and consumption is being challenged by sustainable development, as the current approach in fact assumes unlimited growth as opposed to limited resources in question (Fuad-Luke, 2009, p.23). This brings about the terms of "efficiency" and "sufficiency". In order to achieve a sustainable world, the use of energy and materials can be reduced by increasing their efficiency, and current quality of life can be sustained and, maybe, even improved (Meadows et al, 1992, p.140). On the other hand, even though such innovations on efficiency reduce the environmental impacts and economic costs, "it may not

lead to sustainable development as long as consumption continues to increase" (Cooper, 2005, p. 59).

2.2.1. Sustainable Design and Its Approaches

In the past forty years, various tools and approaches towards sustainable development have emerged, illustrating the multifaceted nature of sustainability concerns (Chapman, 2005, p.6). Now the challenge of sustainable development is to reconsider our current daily needs and wants, and imagine alternative paths to achieve sustainability within the places, spaces, and systems existing today (Walker, 2008, p.28). In addressing this challenge, there are different approaches and tools developed to achieve sustainable production and consumption. In Figure 2.1., the ones related to product design are divided into three: life-cycle assessment and eco-design, sustainability and systems thinking, and product design for sustainability.

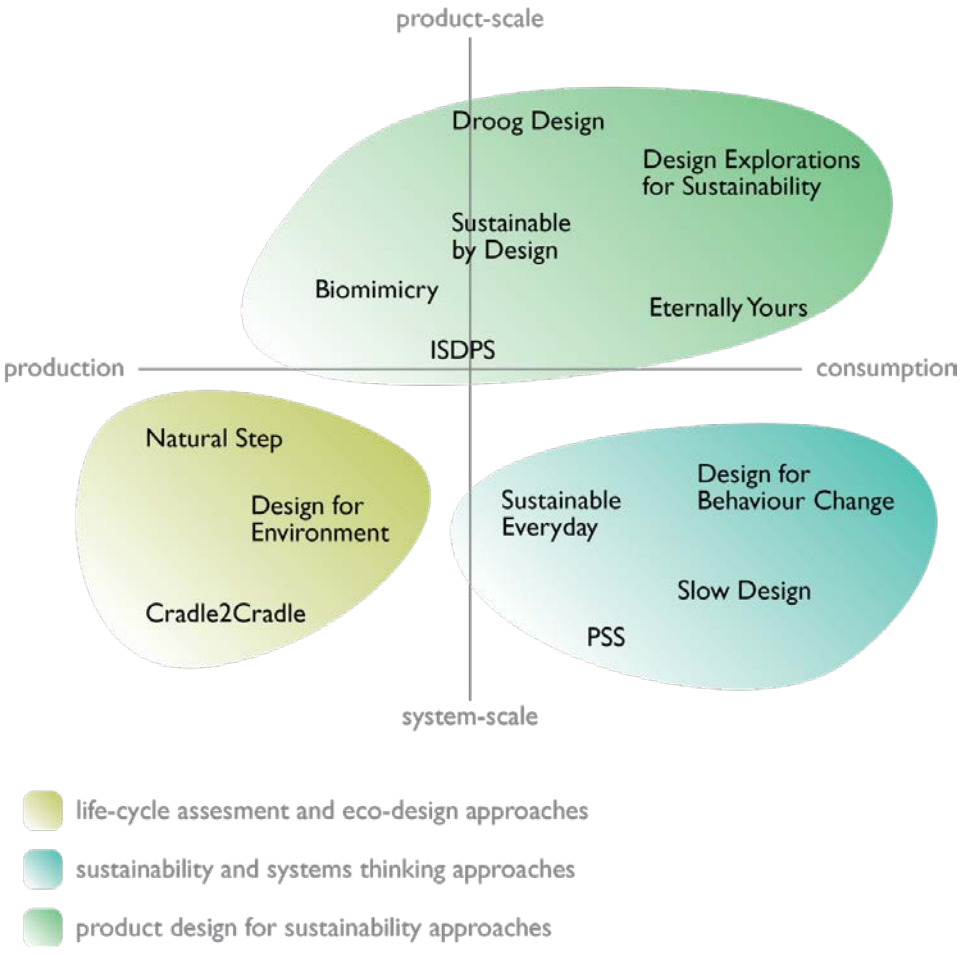

Figure 2.1 - Approaches for sustainable production and consumption.

Life-cycle assessment and eco-design approaches are mainly focusing on the quantification of the environmental impacts of a product or a system throughout its whole life-cycle from designing to discarding, and the improvements to reduce the environmental impacts of that product or system (e.g. from the extraction and processing of resources to production and disposal). Sustainability and systems thinking-based approaches are about designing and emphasizing social aspects of design-and-production systems to achieve sustainable means of consumption and production. Product design for sustainability approaches are about designing on product scale, focusing more on the way products are designed and used through rethinking them to achieve sustainability.

In Table 2.1, the approaches are placed within their respective groups with a description for each of them, and the ones focusing on products themselves in the context of sustainable production and consumption will be explained in the following section.

Table 2.1. Approaches to Sustainable Production and Consumption.

life-cycle assessment and eco-design

Cradle to Cradle

'Cradle to Cradle' is an approach towards separating resources used for production into technical and biological 'nutrients', and aims at each of those nutrient groups having their own close loop cycles. By achieving the respective close loops of industrial and natural systems, the approach aims at eliminating waste by turning it into a resource for production (McDonough, & Braungart, 2002).

Design for Environment

Design for Environment aims at creating products and processes throughout the life cycles of them, with respect to sustainability considerations (i.e. environmental stewardship, safety and well-being of humans, and sustainability of natural resources) (Fiksel, 2009).

Natural Step

Founded by Karl-Henrik Robert, in 1989, in Sweden, the Natural Step is a non-profit organization striving to achieve four system conditions for a sustainable society: no excessive extraction of natural resources, no use of unnatural, man-made toxic materials, no environmental degradation through overharvesting, or other modifications, and the ability to meet human needs worldwide (Robert, 2002, p.65).

sustainability and systems thinking

Product Service Systems (PSS)

Product Service Systems (PSS) is an innovative business model which proposes the replacement of products by systems of products and services to fulfill consumer needs and preferences. Through PSS; it is aimed to achieve higher added value and less environmental

Table 2.1.Approaches for Sustainable Production and Consumption (continued).

impact than the current products generating (Manzini & Vezzoli, 2002).

Slow Design

Slow Design is a holistic approach to creative thinking, processes and outcomes, envisioning positive impacts of designed products, environments and systems, on humans and environment (slowlab.net). The approach encourages "a slower, more considered and reflective process" through constructively critiques the current processes and technologies (Fuad-Luke, 2009, p.22). In this case, slowness does not refer to the time spent, rather describes an expanded state of awareness, accountability for daily actions, and the potential towards a wider-ranged experience for individuals and communities.

Sustainable Everyday

Sustainable Everyday is an approach for developing future scenarios in the context of urban life. It considers what everyday life might be in a sustainable society, and proposes sustainability scenarios about ways of life and well-being criteria accordingly. It suggests that such scenarios are important in perceiving the notion of sustainability, which is significant in the process of sustainable development (Manzini & Jegue, 2003).

product design for sustainability

Biomimicry

Biomimicry is an approach towards considering nature as model, measure and mentor, rather than just a material resource. It proposes that by observing and inspiring from nature to solve human problems, sustainable innovation can be achieved (Benyus, 1997).

Design Explorations for Sustainability

Design Explorations for Sustainability is an approach to achieve transition from obsolete products to useful objects of aesthetic interest, through the re-contextualization of them (Marchand and Walker, 2007). The approach aims reconcile various polarities such as, old and new, valued and unvalued, craft and mass-produced, and diversity and unity (Marchand and Walker, 2007).

Droog Design

Droog Design, a contemporary Dutch design company founded in 1993, challenges the present material culture through design ideas on sparing use of resources, recycling and deliberate lack of styling (Ramakers, 2002). Droog Design takes Mies van der Rohe's motto 'less is more' one step forward, and offers designs that are 'less and more' (Ramakers, 2002).

Eternally Yours

Eternally Yours, founded by a group of Dutch industrial designers in 1995, in an approach towards elongating life-spans of products. It focuses on the psychological life-span of products, since it highlights the problem of the discarding of products no matter how well

Table 2.1. Approaches for Sustainable Production and Consumption (continued).

functioning they are (Verbeek et al, 1998). ISDPS Integrated Scales of Design and Production for Sustainability (ISDPS) is an approach emphasizing local and regional diversity through introducing greater localization and enabling post-use at the local-batch production scale (Dogan, 2007). Sustainable by Design Sustainable by Design is an approach criticizing the conventional means of designing and producing, and the current notion of aesthetics through design explorations. These explorations by Stuart Walker are designs of everyday functional objects designed with a combination of mass produced parts with locally produced components, reused and recontextualised materials and objects (Walker, 2006).

2.2.2. Approaches on Product Design for Sustainability

2.2.2.1. Droog Design

Droog Design is a contemporary design firm founded in 1993 in the Netherlands. By that time, the idea was to present the works of young Dutch designers and their unique ideas on sparing use of resources, recycling of materials, deliberate lack of styling, etc. (Ramakers, 2002, p.6).

The motto of Droog Design, as stated by Ramakers, is "less and more" indicating that, the outcomes of Droog Design projects are taking Mies van der Rohe's motto 'less is more' a step further by bringing less and more together (2002, p.7).

An example of this approach through design can be seen in Function Tiles (Figure 2.2) by Arnout Visser, Erik Jan Kwakkel and Peter van der Jagt (1997). Designers redefine the bathroom environment through the needs of user, and offers solutions for bathroom accessories by utilizing the already existing surfaces - i.e. bathroom tiles.

The approach of Droog Design on environmental sustainability is straight-forward and effective. Ramakers indicate that, "Recycling simply has to be done. Some designers saw the environment and its attendant issues of disposability and planned obsolescence, as a new source of inspiration" (Ramakers et al. 1998, p.39). This attitude can be seen in Tejo Remy's Rag Chair (1991) produced by repurposing of materials, which is a critique of excessive consumption. The chair consists of different used cloth pieces, or rags, that are held together by belts to create a chair form (Figure 2.3).

Figure 2.2 - Function Tiles, designed by Arnout Visser, Erik Jan Kwakkel and Peter van der Jagt (retrieved and adapted on August 08, 2012, from: http://drooglab.com/projects/spaces/dry-bathing/function-tiles-by-arnout-visser--erik-jan-kwakkel--peter-van-der-jagt/).

Figure 2.3 - Rag Chair, designed by Tejo Remy (reproduced from Remakers et. al., 1998).

2.2.2.2. Eternally Yours

Founded in 1995, *Eternally Yours* is an approach against rapid disposal of products designed to be discarded after a short period of time no matter how well-functioning they are (Verbeek et al, 1998, p.29). *Eternally Yours* believes that there are four possible directions to achieve

sustainable production and consumption: shifting from products to services, eco-design, recycling, and elongating life-spans of products. The last one, elongating life-spans, is what Eternally Yours is concerned about the most. As Thackara indicates: "An apparently simple question - how do we increase the durability of products? - proved, upon examination, to be complex and multi-dimensional" (Van Hinte, 1997, p.14). Thus Eternally Yours includes people from different backgrounds to work on the problem.

The change is pointed out as from 'form follows function' to 'form follows fun' regarding this as a problem beyond product obsolescence (Verbeek et al., 1998, p.32). The reasons for the unsustainable consumption patterns of humans are not based on the technical or economical issues, but rather a psychological effect.

What is suggested by the approach is not a nostalgic turn-back towards leather and wood as materials, but a total review of products and services to support product life-span longevity, and be open to every possible path that can achieve that (Van Hinte, 1997, p.20-21).

2.2.2.3. Design Explorations for Sustainability

Design explorations for sustainability is an attempt towards research through design - where designers become researchers as well, and use the act of designing as a means of research - to "allow a transition from technologically and/or aesthetically obsolete products to useful objects that are of aesthetic interest and in line with the economic, social and environmental principles of sustainability" (Marchand & Walker, 2007, p. 1).

The emphasis of the design explorations by Marchnand & Walker (2007) is on creating a family of objects through re-contextualization of objects. The examples are a family of diverse drinking glasses with applied red dots (Figure 2.4), and a family of diverse cutlery pieces with red coated handles (Figure 2.5) designed by Anne Marchand. These exploratory designs aim to "reconcile various polarities": old and new, valued and unvalued, craft and mass-production, custom and standard, local and global, and diversity within unity (Marchand & Walker, 2007, p.4). By doing so, these examples explore "the issues of sustainability, premature end-of-life and elevation of objects through building new connections between objects by building new connections between objects and contexts" (Marchand & Walker, 2007).

Figure 2.4 - Family of drinking glasses with red dots by Anne Marchand (reproduced from Marchand, 2008).

Figure 2.5 - Family of cutlery pieces with red handles by Anne Marchand (reproduced from Marchand, 2008).

2.2.2.4. ISDPS

Integrated scales of Design and Production for Sustainability (ISDPS) is "an approach that recognizes the benefits of mass-produced uniformity and the benefits of local and regional diversity" (Doğan, 2007, p.1). The approach aims to raise the effectiveness of localization of design, production and post-use, through integrating it with mass-production. An introduction of greater 'localization' is key to the approach and the term 'localization' refers to batch production scale offering design solutions for diverse user tastes, needs and preferences, and local and regional levels of post-use services (i.e. repair, reuse, recovery, refurbishment) (Doğan, 2007).

The concept proposes blurring the lines between scales of design and production (i.e. local craftsmanship, batch-production, and mass-production), thus allowing variety and divergence

with the same design concept, and enabling adaptability and flexibility via design details and connections (Doğan, 2007, p.103).

Doğan (2007) presents various design explorations developed and produced by bringing together locally made parts with mass-produced ones. The 'Black Lamp' which is locally assembled using mass-produced parts (Figure 2.6) - or with a combination of mass and locally produced parts (Figure 2.7) - shows the integration of various scales of design and production. The locally adopted mass-produced parts can be maintained and replaced locally, thus promotes product longevity with post-use services achieved through localization of those services (Doğan, 2007, p.102).

Figure 2.6 - Black Lamp by Çağla Doğan- made out of glass jar, woman's stockings and electrical parts (reproduced from Doğan, 2007).

Figure 2.7 - Black Lamp by Çağla Doğan- made out of glass jar, hand-woven fabric, ceramic lid and electrical parts (reproduced from Doğan, 2007).

2.2.2.5. Sustainable by Design

In his book, Sustainable by Design, Walker (2006) explores various sustainable design considerations by challenging the conventional ways of designing and producing as well as the current notion of aesthetics through design experiments. He suggests,

> "A product which bears the marks of time and use and its own history could, potentially, have a richness lacking in many of today's squeaky clean but rather barren products; but to appreciate this richness we will have to readjust our value system and our expectations of product aesthetics." (Walker, 2006, p.81)

He criticizes the lack of post-use processing - i.e. repair, refurbishment, redistribution, retrieval of materials and components - in most consumer products due to the economical concerns, and obsolescence created by notions of aesthetics and styling (Walker, 2006). Thus, the design explorations that he presents, challenge these problems with respect to various sustainable design considerations -i.e. inventiveness of necessity, improvisation and spontaneity, energy use, local manufacture, and integration of scales (Walker, 2006).

Arc Light by Stuart Walker (Figure 2.8) is an exploration towards inventiveness of necessity, requiring minimum use of resources and energy to produce, and off-the-shelf parts that can be reused after their service in the product.

Figure 2.8 - Arc Light by Stuart Walker (reproduced from Walker, 2006).

Another exploration by Stuart Walker, on product upgrading and maintenance, is the 'pouch Phone' concept (Figure 2.9). It proposes a single fabric wrap to contain loosely connected components of a mobile phone, instead of a rigid enclosure. This flexible wrap does not constrain inclusion of new parts by allowing incremental upgrade through time and eliminating

the disposal of whole products, and it concludes in discarding just the obsolete parts. On the other hand, the individual components can be replaced easily when they reach their end-of-life.

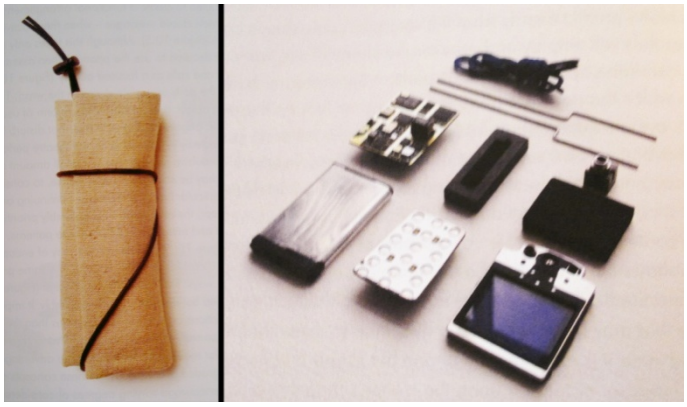

Figure 2.9 - Pouch Phone by Stuart Walker (reproduced from Walker, 2011).

2.2.3. Design Considerations for Sustainability

The current material culture has developed through the notion of obsolescence and people have moved towards considering everything a throwaway item considering all consumer goods and human values to be disposable (Papanek, 1985, p.87). Papanek offers the introduction of two design considerations regarding this matter: the price of the object reflecting its ephemeral character and the act of disposing of the item (Papanek, 1985, p.94).

Regarding the consumption patterns of the society Papanek wrote in his book (1985), the current unsustainable material culture that is rooting for the new and shiny and resulting in product obsolescence (aesthetic and technical) and individual dissatisfactions has to be challenged in the process of sustainable development (Chapman, 2005, p.18).

The approaches explained in the previous section present certain design considerations for sustainability, i.e. recycling, reuse, localization, post-use services, product longevity, etc. These considerations are thought to be crucial in achieving product design within the context of sustainable production and consumption, and are in the process of developing a sustainable material culture. These considerations can be summarized as follows:

- *Enabling post-use services* (e.g. product maintenance, repair, upgrading) at the local scale.
- *Integration across scales* of design and production to introduce greater localization.

- *Aesthetic appeal and diversity*, adaptable to local and regional resources and skills.
- *Transparency* and *authenticity* on 'what the object is' - enabling user comprehension and participation.

(Walker, Marchand, Doğan, 2009, p.485)

Biomimicry, on the other hand, constitutes similar considerations for sustainability (i.e. be locally attuned and responsive, evolve to survive, adapt to changing conditions) within its framework (i.e. Life's Principles), and within the context of this thesis, the biomimicry approach is regarded as a way to innovate towards post-use services like product maintenance, repair and upgrading within the context of sustainability. In the next section, the biomimicry approach will be explained in detail along with its implementation into sustainable product design processes.

2.3. Biomimicry

Biomimicry is an approach for innovation in product development which was introduced by Janine Benyus in her book 'Biomimicry: Innovation Inspired by Nature' (1997). Biomimicry means the examination of nature and its models, systems, processes and elements to emulate, or take inspiration from, to solve human problems. As an approach, it regards nature as a source of inspiration and/or a library waiting to be explored. Benyus explains (1997, p. i) the approach in three main points:

- Nature as Model - studying nature and inspiring from its designs and processes to solve human problems.
- Nature as Measure - an ecological standard to judge the 'rightness' of our innovations.
- Nature as Mentor - a new way of viewing and valuing nature, not what we can extract from but what we can learn from.

In her interview published in the book titled, "Industry of Nature", Benyus explains the emergence of the term 'biomimicry' as a unifying name for approaches towards emulating nature that has been in progress by different individuals around the world (Ternaux, 2011, p. 33). It is possible to see attempts of biomimicry long before the term has become prominent. Velcro invented by George de Mestral in 1941 (Velcro.co.uk, n.d.) is an example to that. By examining the difficulty of removing mountain thistle from his dog's fur, George de Mestral developed Velcro as a fastening system (Figure 2.10, below).

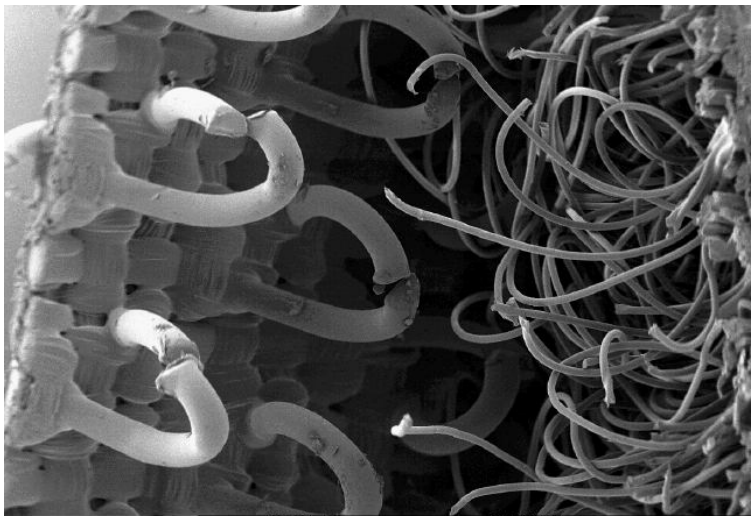

Figure 2.10 - Close-up of Velcro hooks and loops (retrieved from http://get-your.free-mind-map-training.com/images/Velcro.jpg, on 28.07.2012).

Biomimicry has been regarded as an innovative approach to develop solutions in the engineering field. The aim of biomimicry is explained as "to bring together different disciplines - biology and engineering - for product development" (Yen & Weissburg, 2007). To implement biomimicry as an idea-creation approach for innovation, and as discussed in this thesis, for sustainability and design education, it needs to be further explored.

2.3.1. Biomimicry for Sustainability

Inspiring from nature to solve human problems is an act that has been going on ever since the early periods. Leaves with water accumulated in them inspired bowls or mugs, or claws of animals inspired knives and other tools. The very foundation of our basic notions of aesthetics comes from nature, as "nature is the one touchstone all human beings relate and respond to" (Macnab, 2012, p. xv).

Biomimicry is an act of conscious emulation of nature. The species have to adapt to differentiating environments that also forced them towards finding solutions for changing conditions. Realizing nature as an extensive source of information, it is possible to find solutions to various human problems, which the living has probably faced before and adapted to. As Benyus indicates: "After 3.8 billion years of research, failures are fossils, and what surrounds us is the secret to survival" (Benyus, 1997, p.3).

Benyus suggests that there is an inherent sustainability while using biomimicry, beyond novelty, due to the limitations in resource use that organisms face (Benyus, 2011, p. 35). The effectiveness of using resources is to be seen in the inspired/emulated products as well. Apart from that, observing nature and learning from its systems are regarded as logical, since nature is an example of an industry with complete mastery of sustainable development (Ternaux, J. P., 2011).

Unruh mentions biomimicry as a "more sophisticated offshoot of industrial ecology approach" and as a developed version of life-cycle assessment based approaches (Unruh, 2010, p. xiii). On the same topic, Reap (2009) suggests that "biomimicry, the way it is used, offers reductionism in raw material, energy, waste, etc." and criticizes narrowing the use of biomimicry, as a tool for solving particular problems, to the conceptual and embodiment phases of design. He suggests, by doing so, the applicability of biomimicry in the realm of environmental sustainability is limited as well, thus he offers a more holistic approach in re-imagining whole systems via the biomimicry approach.

2.3.1.1. Life's Principles

Life's Principles is a framework of sustainability developed by Biomimicry Guild and InnovationSpace at ASU in 2009, as an evaluation tool for the sustainability of products developed. The Life's Principles (Figure 2.11, below) present the overarching patterns found amongst species surviving and thriving on Earth, starts with two statements: life adapts and evolves, and life creates conditions conducive to life (Isle & Leitch, 2010).

This framework indicates six points that are needed to be followed to achieve sustainability, inspired by nature (i.e. patterns found among species). These points are: evolve to survive, be resource efficient, adapt to changing conditions, integrate development with growth, be locally attuned and responsive, and use life-friendly chemistry.

These points are in relation with the design considerations of sustainability mentioned in the previous section - i.e. enabling post-use services and integrating scales. Yet, the Life's Principles is a tool developed for the evaluation of the sustainability of products, thus the integration of it as the basis of design considerations has not been explored yet.

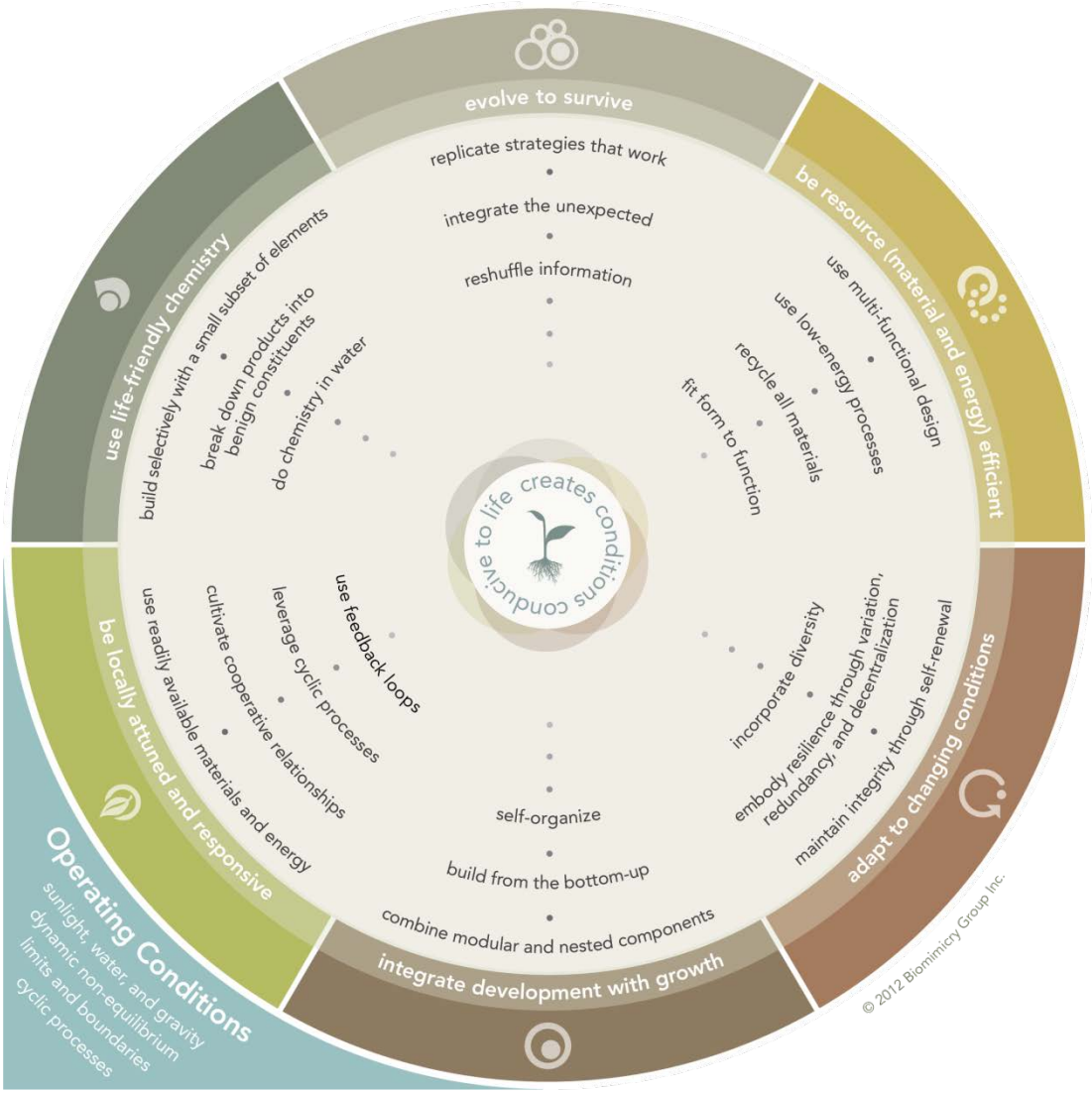

Figure 2.11 - Life's Principles Framework (adapted from http://static.biomimicry.org/wp-content/uploads/2012/04/lifes_principles_v5.png , on 28.07.2012).

2.3.2. Biomimicry for Sustainability in Product Design

The integration of biomimicry into the design process assumes two main approaches. Badarnam (2009) explains them as follows:

- Defining a design problem and then referring to the nature's way of solving it.
- Defining a behavior or function in nature and transform it into a design.

These approaches are referred to as Biomimicry Design Spirals (Macnab, 2012, p.210), individually named 'challenge to biology' (Figure 2.12) and 'biology to design' (Figure 2.13), including the steps below.

- Identifying - developing a design brief of the need and identifying the core problems
- Interpreting - *biologizing* the question, asking the questions from nature's perspective
- Discovering - looking at natural processes and organisms that have the answer to those questions
- Abstracting - finding the repeating patterns and processes within nature that achieves success
- Emulating - developing ideas and solutions based on natural models
- Evaluating - comparing the ideas developed to life's principles

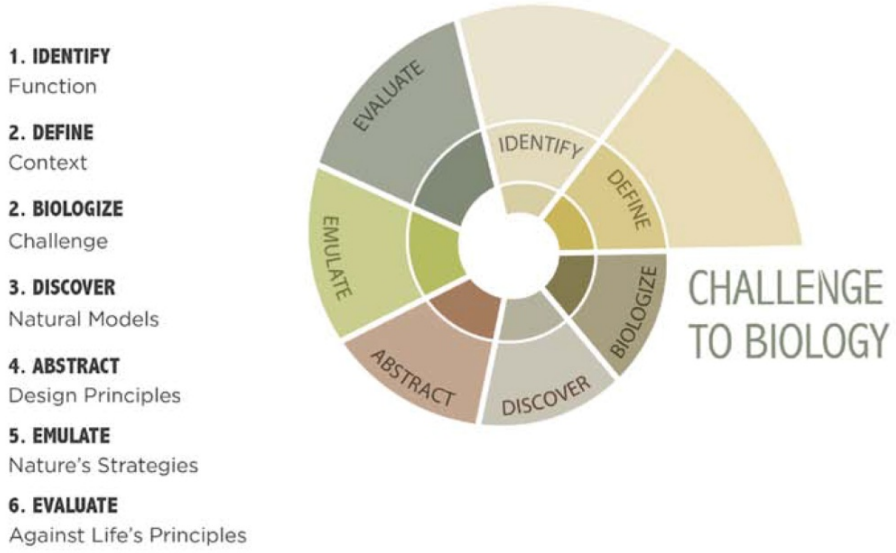

Figure 2.12 - Biomimicry Design Spiral - Challenge to Biology (reproduced from Macnab, 2012).

Figure 2.13 - Biomimicry Design Spiral - Biology to Design (reproduced from Macnab, 2012).

This thesis focuses on the first approach 'challenge to biology', as it follows a design process developed for educational purposes (see Section 3.3.1). Designers are by and large responsible for finding solutions based on an already defined design brief, or at least a particular design challenge. Considering this approach (challenge to biology) certain challenges arise due to the interdisciplinary nature of the biomimicry approach. This interdisciplinary nature "presents complications that counter-balance its considerable potential" (Yen & Weissburg, 2007).

The main problem in integrating biology knowledge into the design process is the lack of in-depth biology knowledge of practitioners. Design practice already constitutes an interdisciplinary nature. Not being a specialist on a specific material, technique or sector, designer creates the links between objects, flows of information, symbols, etc. and the tools and methods of biomimicry are now being appropriated to the design process as well (Ternaux, J. P., 2011). These tools and methods (e.g. biomimicry design spirals, biologists at the design table, etc.) require certain knowledge on nature, and on the perception and interpretation of nature.

Regarding the key aspect of biology knowledge, various tools and techniques were proposed. One of them is 'biologists at the design table' as a consultancy-based approach. It proposes biologists to be participated in the design process and interpret nature's solutions for design problems. The consultants are explained as biologists, who are able to translate nature's strategies to meet the design challenges at hand, who are trained in biomimicry design methodology and helpful during the development of products, and who contribute to the design process from brainstorming to prototyping with continuous addition of biological insight (Biomimicryguild.com, n.d.).

Asknature.org is another tool proposed considering the challenges towards incorporating the biology knowledge. It is a free, open-source project, built as an online inspiration source for natural systems and organisms. It aims to bridge the gap between biologists who want to share information on nature and designers, architects, engineers, etc. who want to make use of such information emerged from nature to develop solutions (Benyus, n.d.). It is a systematic approach to classify natural systems and organisms through strategies inspired by nature. In order to achieve that, the website offers a Biomimicry Taxonomy, through which the strategies that are of interest can be found, and the examples of natural systems and organism can be reached. Figure 2.14 is a reproduced image of the Biomimicry Taxonomy that focuses and highlights the strategies utilized in this research.

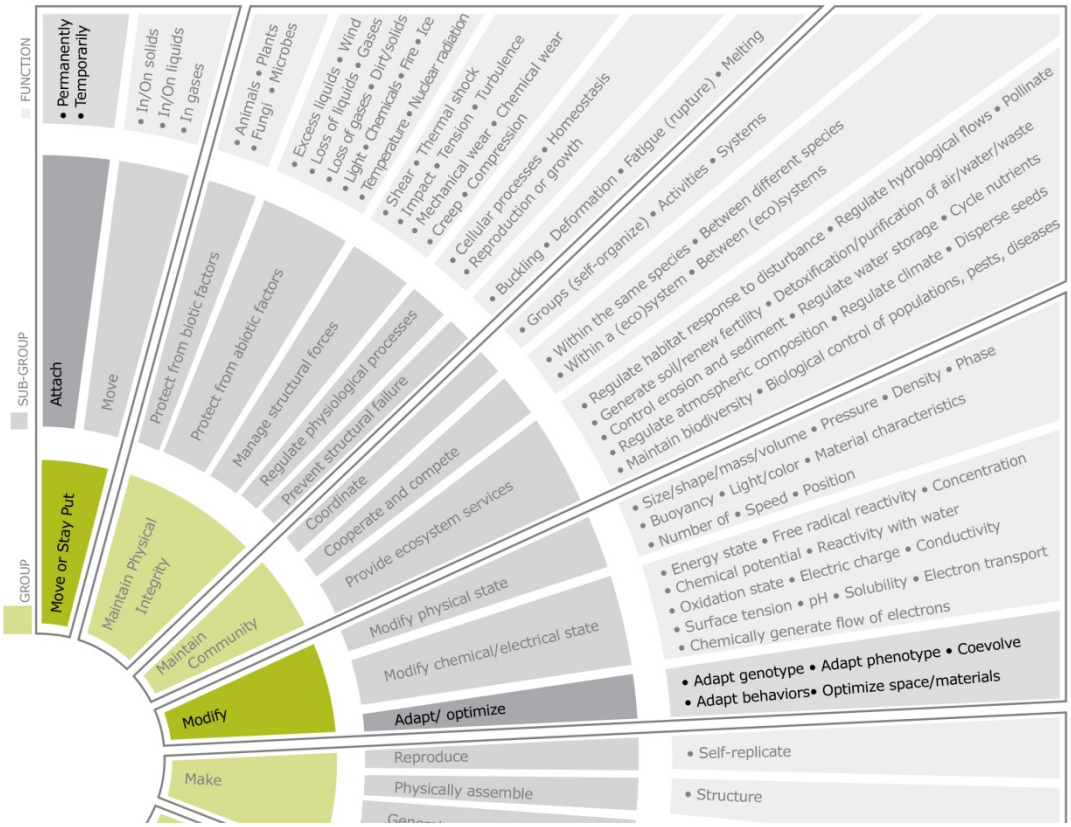

Figure 2.14 - Biomimicry Taxonomy with highlighted strategies (retrieved and adapted on July 31, 2012, from http://ben.biomimicry.net/curricula-downloader/?filename=Biomimicry-Taxonomy_V5.pdf).

A more subtle tool for design student and potentially for product designers, called Biomimicry Sketch Analysis (BSA) was developed in the Department of Industrial Design at METU to learn and inspire from nature through hands-on observations, and to translate them into design ideas within the context of the project at hand. The BSA tool will be explained in more detail and with examples in the following chapters (Chapter 3 and 4).

2.3.3. Biomimicry Case - the Interface "i2" Carpet Line Story

InterfaceFLOR is a company founded in 1970s, and introduced carpet tiles to the United States. The carpet tiles, invented by the Heguetile company in Europe in 1955, is an innovative approach for the installation of carpet floors (Interface History, n.d.). When the founder and chairman of InterfaceFLOR company, Ray Anderson, became interested in sustainability, he set up a meeting with the designers of the company and Janine Benyus, to create a new series of carpet tiles that were environmentally sustainable.

The story began with the question of how would nature make a floor, and through the workshop conducted with the InterfaceFLOR designers by Janine Benyus, the designers were led to a forest area to observe and find a solution to the problem. Fallen leaves on the forest floor captured the attention of the designers, and it was realized that, there was a uniformity of slightly different colors and shapes on the forest floor (Innovators, Episode 3, 2011). Figure 2.15 might be helpful in visualizing what they observed. This realization led towards creating slightly different carpet tiles that creates a harmony when brought together. This approach is very similar to the one that Marchand (2008) refers to as *continuity in diversity*.

Figure 2.15 - Inspiration source for Entropy Carpet - dead leaves accumulated on the forest floor (retrieved on November 14, 2012, from http://www.asknature.org/product/a84a9167f21f1cc690e0e673c4808833).

Although it was an innovative idea in modular carpet tiles, its effectiveness on environmental sustainability was realized later. At first, it was referred as "a leap in manufacturing process" by John Bradford, since the conventional manufacturing processes were about producing identical replicas and the question was about manufacturing carpet tiles with different patterns (Innovators, Episode 3, 2011). Yet, upon slight changes in production process, the production of Entropy carpet (Figure 2.16) resulted in savings of material and labor (Ternaux, 2012, p.191) as there was no need for checking if the produced parts were perfect matches (Innovators Episode 3, 2011) or the ends of the carpet rolls could be used as carpet tiles (Innovators, Episode 3, 2011).

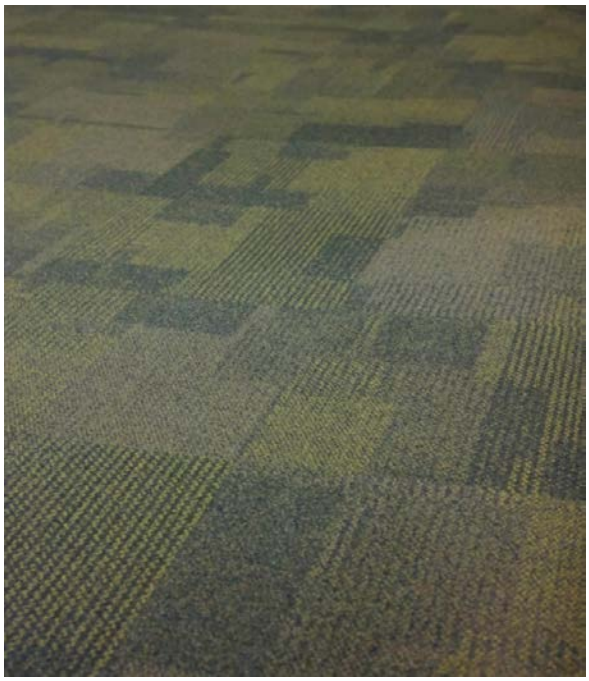

Figure 2.16 - Entropy Carpet by Interface (reproduced from Ternaux, 2011).

The advantages of the design idea other than the ones at the production phase were on the installation of the carpet tiles and the post-use services for repairing and maintenance. There was no need to check for matching joins, or even a direction, in the installation of the carpet (Ternaux, 2012, p.119) and only the old and broken tiles could be replaced by the new ones without losing the uniformity of the carpet floor, as the color and shape of the replaced tiles would not outshine the other tiles (Innovators, Episode 3, 2011).

The Entropy carpet design process is an example of the 'challenge to biology' approach of biomimicry. Table 2.2 shows the steps taken during the design process of the Entropy carpet.

Table 2.2 - 'Challenge to Biology' Steps for Entropy Carpet.

Identifying to design a carpet with reduced environmental impact
Interpreting "how would nature make a floor?"
Discovering accumulated fallen leaves on the forest floor

Table 2.2 - 'Challenge to Biology' Steps for Entropy Carpet (cont.).

Abstracting slightly different colors and forms create uniformity on the forest floor Emulating creating tiles that are different from each other, yet constitutes similar colors and patterns Evaluating resource efficient (less waste, less labor in production and installation), adapting to changing conditions (by replaceable parts)

As can be seen in Table 2.2, the Entropy carpet case constitutes positive outcomes regarding the sustainability considerations - i.e. enabling post-use services, aesthetic appeal and authenticity. Although the biomimicry approach did not aim to achieve these outcomes through design *per se*, the result enabled them.

In the next section, the focus of thesis regarding sustainable design education (SPD), i.e. the implications of the biomimicry approach for sustainable design considerations, will be explained within the context of SPD approaches around the world.

2.4. Design Education for Sustainability

Education for Sustainable Development (ESD) is an integral part of movement towards a sustainable future, as it is crucial to educate future generations with the awareness of current environmental, social and economic issues. UNESCO has named the time period between 2005 and 2014 as 'the United Nations Decade of Education for Sustainable Development' (DESD) with the aim of integrating principles of values and practices of sustainable development into all aspects of education and learning in order to address the social, economic, cultural and environmental issues that are facing in the 21st century (UNESCO, 2005).

As discussed earlier, design as a profession has its share of responsibility towards sustainable production and consumption, regarding environmental, social and economic considerations. Papanek, in his book Design for the Real World (1985), criticizes the course the industrial design profession took, and introduced the problems that the profession is imposing on the

world. His thoughts on the environmental problems the world faces and the designers' role for them are (Papanek, 1985, p.56):

> "The designer-planner shares responsibility for nearly all of our products and tools and hence nearly all of our environmental mistakes. He is responsible either through bad design or by default: by having thrown away his responsible creative abilities, by 'not getting involved', or by 'muddling through'."

As discussed throughout this section, our current patterns of production and consumption have to be challenged to move towards sustainability. For the design profession, it is more about "rejection of convention and of aesthetics" without excluding history and experience of the profession, and this way of thinking should start in design education (Walker, 2006).

In that regard, there are industrial design programs around the world (e.g. TUDelft, Loughborough University, METU, etc.) integrating sustainability considerations into their curriculums at different levels (i.e. compulsory or elective courses, practical or theoretical courses, etc.) The researches on design education for sustainability done by Ramirez (2006, 2007) indicate that a majority of design educators are "interested or very interested in teaching sustainable design" (Ramirez, 2007, p.1) and states that:

> In general, the ID education community can be viewed to be positively responding to the challenges and to its responsibility in preparing tomorrow's industrial designers to become responsible practitioners who can envision the sustainability implications of their design works" (Ramirez, 2007, p.5).

Currently there are many tools and networks concerning the industrial design education for sustainability to aid students, educators and practitioners understand and incorporate sustainability into their works. In Table 2.3, these tools and networks around the world are given below.

Table 2.3 - Tools and Networks for Design Education for Sustainability.

Okala / Ecological Design Guide
Okala ecological design guide provides design educators and students with information about eco-design, lifecycle strategies and environmental impact tools -i.e. LCA, impact factors, etc. - and explores designer's role in dealing with environmental issues (White, *et al*. 2010).

Table 2.3 - Tools and Networks for Design Education for Sustainability (continued).

LeNS

The Learning Network on Sustainability (LeNS) is a network to provide educational resources, and tools for design students, teachers, researchers and designers. It focuses on the curricula development on design for sustainability on product service systems and aims to encourage designers, design students and design educators to contribute to sustainable development (LENS, n.d.).

Sustainable Design Network (SDN)

SDN is a multi-disciplinary research network on sustainable design issues, particularly on tools, methods, and techniques and their implementation. It aims to bring different disciplines - i.e. engineering design, industrial design, manufacturing, management, environmental management, marketing, etc. - together, and provide a mechanism of knowledge transfer in between (SDN, n.d.).

ToolBox

Created by Bhamra and Lofthouse in Loughborough University, Toolbox was created to provide guidance and material support for lecturers who want to incorporate sustainable design considerations into their courses. It presents eight blocks containing various information, tools and methods, which can be used for one off lectures to 12 week course modules (Toolbox for Sustainable Design Education, n.d.).

Gaia Education

Gaia Education is an education network focusing on curricula development for sustainable community design. It assumes a holistic approach to sustainable design education, arranges worldwide training programmes on eco-villages and sustainable development, and works in collaboration with universities, governments and NGOs for creating eco-villages (Gaia Education, n.d.).

Biomimicry Education Network (BEN)

BEN, created by Biomimicry institute is a network for providing educators and students materials and resources for using biomimicry, and sharing experience on the implication of biomimicry for education and design cases (Biomimicry Education Network, n.d.).

Abovementioned tools and networks with different focuses - i.e. eco-design, product service systems, eco-villages, biomimicry, etc. - constitute the current overview of the implications of sustainability concerns for design education around the world. Providing different set of tools and methods, it is important to understand the background on design education for sustainability, which this thesis is built upon.

The research for this thesis is conducted in the Department of Industrial Design at METU, which has a different approach on the integration of sustainability into design education. Focusing on sustainable consumption and production (e.g. enabling post-use, integration of scales, etc.), it has utilized generative and participative tools for sustainability, such as post-use design thinking integrated into the idea-generation phase of design process (Coşkun and Doğan, 2010) and generative research techniques - e.g. experience reflection modeling - for sustainability (Turhan and Doğan, 2012; Turhan, Doğan and Korkut, 2011).

2.4.1. Biomimicry for Sustainability in Product Design Education

Considering the main aim of this research, it is significant to understand what is being implemented around world within that context. Table 2.4 shows three approaches on the incorporation of biomimicry into the design education.

Table 2.4. Current Approaches on Design Education and Biomimicry.

InnovationSpace, ASU InnovationSpace is a trans-disciplinary education and research lab, between the Institute of Design and the Arts and the School of Engineering and the School of Business at the Arizona State University. It aims to provide education on the development of products that create market value, serve societal needs and minimize impacts on the environment. In order to achieve that, InnovationSpace assumes two strategies: integrated innovation model and biomimicry approach (InnovationSpace, n.d.).
Biomimicry as a Basis for Integrative Pedagogy for Sustainable Design Education Developed in the National University of Singapore (NUS), this is an approach for providing two 13-weeks project courses based on integrating biomimicry into design for sustainability framework. In these courses, 'biology-to-design' and 'challenge-to-biology' approaches are included individually within the framework of design for sustainability (Hoyos & Saiki, 2008).
Biomimicry Workshops at the Idea-Generation Phase Biomimicry Workshops at the Idea-Generation Phase is a recent educational approach conducted at the University of Houston. It implements the biomimicry approach at the idea-generation phase for sustainability purposes, through a week of workshop - consisting of introduction to biomimicry, guided observation of nature, searching databases and creating ideas on the natural inspirations - and later a one-day workshop on another guided observation of nature (Kwon & Fraiser-Scott, 2012).

As can be seen on the abovementioned table, there have been various approaches towards the implication of biomimicry for sustainable product design education - i.e. education and research lab, project courses, workshops. Among these approaches, the last two of them - i.e. biomimicry as a basis for integrative pedagogy for sustainable ID, and biomimicry workshops at the idea-generation phase - are important within the context of this research. The approaches are explained in detail below.

2.4.1.1. Biomimicry as Basis for Integrative Pedagogy for Sustainable Design Education

This approach is the result of two experimental project courses conducted in NUS in the academic years of 2006-2007 and 2007-2008. The experimental courses offered a learning spiral for teaching and learning for DfS, integrated with the biomimicry approach. Figure 2.17 illustrates the learning spiral developed for DfS and biomimicry (Hoyos, 2007).

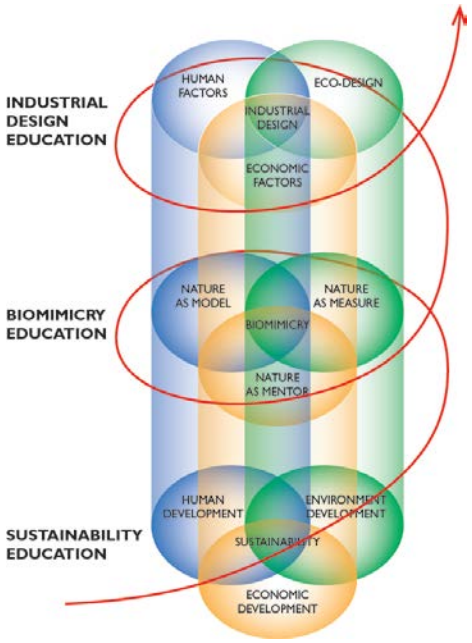

Figure 2.17 - Learning Spiral of a proposed teaching and learning method for DfS in ID (adapted from Hoyos & Saiki, 2011).

The learning spiral consists of three basic parts -i.e. sustainability education, biomimicry education and industrial design education - and offers a filtering process, in which the steps are viewed within the next one's perspective. Two experimental courses were developed through

this learning spiral, assuming different strategies - 'biology to human needs' and 'human needs to biology' - consisting of same phases in different orders. Figure 2.18 shows the project phases and the design processes for these strategies.

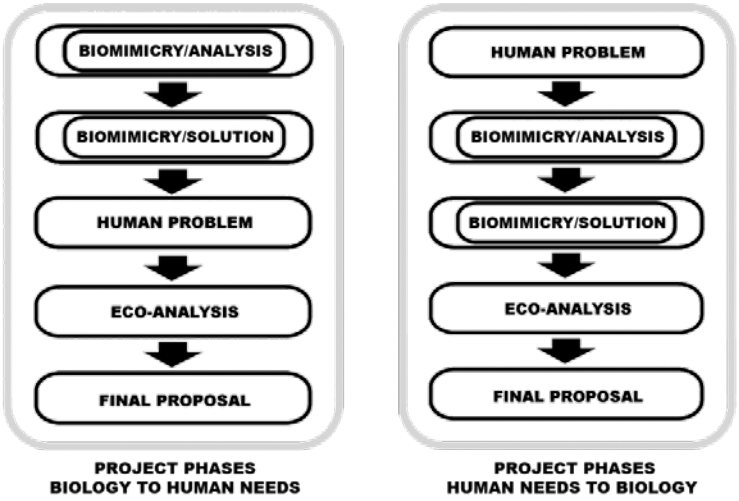

Figure 2.18 - Project phases for experimental courses (adapted from Hoyos & Saiki, 2008).

For each course, the interviews with students conducted afterwards point out the positive effect of the biomimicry approach leading improvement in creative thinking skills for sustainable solutions. On the comparison of two courses, the first strategy - *biology to human needs* - was mentioned to be easier for the students to follow and apply than the second strategy - *human needs to biology*. Furthermore, in both courses, a systems-thinking approach was encouraged to develop solutions, yet inspiring from nature for form and function proved to be easier for students, thus natural inspirations were used for these purposes (Hoyos & Saiki, 2008). The examples of project outcomes from each course are given in Figure 2.19 and Figure 2.20.

The clothes hanger in Figure 2.19, is inspired by the arrangement of the leaves of aloe vera plant to offer a solution providing more space for hanging clothes (Hoyos, 2007). The shoe box in Figure 2.20, is mentioned to reduce the material use by 30 percent through inspiring from cocoons as natural packaging solutions (Hoyos & Saiki, 2008).

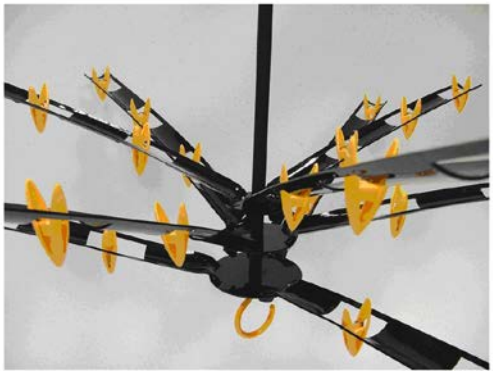

Figure 2.19 - Clothes hanger developed through the analysis of aloe vera plant in the experimental course 'biology to human needs' (reproduced from Hoyos, 2007).

Figure 2.20. - Shoebox developed through the analysis of cocoons in the experimental course 'human needs to biology' (reproduced from Hoyos & Saiki, 2008).

2.4.1.2. Biomimicry Workshops in Idea-Generation Phase

In this approach, the biomimicry approach was integrated into design process with the focus of sustainability prior to the idea-generation phase. The approach assumes the approach of 'Biology to Design', and offers a workshop of four days to convey knowledge on the biomimicry approach and provide students with the experience in utilizing biomimicry through developing small-scale design solutions. The workshop plan is as follows (Kwon & Fraiser-Scott, 2012):

- Day 1 - Biomimicry Introduction: an introductory lecture on the biomimicry approach, the reasons for adopting this approach, and the methods and tools for using nature as model.
- Day 2 - Biomimicry Walking Trail: a hands-on analysis done by students in nature through the use of a tool named *iSite*.

- Day 3 - Extended *iSite* Experience with AskNature.org: an online database research for further analysis of natural systems and organisms.
- Day 4 - Team Project Presentation: a group project done within the workshop utilizing the biomimicry approach.

iSite is a tool to direct students towards finding pre-assigned organisms or systems, and observe and analyze each of them for about 20-30 minutes. During the observations, the students were expected to answer the following questions on a document (Kwon & Fraiser-Scott, 2012):

- What relationship do you see? How about patterns? Describe or sketch them.
- What are some adaptations (behavioral or physiological) you see as a response to biotic or abiotic pressures (wind, predation, rain, decay, etc.)?
- Can you see the ways that life is shaping its environment (rather than the environment shaping life)?
- Rather than asking "what is this organism doing?" ask "how does this behavior fit the environment." Name four things that this organism is interacting with and describe how that interaction is occurring.
- What gradients do you see? What edges do you see? How do the gradients and edges fit together?

Through answering the questions of iSite tool, the students are led towards analyzing the natural organisms and systems, and experience this analysis step through a more structured way. The extended iSite experience through the use of online databases offers an analysis phase over a wider natural inspirations source. The workshop outcomes were produced by groups of students, and the workshop was evaluated by the students participated in the project course. Figure 2.21 shows an example of the workshop outcomes.

Figure 2.21. A floating garden developed throughout the workshop (adapted from Kwon & Fraiser-Scott, 2012).

In the example above, a floating garden acting as a filtering system using native Texas plants is presented. The idea was inspired from filter feeding mechanism of sponges and the structure of weight distribution on water systems (Kwon & Fraiser-Scott, 2012).

The aforementioned approaches towards the implications of the biomimicry approach for sustainable design education present different methods and tools for observing, analyzing and transferring the models and systems of nature -i.e. iSite, field trips, use of online databases, biomimicry projects, etc. - and show the pros and cons of the methods and tools for achieving sustainable design considerations and conveying the different aspects of this approach to the design students. As can be seen in the case of Interface Entropy Carpet (see Section 2.3.3), the biomimicry approach constitutes a certain potential in meeting sustainable design considerations - i.e. post-use services like product maintenance, repair and upgrading, localization, product longevity, etc. - and considering this potential, the relationship between biomimicry and sustainability within the context of product design education should be explored further.

In this thesis, the implications of biomimicry for sustainable product design education will be explored through the integration of an analysis and design tool, developed in the Department of Industrial Design, METU -i.e. Biomimicry Sketch Analysis (BSA) - at the idea-generation phase of the product design and development process. In the next chapter, the methods and tools used and developed within the context of this research will be explained in detail.

CHAPTER 3

METHODOLOGY

This chapter explains the main components of the research, and the data collection and analysis methods used, and an idea generation tool developed within the context of the research. In particular, preliminary survey, the biomimicry exercise incorporated into the idea generation phase, semi-structured interviews conducted with the industrial design students, content analysis, thematic coding and analysis, and their utilization throughout the research will be explained under the titles of pilot study and primary research.

3.1. Research Stages

Biomimicry is an approach that has started to be utilized in the area of product design by designers and producers even before the term has itself surfaced. Its incorporation into sustainability practice and education, on the other hand, is relatively new and there are a few products that have been developed through this approach (e.g. Interface Floor Entropy Carpet, see section 2.3.3). Regarding this relatively new approach, tools, methods and even education programs have been recently emerging (see section 2.4.1) and they are currently at the development stage. Consequently, to explore and understand the implications of biomimicry for sustainability in product design education, an idea generation tool - namely, Biomimicry Sketch Analysis - was developed and integrated into the process of an industrial design educational project carried out in the Department of Industrial Design at the METU in the fall 2011 academic term. The education project namely, "Sustainable Design Solutions: Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles" aimed to develop sustainable solutions through rethinking and reintegrating ceramic bathroom accessories with bathroom tiles. Within the context of the project, a family of products was developed. The project was carried out in collaboration with Kale Group, a major ceramics products manufacturer in Turkey.

The research consists of three parts: literature review, pilot study and primary research. The pilot study aims to understand the level of awareness on the biomimicry approach among the third year industrial design students. Considering the main aim of the research, the primary research consists of three stages: development of biomimicry exercise and its integration into the design project, the analysis of the project outcomes and the semi-structured interviews. Figure 3.1 shows the research stages and their relations.

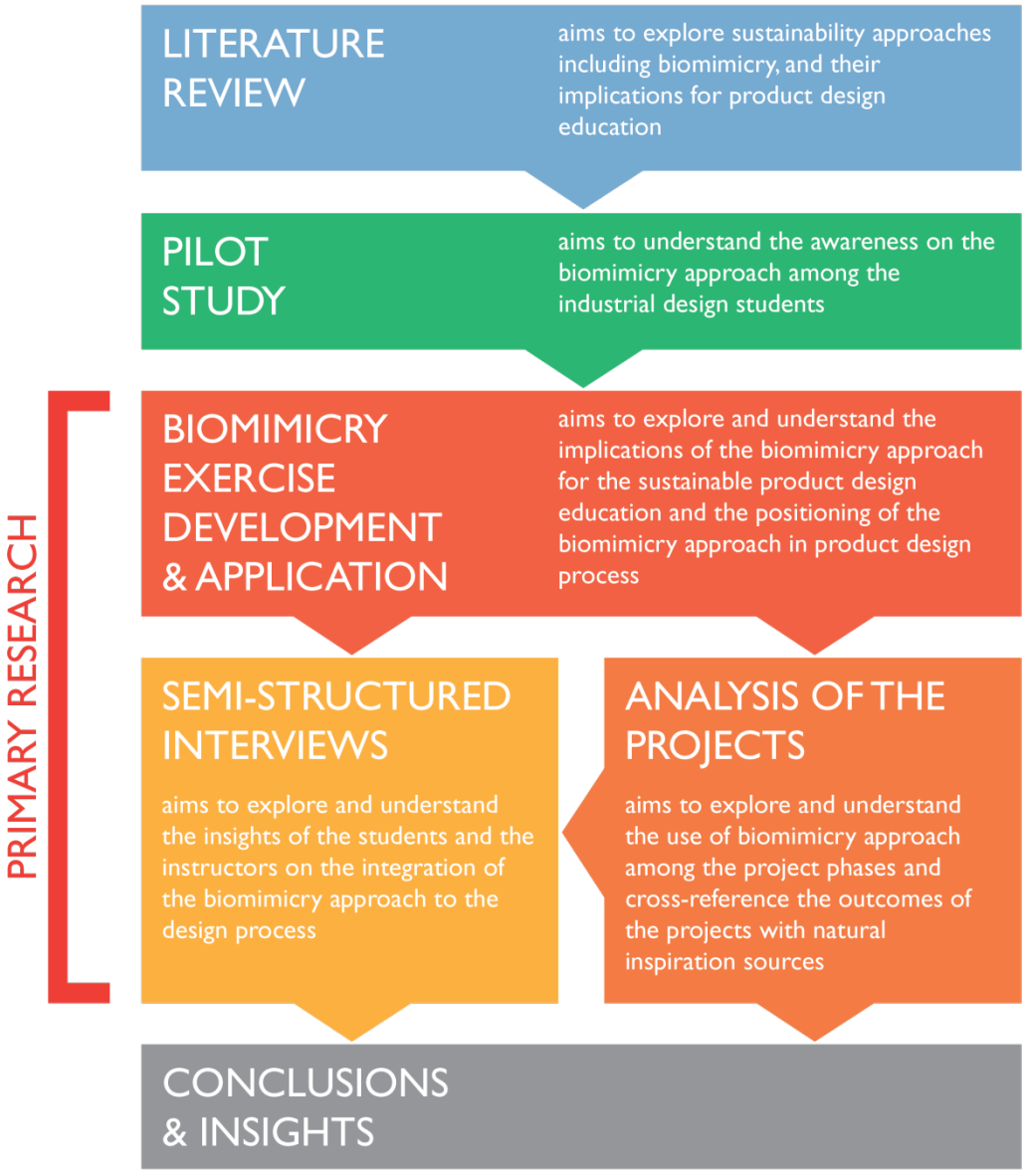

Figure 3.1 - Research stages and aims of the stages.

3.2. Pilot Study

Regarding the main aim of this research, it is important to understand the level of awareness among the industrial design students on the biomimicry approach. This pilot study aims to gain insights into this awareness, prior to the primary research, for two purposes: to understand and explore the interest in the newly-developing biomimicry approach, and to support the development of the primary research steps. To achieve that, this pilot study was conducted in the form of a survey, and both qualitative and quantitative analyses were employed to analyze the data. The following sections will explain the pilot study phase of the research.

3.2.1. Population and Sampling

The pilot study was conducted with the third year industrial design students in the fall semester of 2011-2012. There were 37 out of 41 students who contributed to this study, all of which were from the third-year industrial design studio.

3.2.2. Data Collection: Preliminary Survey

To explore the awareness of the design students on the biomimicry approach, an initial survey with open-ended questions were prepared and asked in the form of a questionnaire. The open-ended questions prepared for this survey are as follows:

- Have you heard about the term biomimicry before? If yes, from which source(s)?
- Would you explain what biomimicry means or refers to?
- Do you know any example(s) of biomimicry in terms of its application(s) for product design?

As for the analysis of the survey results, different themes for each question were created and the data was categorized accordingly. Through this analysis, the data was translated into the results presented in the next chapter. The second part of the first question - i.e. 'If yes, from which source(s)?' - was not considered in the analysis, as the responses for this part of the question was not very specific and explanatory, so they were not included in the analysis part.

The results provided a general overview of the awareness of the students on the biomimicry approach and aided in developing the primary research steps, and directly utilized in the

integration of the biomimicry exercise into the undergraduate industrial design project (see section 3.3.2). In the next section, the primary research and its steps will be explained in detail.

3.3. Primary Research

Within the context of this study, the primary research includes three parts: the development and the integration of a biomimicry sketch analysis exercise, the analysis of the assignment outcomes in accordance with the project process, and the semi structured interviews with the students and the instructors. The following sections will explain these steps.

3.3.1. Development of the Biomimicry Sketch Analysis Exercise

The development of a certain exercise helped the students better understand the sustainability considerations included in the design education project (see section 2.2.3) through the selected biomimicry strategies inspired by nature (see section 2.3.2).

Considering the main aim of this research, it is important to realize the capabilities and limitations of product design students. On one hand, adapting towards a new approach, the educational context provides the researcher with the flexibility in integrating new tools for the idea-generation phase. On the other hand, as ID students lack experience in the design processes, the necessity of clear explanation of and guidance throughout the exercise stages arise. In industrial design education curriculum, there is no biology course or any in-depth biology knowledge conveyed to the students, thus a more familiar form of nature observation appeared to be appropriate within the biomimicry approach for design education, rather than going through various databases and resources on biology that requires a depth of biology knowledge to comprehend it in the first place. Thus a hands-on approach for nature observation was decided upon for this biomimicry exercise by the studio instructors that did not require micro level of observation and inherent biology knowledge. As for observing, analyzing and understanding how natural systems work, designers' skills in sketching were considered appropriate to observe and translate the nature's knowledge into the development of design solutions. Thus, an exercise consisting of the following three main stages were necessary:

- **Observation:** This stage utilizes the observation skills of a designer without the necessity of inherent biology knowledge and microscopic level of investigation.

- **Analysis:** This stage utilizes the sketching and visualizing skills of a designer to understand the ways that the natural systems work.
- **Transfer:** This stage stimulates the creativity of a designer to transfer those findings into solutions considering the project design considerations.

At this point, a paper on Biomimicry Student Design Challenge was encountered (Eggermont, 2009), and the example of a sketch analysis during the process was observed and adapted as the BSA format (Figure 3.2). The paper was on the different approaches that the participating institutions utilized for the design challenge, and conveyed the overall processes during the design process.

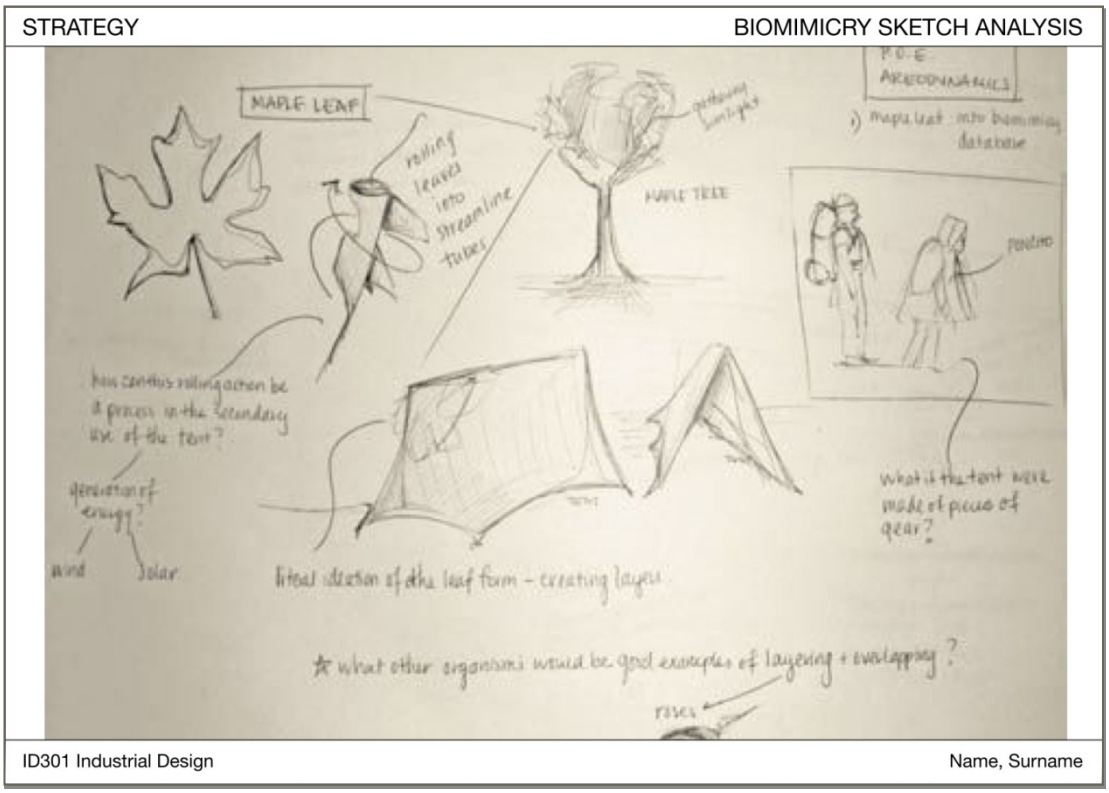

Figure 3.2 – The BSA format example with an analysis of maple leaf for developing a solution of folding and carrying a camping tent (adapted from Eggermont, 2009).

When observed, the sketch analysis was consisting of three basic parts: the inspiration source, the analysis and the features of the inspiration source, and the transfer of those features into design problem at hand. The example was consistent with the phases of the developed exercise for this research, thus the researcher with the feedback from the studio instructors

developed this example into a more systematical, and an analysis and solution-oriented tool, namely Biomimicry Sketch Analysis (BSA).

The biomimicry exercise was considered as a way to integrate the biomimicry approach into the product design education for sustainability. The exercise was developed considering the idea generation phase of the design process and the design considerations for sustainability within the context of the design education project.

3.3.1.1. Positioning of the Exercise in the Design Process

The process of design projects (educational or non-educational), has similar steps with the Biomimicry Design Spirals (see section 2.3.2). The design process generally consists of the following phases: research, idea generation (divergence), design detailing (convergence), evaluation and appropriation, and final design solution. (Table 3.1)

Table 3.1 - Biomimicry Design Spirals and Design Process.

Steps of Biomimicry Design Spirals	Steps of Design Process
Identifying	Research
Interpreting	Idea Generation (divergence)
Discovering	
Abstracting	
Emulating	Design Detailing (convergence)
Evaluating	Evaluation and Appropriation
Final Design	

Table 3.1 shows the steps of Biomimicry Design Spirals and design process in relation to each other. As can be seen in the table, Biomimicry Design Spiral steps of identifying, emulating and evaluating constitutes similarities with the design process phases of research, concept development, and evaluation and appropriation. The highlighted steps - i.e. interpreting, discovering, abstracting - fall into the category idea generation phase in the design process.

Considering this, the BSA exercise was developed including these highlighted steps and was put into practice systematically at the idea-generation phase of the design process. The steps of the BSA exercise are observation, analysis and transfer, which fall into the steps of interpreting, discovering, and abstracting of the Biomimicry Design Spirals.

The BSA was developed to be integrated into idea-generation phase of the design process through which initial design ideas were informed and inspired by nature.

3.3.1.2. Incorporating Sustainability Considerations into the BSA Exercise

This assignment was developed and incorporated for the exploration of the sustainability considerations included in the educational project. The biomimicry approach constitutes certain potential to achieve sustainable solutions, yet the sustainability considerations have to be considered at the early stages of the design process.

During the research step of the design process, the design considerations for the project are explored and refined, through literature search, user observations and field studies. In this step, the design considerations for sustainability - i.e. enabling post-use services for product maintenance repair and upgrade (*see* section 2.2.3) - are defined more in depth according to the project at hand. For the BSA exercise to be effective in regard to sustainability, these considerations were interpreted within the biomimicry approach and the strategies included in this approach (i.e. attach-detach and adapt). The Biomimicry Taxonomy (*see* section 2.3.2) is an applicable tool to ease this interpretation and help better connects the sustainable design considerations with biomimicry strategies. As a result of this interpretation and connection, the *strategies* present in nature (e.g. attach-detach and adapt) are pointed out as a basis of the utilization of the BSA exercise.

Defining the *strategies* is an important part of the BSA exercise, as they constitute the aim, content and direction for it. In order to utilize the BSA exercise for sustainability, it is crucial to match the design considerations and biomimicry strategies within the context of sustainability, during the research step. As a result, the *strategies* defined for the BSA exercise will lead towards the creation of sustainable ideas.

3.3.1.3. Expected Use of the Exercise

This exercise was developed with the purpose of exploring and understanding the implications of biomimicry for sustainability in product design education. Sustainability being the keyword here, the BSA exercise is expected to be utilized according to the considerations within the context of sustainability mentioned above. The BSA exercise provides a unique approach as it brings together the observation and analysis of an inspiration source, and its transfer into an idea for the design project. In a way, the exercise constitutes of research and idea-generation

at the same time, and acts as a transition phase between those project phases. Consequently, the BSA exercise presents considerable potential in the development of sustainable solutions from the beginning of the design process.

The following section explains the integration of the BSA exercise into an undergraduate industrial design project as the focus of this research.

3.3.2. Integration of the Biomimicry Exercise into the Undergraduate Industrial Design Project

The BSA exercise was developed and then integrated into the idea-generation phase of the undergraduate industrial design project for this research. The educational project included the BSA exercise as an assignment in the project schedule. The integration of this exercise consists of the following steps:

- Presentation on the biomimicry approach and the BSA exercise within the context of the project by the researcher
- Conducting the BSA exercise and the critiques by the studio team
- Collecting and presenting the outcomes of the BSA exercise

In this section, the steps of the integration will be explained briefly.

3.3.2.1. Preparation of the Biomimicry Presentation

In order to prepare the students for the BSA exercise, a presentation on the biomimicry approach and its relation to the project was presented by the researcher. As biomimicry is a newly developing approach, and the students generally lack insights into it, and a presentation on what the biomimicry approach is, and, how it works are crucial to get them familiar with biomimicry and present the potential it has for the project.

The researcher benefitted from the results of the pilot study for the preparation of the presentation as this initial study provided a general framework including the students' insights into their awareness of the biomimicry approach. As a result, a presentation consisting of the following was prepared:

- The definition of biomimicry

- The utilization of biomimicry in product design - i.e. Biomimicry Design Spirals
- Examples of biomimicry cases
- Biomimicry strategies defined for the project
- Examples of potential inspiration sources divided according to defined biomimicry strategies
- The BSA exercise and its phases

As this presentation aims to prepare the students for the BSA exercise, it is important to use a number of examples for the strategies that will be used in the exercise. Through giving examples, the strategies can be better understood by the students. Giving only the definition of the strategies is not useful, since the design students are not very familiar with nature and its processes, let alone the strategies themselves. Figure 3.3 shows a slide from the presentation, giving an example of the 'adapt' strategy, conveying the name of the inspiration source, a brief explanation of its unique feature and an image of it, so that the function can be seen (full presentation in Appendix A).

Figure 3.3 - A slide on an example for adapt strategy.

It is important to give more than one example on one strategy, since there are generally other ways that the strategy is utilized. For example, Figure 3.3 (above) shows an example of 'adapt' strategy on minimizing material use, yet there are also other examples on minimizing the space, creating safer forms, etc. Providing a range of examples prevents students focusing on only one aspect of a strategy (full presentation in Appendix A).

3.3.2.2. Conducting the Exercise and Critiques

Within this research, the exercise was given to the students in the form of an assignment, yet it was important that the instructor provided help throughout the exercise. Since the students were fairly new to the biomimicry approach, they could be overwhelmed with the knowledge conveyed to them through the presentation. How well and informative the presentation is prepared, it is crucial to provide the students with support through answering the raising questions they have on each phase of the exercise.

Critiques through the exercise are important in the sense that the students as novice designers are inexperienced in perceiving nature from the perspective of the biomimicry approach. Because of that, the critique sessions are helpful in building up that perspective through discussing on the inspiration sources that the students find and share. It is also important to discuss the following phases of the exercise - i.e. analysis and transfer - in order to lead towards outcomes of better quality and influence in the context of the project's design considerations which were developed further in detail by students through user observations, literature research and biomimicry.

3.3.2.3. The Outcomes of the Exercise

The outcomes of the exercise are to be collected and presented in a collective manner, meaning the outcomes need to be shared among the students to provide rich inspiration sources for all of the students. As the BSA exercise constitutes the perspective of the individual student, the inspiration source and the transfer of that inspiration source may trigger another idea resulted from the same inspiration source for another student. This enables all of the students to acquire a wide range of inspiration sources from nature they can benefit from, as well as to have a better understanding of the design considerations for sustainability within the context of the project.

3.3.2.4. Population and Sampling

For this research, the BSA exercise was integrated into the third year design studio project (as mentioned earlier) at the idea-generation phase of 'Re-integrating Bathroom Accessories with Bathroom Tiles' project. 39 out of 41 students have participated in this exercise and submitted their outcomes for it, and the results were shared among the peer students.

3.3.3. Analysis of the Outcomes of the Exercise in accordance with the Following Phases of the Project

Considering the scope of this research, it is important to analyze to what extent the outcomes of the BSA exercise are used within the design process. In order to analyze the use of the BSA outcomes in the following phases, the results from these phases were collected and cross-referenced among each other. In the design process this research was conducted upon the phases, which were the Matrix exercise, the Task exercise, pre-jury and final jury (*see* Section 4.2.1.2). The project briefs for each phase are included in Appendix B. To provide an example of the cross-referencing, Figure 3.4 shows an outcome of the BSA exercise, which is later used and developed in the Matrix exercise (Figure 3.5) by a student.

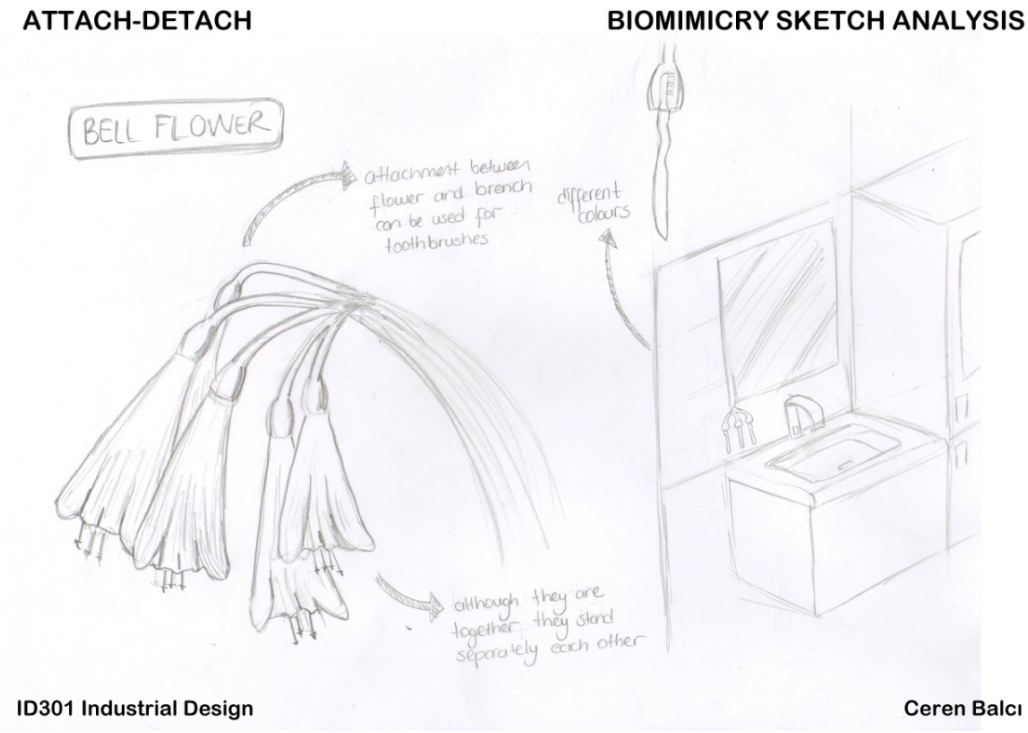

Figure 3.4 - Cross-referencing example - an outcome of the BSA by Ceren Balcı.

Figure 3.5 - Cross-referencing example - the BSA outcome later used in the Matrix exercise by Ceren Balcı, Derya Adıyaman, Gökçe Evren, Medina Bekteşeviç and Yasemin Canik.

The above mentioned figures illustrate an example of the cross-referencing made among the results of every phases of the design process for each student. All of the results gathered by the researcher were cross-referenced based on the visible features, digitally marked - e.g. green plus sign in Figure 3.5 - and filed accordingly, per student. This provided insights into the use of the biomimicry approach throughout the design process and helped the researcher better examine and understand the implications of it. These results (the students' submissions for each phase) were utilized during the semi-structured interviews to encourage the interviewees towards talking more in-depth about their experiences on the biomimicry approach as well.

3.3.3.1. Population and Sampling

Out of 39 students who provided the outcomes of the BSA exercise, 37 of them were accounted for this analysis. The missing two students did not provide outcomes for other phases of the project, which rendered them ineligible for the analysis.

3.3.4. Interviews on the Integration of the Biomimicry Approach

Following the research steps mentioned above, getting the insights of the students and the instructors were important for this research. The data collection method used was semi-structured interviews for both the students and the instructors. The data analysis methods used are thematic coding and content analysis for students, and content analysis for instructors. In this section, these methods will be explained along with their utilization in this research.

3.3.4.1. Data Collection: Semi-structured Interviews

Semi-structured interview is a data collection method in which the interviewees are encouraged to talk about the topic under investigation in depth, without using pre-determined, focused or short-answer questions (Cook, 2008). Semi-structured can be placed in between the structured interviews - in which predetermined questions with fixed wording are used - and unstructured interviews - in which interviewee is allowed to talk freely without any predetermined questions. Thus, semi-structured interviews are open to new directions within the context under investigation and the interviewee is free to elaborate on the topic, yet the direction and the content of the interview stays in control of the researcher.

Semi-structured interviews are limited in regard to the recall of the participant, the ability of the participant in expressing his/her experience and the ability of the researcher to ask the right questions (Cook, 2008). In this research, the analysis of the outcomes of the biomimicry exercise in accordance with the following phases of the project was used to overcome some of the limitations - the recall of the participant and the ability of him/her to express experiences - as much as possible, through providing visual materials (i.e. project outcomes) during the interviews. The visual material prepared for the interviews were unique to each interviewee - i.e. his/her design process.

To overcome the limitation of finding the right questions, a series of pilot interviews was conducted. As a result, the questions for the semi-structured interviews were revised or rephrased. Table 3.2 shows the final version of the interview questions.

Table 3.2 - Semi-structured Interview Questions for Students.

I - General Analysis

Q1. How would you evaluate the biomimicry sketch analysis assignment? Could you talk about the process in general?

Q1A. Were the processes of the assignment clear to you? Could you explain the processes in more detail?

Q1B. How influential was the biomimicry presentation for you in understanding the assignment and the idea generation phase in relation to the biomimicry strategies? What are the examples you recall or you are impressed about?

Q1C. Could you evaluate the place and the influence of the assignment on the idea-generation phase of the project?

Q1D. How do you think the idea-generation phase was affected due to the individual conduct of the assignment?

Q1E. What would you evaluate this assignment with respect to the phases of the assignment: the source of inspiration, its analysis and the transfer of this analysis? To what extent were you able to transfer these analyses into the idea-generation phase?

Q1F. Did the literature search and user observations you conducted beforehand affect the selection of the source of inspiration and its analysis? If yes, could you please explain it with examples?

Q2. What do you think was the aim of this assignment? Were you able to achieve those aims? In what ways?

Q3. What are your suggestions to improve this assignment? What were the problems and difficulties you encountered during the assignment? What are you suggestions to eliminate those?

II- Individual Analysis

Q4. How did the outcomes of this assignment affect the following phases of the project?

Q4A. Did you use the outcomes of the assignment in the Matrix exercise? If yes, could you point them out on the presentations and explain how you used them? If no, why?

Q4B. Did you use the outcomes of the assignment in the Task exercise? Did you use them in the Matrix exercise as well? If yes, could you point them out on the presentations and explain how you used them? If no, why?

Q4C. How did these initial ideas you created during the assignment affect the ideas you developed for the pre-jury? Could you explain it with examples?

Q5. How did you use the results of this assignment in the following phases of the project? As they were? By developing and changing them? By compiling more than one idea?

Q6. Did you use other inspirations from nature in the following phases of the project? If yes, what are those inspirations? Were they the results of other students' assignment?

Q7. Have you come across of such an analysis method before? If yes, where? What do you think about its place for and influence on your future projects?

Q8. Now that you have seen your biomimicry analysis and the following steps of the project in relation to that, what are your suggestions for the improvement of the assignment?

As presented in Table 3.2, the interview questions focusing on various issues regarding the integration of the biomimicry approach into the idea-generation phase of the design process were divided into two parts. The first part was about the general integration of the biomimicry approach into the design process. The second part was about the assessment of the individual use of the biomimicry approach in the design process.

The interview sessions took roughly between 15-30 minutes and a consent form was provided prior to the interview sessions considering the usage of visual materials that the students provided along with the responses to the interview questions. Each interview session was audio recorded to prevent any kind of data loss, and the recorded data was later verbatim transcribed to enable the analysis of the data thoroughly. It is important to point out that, in the course of the interview sessions, additional questions emerged and asked depending on the flow of the interview, while particularly focusing on the project outcomes. Furthermore, the interview questions were prepared in Turkish (Appendix C), and later translated in English for the exchange student.

3.3.4.2. Data Analysis: Content Analysis

Content Analysis is a commonly used method in analyzing both qualitative and quantitative data and is described as the "intellectual process of categorizing qualitative textual data into clusters of similar entities or conceptual categories to identify consistent patterns and relationships between variables and themes" (Julien, 2008). Through content analysis, data collected using various mediums - e.g. interview transcripts, newspapers, speeches, drawings, photographs, video recordings - can be analyzed. There are two approaches on content analysis: deductive and inductive. The deductive approach assumes codes or categories derived from pre-existing theories or concepts, and analyzes the data set in a quantitative fashion. On the other hand, the inductive approach - i.e. qualitative content analysis - is about detailed reading of the data and revealing the contextual content within. It is useful in the sense that both conscious and unconscious messages in the text can be identified and presented. In this research the inductive approach was adopted, and, both the analysis of the outcomes of the BSA exercise and the semi-structured interview results were considered as the data sets and analyzed altogether. Using the inductive approach, the following categories and sub-categories were derived from the data sets (Table 3.3).

Table 3.3 – The Categories Derived from the Analysis of the Primary Research.

Categories	Sub-categories	Category Description
Biomimicry Approach in Design Process Phases	• Research Phase • Idea-generation Phase • Design detailing Phase • Final Jury	Implications of the biomimicry approach for the design process according to project phases
BSA Exercise	• Biomimicry Presentation • Strategies from Nature • BSA stages • Individual Assignment • Perceived Aim • Outcomes	Integration of the BSA Exercise into the design process and its stages
Future Projection	• Influence of the Biomimicry Approach • Insights on Further Development of the Assignment	Effects of the biomimicry approach on students, and insights into the application of the BSA exercise

As a result of this categorization, the interview results and the BSA outcomes were analyzed under respective categories and sub-categories. Some of the results were presented through thematic coding and analysis as explained in the next section.

3.3.4.3. Data Analysis: Thematic Coding and Analysis

Thematic coding and analysis is a data analysis strategy to segment, summarize, and reconstruct the qualitative data to capture and present important concepts within the data set (Ayres, 2008). It generalizes the information gathered from the data set to present findings in a meaningful and useful way, under the synthesized themes. The outcomes of the thematic coding and analysis are descriptive and they include important concepts and processes along with patterns of experience within those concepts.

In this research, it was used to aid the results of the content analysis and present outcomes of the semi-structured interviews in a more useful way, by categorizing the students into groups according to their perception of the biomimicry approach and its usefulness, and the outcomes

of the projects. The data sets used for thematic coding and analysis are the same with the content analysis: the analysis of the outcomes of the biomimicry exercise within the design process and semi-structured interviews conducting with the third year industrial design students. As a result, the following groups were set:

- Students who found the biomimicry approach helpful and developed a design project inspired and informed by nature
- Students who found the biomimicry approach helpful, yet were not able to develop design projects inspired and informed by nature
- Students who found the biomimicry approach not helpful enough, yet developed a design project inspired and informed by nature
- Students who found the biomimicry approach not helpful enough and did not develop design projects inspired and informed by nature

The results of thematic coding were presented under the respective groups' titles with both qualitative and quantitative results.

3.3.4.4. Population and Sampling

The interviews were conducted with the third-year ID students who developed design projects. The interviews were conducted with 33 out of 37 students. 4 of the students were excluded since they were not available throughout the interview schedule.

3.3.5. Limitations of the Study

The researcher has worked as a teaching assistant in the Department of Industrial Design, and he attended the third year design studio as a visiting instructor during the educational project, through which this research was conducted. This involvement provided the researcher with the opportunity to analyze the design process throughout the project and gain insights into the idea-generation phase. The researcher benefited from this knowledge during the analysis of the outcomes of the BSA exercise in accordance with the project phases, and utilized the analysis in the following research steps. However, this involvement in the project may have affected the attitude of the students during the interview sessions in regard to the student's responses to interview questions. This hindrance was tried to be avoided as much as possible, by giving the

participants (i.e. the students) in-depth information about the research context during the interviews - i.e. that they would not be evaluated by any outcome from the interviews.

This was the first time that this type of an assignment was implemented in a studio project, and the studio team was not experienced about this process. In addition to that, the BSA tool was not fully developed for the industrial design students and the biomimicry approach is a newly developing area itself for design education. There are only a few educational projects, and the method and tools within the education context are not clearly explained or provided in these sources. It should also be noted that, the exercise was integrated into a 9-week design project, which had other tools and methods already planned considering the teaching goals for that particular project. Consequently, the allocated time for the incorporation of the exercise was limited.

All of the interviews were conducted in Turkish - except one, with an Australian exchange student. The reason for that is the majority of the third-year students' native language was indeed Turkish, and the aim was to provide a thorough information exchange during the interviews for receiving more in depth insights of the interviewees. The interview questions were translated into English by the researcher for the participation of the exchange student, with the same purposes as well.

The content analysis and thematic coding were the preferred data analysis methods for this research. In the content analysis, the results depend on the ability of the researcher to make inferences from the data sets. In thematic coding and analysis, the results are generalized for the themes - i.e. students groups - to better convey the results derived from the data sets. Consequently, the interview transcripts were coded and analyzed word by word by the researcher.

This chapter has provided information about the research steps, and the data collection and analysis methods used within those steps along with their utilization. The results of the whole research phases will be presented in the next chapter in a detailed and reconstructed way.

CHAPTER 4

RESEARCH

This chapter presents the conclusions and findings from and insights into the pilot study and primary research based on a design education project. The outcomes of the primary research are given in three steps. The first section presents the outcomes of the pilot study and the semi-structured interview, the second section presents examples of the student project cases along with their case by case interview results, and the third section presents the insights of the instructors. The chapter concludes with overall conclusions of the primary research.

4.1. Pilot Study and its outcomes

As this research is on the implications of the biomimicry approach for a design project, it appeared to be significant to understand the level of awareness among the industrial design students (see Section 3.2). This research including a pilot study was conducted with the third-year students of 2011-2012 Fall semester in the Department of Industrial Design at METU. There were three questions asked to the students in the form of a survey, and the outcomes were presented in line with these questions. 37 out of 41 third-year students participated in the survey.

Question 1: Have you heard about the term biomimicry before? If yes, from which source(s)?

This question is a short answered one, and the answers and their distribution among the third-year students are visualized in Figure 4.1 (below).

Out of 37 students who participated in the pilot study, only 12 of them had an idea on what biomimicry was. The second part of the question was not included in the analysis part, as the responses were not specific and/or explanatory (see Section 3.2.2).

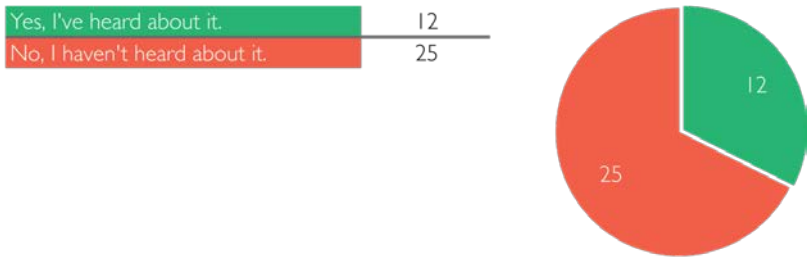

Figure 4.1 - Answers to the Question 1 of the Pilot Study.

Question 2: Would you explain what biomimicry means or refers to?

This question was on the understanding of the students' perception of the biomimicry approach, and the responses were divided into four groups through the analysis. *Imitating nature / inspiring from nature to solve design problems*, were the answers providing a short explanation of biomimicry. *Using / copying nature's solutions for design problems* refer to bio-utilization or bio-assisted technologies, which refer to using actual natural resources directly to solve design problems. *Form-based inspiring from nature* refers to only form based inspirations rather than inspirations from functions and systems in nature. *A living organism imitating another* refers to actual mimicry observed among living organism as a survival mechanism. Figure 4.2 shows the results of this question, with respect to the categories mentioned, for 12 students who have heard about biomimicry before.

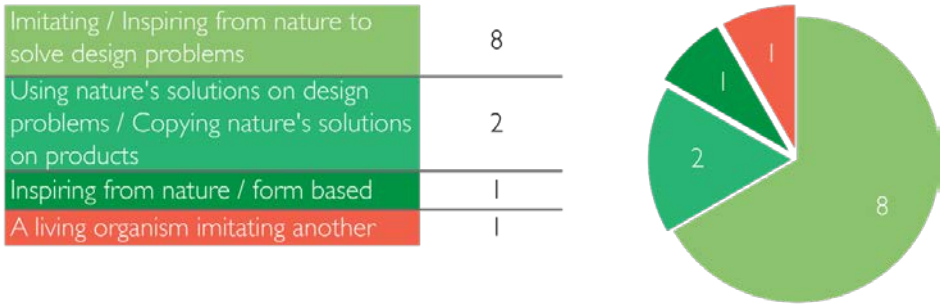

Figure 4.2 - Answers to the Question 2 of the Pilot Study.

8 out of 12 students were able to respond regarding the actual definition of biomimicry. 2 out of 12 students defined bio-utilization or bio-assisted technologies, and 1 out of 12 specifically mentioned that the inspiration should be form based. 1 out of 12 students defined mimicry as a survival strategy for living organism in nature.

Question 3: Do you know any example(s) of biomimicry in terms of its application(s) for product design?

6 out of 8 students who previously gave an actual definition of biomimicry were able to answer this question, by the definitions mentioned in Figure 4.3. The examples provided were Velcro, box fish inspired car, gecko adhesive, Japanese fast train, submarines, plane wings and Interface carpet.

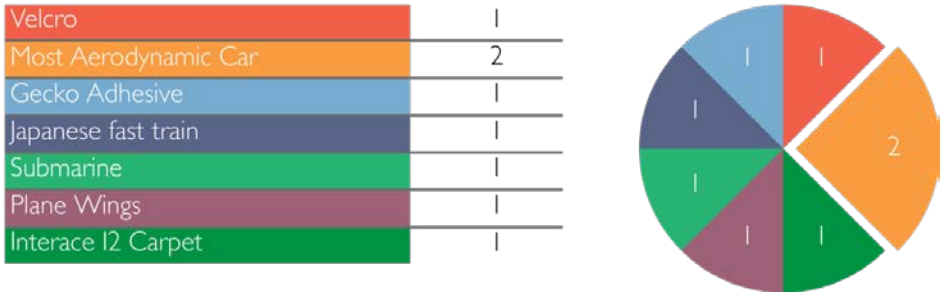

Figure 4.3 - Answers to the Question 3 of the Pilot Study.

Out of the 7 examples mentioned by the respondents, boxfish inspired car was mentioned twice and other examples once. The examples showed that these six students had a clear idea about the meaning of biomimicry and its applications around the world.

In general, only 8 out of 37 students were aware of what biomimicry really was. The remaining 29 students either did not have any idea about the biomimicry approach, or what they knew about it was not refined. Some of the examples provided by the students required specific knowledge on chemistry (i.e. gecko adhesive) and engineering (i.e. plane wings and submarine). These results were found useful later in the preparation of the biomimicry presentation presented during the integration of the biomimicry exercise into the educational design project upon which the primary research was conducted.

4.2. Primary Research

4.2.1. About the Project

This section explains the background of the second project developed for and incorporated into the Industrial Design III course in 2011-2012 Fall semester, namely 'Sustainable Design

Solutions Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles in Collaboration with Kale Group." The project is about bringing two differentiated product categories, bathroom tiles and bathroom accessories that affect the bathroom environment. The bathroom accessories sector has developed on its own, producing products and product families made out of various materials such as metals, glass, ceramics, plastics, etc. Similarly, bathroom tiles sector presents its own products, without considering the bathroom accessories and their effects on the bathroom environment. This project was developed as an attempt to redefine bathroom environment through taking both of those product categories into consideration.

Considering the aim of reintegrating those two sets of products, which have been developed with respect to their own aesthetics, needs and expectations and have their own material cultures developed over the years, the students rethink these product categories in order to bring them together with a particular emphasis on product maintenance, repair and upgrade within the context of the bathroom environment. The biomimicry approach found to be suitable to aid the students in achieving these sustainable considerations, thus this educational project was considered as a subject for this research.

On top of that, this project was done in collaboration with Kale Group (a major Turkish company producing ceramic products for different markets). The project mainly focused on ceramics for bathroom tiles along with other materials used for bathroom accessories (e.g. metal, wood, glass, etc.)

The studio instructors considered Biomimicry as a promising approach offering a wide-range of inspirations for possible problems on systems-level, in different categories, such as attachment, cleaning, adaptability, etc. That's why biomimicry was integrated into the project from the beginning.

The next section explains the definition of the project according to the design brief given to the third-year students.

4.2.1.1. Project Brief and the Definition of the Project

The aim of the project was stated as developing sustainable design solutions which demonstrate the potential of personalization and biomimicry in ceramic bathroom accessories and products. A family of products were expected to be produced, including: bathroom tiles,

soap dish holders, toothbrush holders, towel bars, soap dispensers, shelf fixtures, toilet brushes, toilet roll handlers, etc.

Personalization aspect was regarded as one of the sustainable design considerations, as it strengthens product-user relationship and, evidently, prolongs the product life-span. Biomimicry was integrated into the project to enable the students to explore various strategies inspired by nature -i.e. attach-detach, make modular, assemble, adapt, etc. - to enrich the idea-generation of phase of the project to better explore the sustainable design considerations particularly product maintenance, repair and upgrade. The design brief can be examined in Appendix B in detail.

In the next section, phases of the project are mentioned briefly, followed by the idea-generation tools used at the early phases of the project.

4.2.1.2. Phases of the Project

The project is mainly divided into four phases, which can be seen in Table 4.1. The first phase is the design research on the area of interest (i.e. the bathroom environment, sustainable design considerations) through literature research and field observations. The second phase is the idea generation and initial design explorations, at which biomimicry exercise and Matrix exercise take place, with the expected outcome of diverse design solution areas. The third phase is the design detailing and user testing, in which Task exercise is used to explore further the design solution areas resulted from the previous phase and the user testing through building mock-ups. The final phase is the final design solution presented through presentation boards and full-scale appearance models of the whole product family.

Table 4.1 - Phases of the Project as in the Project Brief Presented to the Students.

Part 1- Literature Search, Field Observations and Project Dimensions The students conduct literature search on assigned topics, make user observations in private homes, and survey the existing bathroom accessories in the market, and based on the major conclusions the students reach, they propose project dimensions (allocated time: 1,5 weeks).
Part 2 – Idea Generation Phase The students work on project dimensions and develop initial ideas through the

Table 4.1 - Phases of the Project as in the Project Brief Presented to the Students (continued).

BIOMIMICRY exercise and MATRIX exercise to explore diverse design solutions (allocated time: 1 week). *Output:* Diverse design solution areas for integrating bathroom accessories with bathroom tiles. **Part 3 – Design Detailing and User Testing** The students further explore the initial design ideas through the TASK exercise. In order to assess the potential of design solutions, they build mock-ups and conduct interviews with potential users (allocated time: 4 weeks). *Output:* Alternative design solutions, mock-ups and user testing results. **Part 4 - Final Design** The student present the final design solution with real size appearance models of the whole product family. * Project Calendar can be observed in Appendix D

As presented in the table, the biomimicry approach was incorporated into the idea-generation phase of the project along with the Matrix exercise. The generated design ideas were then developed further in the Task exercise, and two of them with further detailed were presented during the preliminary jury. In the following section, the means of integrating Biomimicry Sketch Analysis to explore sustainable design considerations defined in the project brief at the idea-generation phase of this project are explained.

4.2.1.3. Biomimicry Sketch Analysis Exercise (BSA)

The BSA was incorporated in the idea generation phase as a three-day exercise. The aim of it was to let students observe, explore and document different natural systems and organisms (e.g. animals, insects, plants, trees, seeds, etc.) within their nearby environment. The exercise was to be performed individually. The students were expected to inspire from nature and develop diverse solutions without limiting their own perspective, which was thought to be important for this particular exercise. It was found to be significant for the students to experience nature individually and group work - as creating collective ideas to some extent -

might have implications for limiting the individual ideas to surface. Time constraints - three-day exercise in the process - were effective in taking this decision as well, as a group exercise would require a longer time period to be applied.

For this exercise, the use of online database or sources to find inspirations was limited, and the students were encouraged to go out and step in the nature to make hands-on observations. The aim for this decision was to make better use of the observational skills of the design students and to let them inspire from nature through their own skills as designers, instead of the use of online resources (i.e. aksnature.com) including the results of already observed natural systems. The use of any online resources was allowed after their observation stage of the BSA, to support their findings for developing diverse ideas from various sources of inspirations.

The students were asked to present three different natural systems and organisms, based on the strategies inspired by nature as presented below. They were free to choose an alternative strategy or make an additional one for those two. The strategies were defined as stated in the Biomimicry Taxonomy developed by the Biomimicry Institute (see Section 2.3.2) and the examples of those strategies were given from Asknature.org, through a seminar made right before the assignment (see Section 3.3.2.1). The strategies are as follows:

- attach and detach - permanent or temporary
- adapt - optimizing space or materials, modifying physical state such as changing form, color, or position
- self-defined (optional) - e.g. (self-) clean, resist forces, etc.

As for presenting their results of the BSA, the students were expected to present photographs of three sources of inspiration they chose and prepared three different A3 detailed hand-sketch analysis describing the source of inspiration, its unique feature(s) and component(s), and the implication of the feature(s). An example of the resulting BSA is given in Figure 4.4 and the photographs of the inspiration source in Figure 4.5.

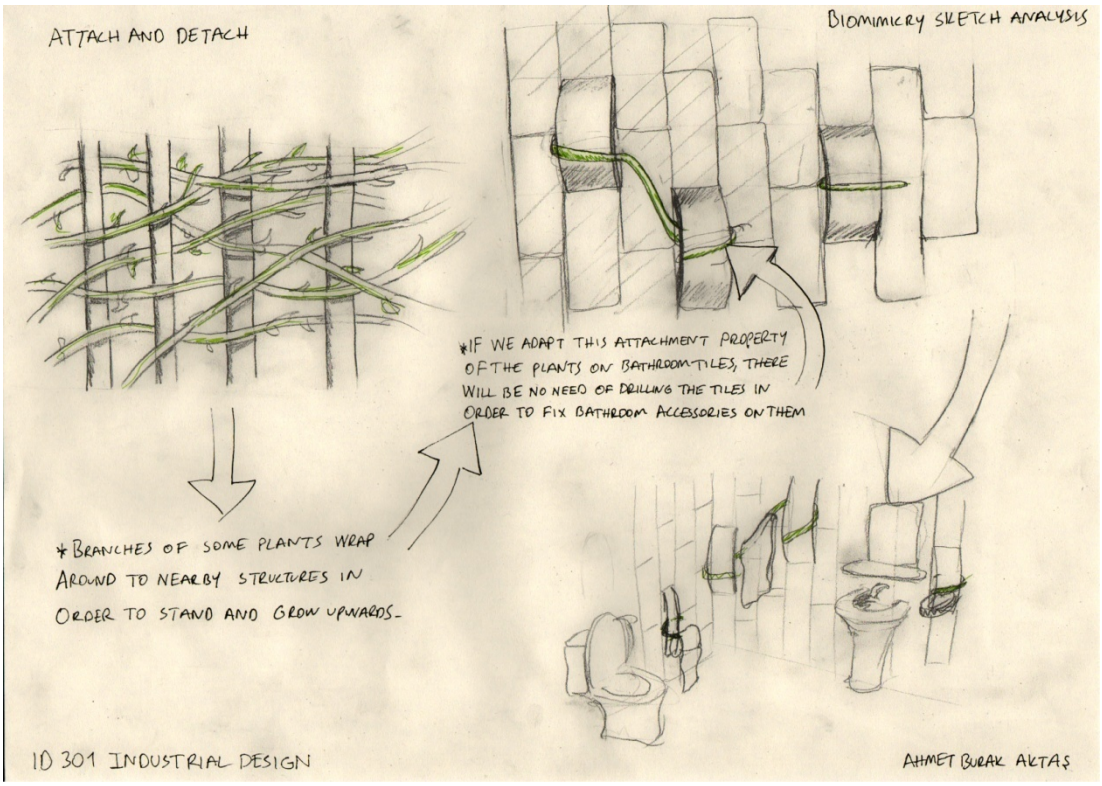

Figure 4.4 - An example of Biomimicry Sketch Analysis presented by Ahmet Burak Aktaş.

Figure 4.5 - The photographs of inspiration source taken by Ahmet Burak Aktaş.

After the submission, the students were asked to pin-up their presentations of the BSA assignment in the third year studio. They observed what everyone else presented for the inspiration sources, how they incorporated the inspiration source into their initial designs, and reflected on the sources. The aim for this was to let the students explore and examine the other students' perspectives in incorporating nature's systems and organism into the project.

In the following section, the later stages of the idea-generation and development exercises and their relation to the BSA exercise are explained.

4.2.1.4. Following Idea Generation and Development Exercises - Matrix Exercise and Task Analysis Exercise

After the BSA exercise, the project included idea-generation exercises, namely the Matrix exercise and followed by the Task exercise. Matrix exercise is a tool which has been developed and used in the Department of Industrial Design since 2003 and has been further developed to be used as an emotionally rich idea-generation tool (Korkut & Dogan, 2010). The Task exercise is a complementary idea-generation tool to further develop and detail generated ideas presenting certain potential within the context of design brief.

As an idea-generation tool, the Matrix exercise aims to help the students generate various ideas based on project dimensions and project themes. For this project, the exercise was completed by the groups of students rather than individually. For the project this research was conducted upon, Table 4.2 shows the project dimensions and themes in the context of the Matrix exercise.

Table 4.2 - Project Dimensions and Project Themes in the Context of Bathroom Tiles and Accessories Project.

	Cozy	Inclusive	Interchangeable	Evolving	*Self-defined*
Free Lego Zone					
My Instant Extended Family					
Interactiles					
Clean Contact					

The first row of the Matrix exercise indicates the project dimensions that have been developed and emerged from the results of literature review and field observations, namely - cozy, inclusive, interchangeable, evolving and multifunctional. The biomimicry approach was not integrated into the Matrix exercise exclusively, yet some of the project dimensions - i.e. interchangeable, evolving - were in coherence with the Life's Principles (see Section 2.3.1.1). The first column proposes various project themes - i.e. free Lego zone, my instant extended family, interactiles and clean contact - to enrich the idea-generation phase. Each group was expected to create a total number of 20 ideas for each cell in the Matrix. Figure 4.6 presents an example from this exercise's outcomes, and design ideas marked with green plusses indicate that they are from the BSA exercise. In this example, the group has added 'multifunctional' dimension as a self-defined project dimension.

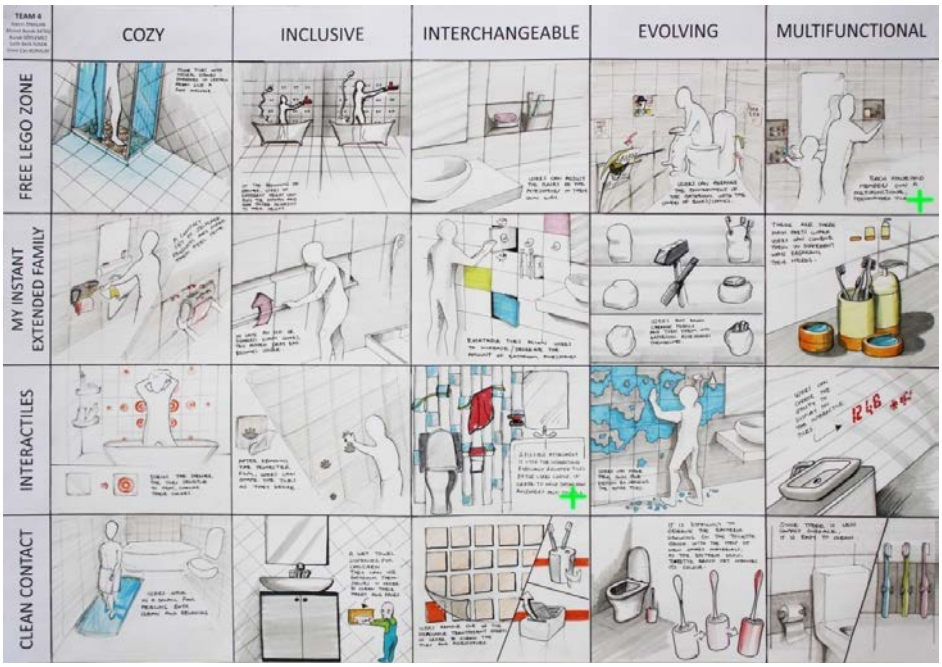

Figure 4.6 – A presentation board for the Matrix exercise presented by Adem Önalan, Ahmet Burak Aktaş, Burak Söylemez, Salih Berk İlhan and Ümit Can Koralay.

The following Task exercise is undertaken individually, and aims to develop and enrich the ideas generated in the idea-generation exercises - i.e. BSA, Matrix - by providing the students with certain 'tasks' to develop the ideas towards. The given tasks for this project are as follows:

1. Make it a product family which empowers and enables kids OR elderly.

2. Make it a product family which allows personalization.
3. Make it a product family which allows upgrading OR repair OR reuse

The students were expected to develop a total of three diverse ideas for three aforementioned tasks by focusing on and/or compiling ideas generated throughout the BSA and Matrix exercises. The integration of the BSA results was up to the students, and the biomimicry approach was not exclusively integrated into the exercise. Figure 4.7 shows an example to the Task exercise outcomes.

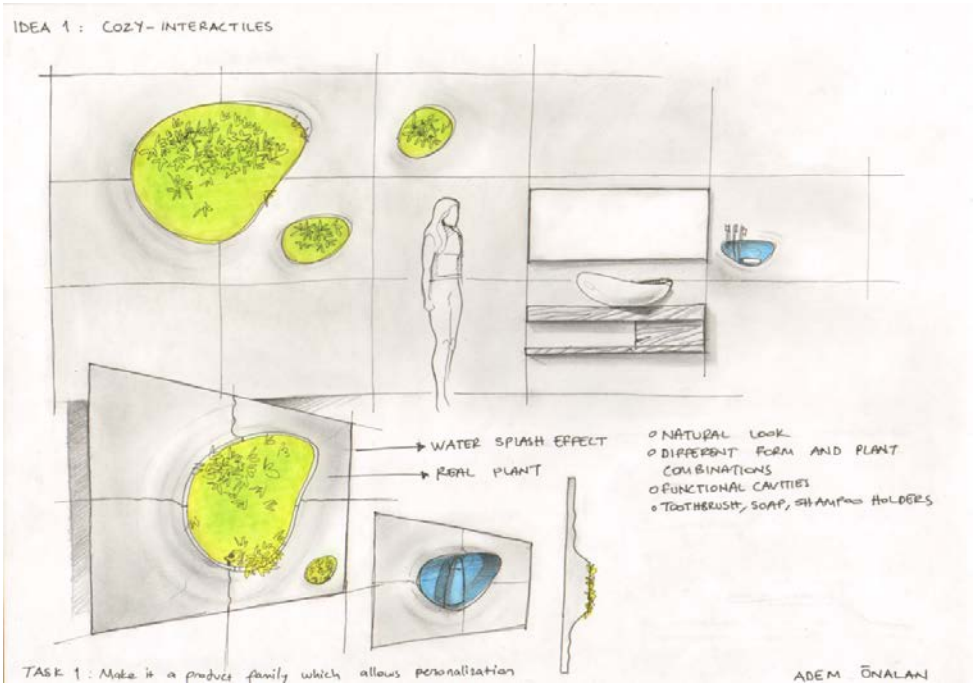

Figure 4.7 – A project example for the Task exercise presented by Adem Önalan.

In the example above, the student has developed further the design idea developed from the free Lego zone - inclusive intersection of his/her group's Matrix exercise outcome through considering the task of 'allowing personalization'.

Understanding these exercises appear to be important for this research, as the use of the biomimicry approach in these exercises are to be assessed in the following sections to better understand the implications of biomimicry and BSA for the educational design project. In the next section, the findings and conclusions from the semi-structured interview for students are presented.

4.2.3. Interview Results for Students

This section of primary research presents the results of the semi-structured interviews conducted with third-year students upon the implementation of BSA into the design project. This section is divided into two: results for four groups of students analyzed in depth in regard to their use of biomimicry and other general results on the insights of the students regarding the BSA exercise.

4.2.3.1. Grouping of Students in Regard to Usage of Biomimicry

Upon analyzing the results of the interviews and the analysis of the project outcomes (i.e. final design solutions presented at the final jury), there appeared to be four groups of students with respect to the incorporation of the biomimicry approach:

- Group 1: These students found the biomimicry approach helpful and developed a design project inspired and informed by nature
- Group 2: These students found the biomimicry approach helpful, yet they were not able to develop design projects inspired and informed by nature
- Group 3: These students found the biomimicry approach not helpful enough, yet they developed design projects inspired and informed by nature.
- Group 4: These students found the biomimicry approach not helpful enough and their design projects were not inspired and informed by nature.

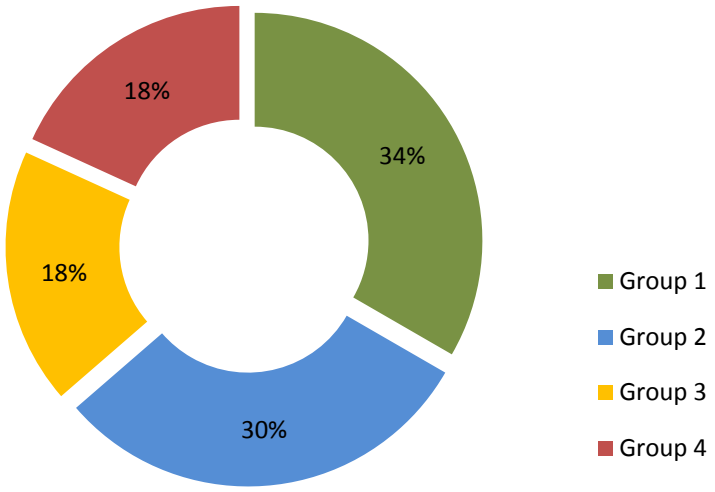

Figure 4.8 – The categorization of the four main student groups in terms of their use of and thoughts on the biomimicry approach.

Figure 4.8 shows the division of students regarding this categorization. In total, 17 out of 33 students developed their final design projects inspired by nature, 11 of which fall into Group 1. On the other hand, 16 out of 33 students developed their design projects that were not inspired by nature, 10 of which fall into Group 2. Overall, there are 22 out of 33 students who found the biomimicry approach helpful for the idea-generation phase (Group 1 and 2), whether they could utilize it or not.

Further results on the use of biomimicry in regard to the following project phases -i.e. Matrix exercise, Task exercise, pre-jury and final jury - , and on the steps and the outcomes of the BSA exercise are explained according to these groups.

4.2.3.1.1. Interview Results of Group 1 based on the Use of Biomimicry

Group 1 students found the implications of biomimicry for the idea-generation of the project as useful in regard to *creating a starting point, number of ideas developed, awareness towards the project needs* and *awareness of nature as an inspiration source*. Considering the effects of the biomimicry approach on the idea-generation phase, these students mentioned that they were not content with the level of incorporation of biomimicry, they simply asked for more. Although the implications of biomimicry were considered to be useful and influential, they pointed the biomimicry approach could have had more potential for the idea-generation.

Creating a Starting Point: The majority of the students pointed out that at the beginning of their design projects, the development of initial ideas were generally appeared to be difficult, as they the students not know where to start with. Thus, an exercise on biomimicry provided them with a starting point to develop ideas upon. Even though the ideas developed during the biomimicry exercise has changed in line with the design considerations of the project, the implication of biomimicry for the idea-generation was thought to be successful for this aspect.

The Number of Ideas Developed: As the results of BSA were displayed in the studio and shared among the students, and additionally they remained in the studio for a period of time, - around two weeks - the students stated the number of ideas have influenced them in a positive way throughout the idea-generation phase of the project.

Awareness towards Project Considerations: The students pointed out the effects of biomimicry strategies included in the BSA - adapt and attach-detach- were actually useful, as they were crucial for developing solutions based on the design considerations predefined in the project

brief. One of them stated that the 'attach-detach' and 'adapt' strategies were what they were expected to do for the project.

Awareness of Nature as an Inspiration Source: The students mentioned that they gained a new perspective about nature in terms of what it had to offer as a knowledge source and how it could be observed and used. One of the students (Student 10) mentioned it as: "There exist things in nature that we were not aware of."

These insights from Group 1 students actually are in line with their project outcomes, as they have generally used the biomimicry approach throughout their design processes and presented their final design solutions inspired by nature. Figure 4.9 shows to what extent they have used the biomimicry approach throughout the design process. Dark green figures show how many of the Group 1 students have used biomimicry in the Matrix exercise and/or the Task exercise. Light green figures indicate the subgroups of Group 1, with respect to the use of biomimicry throughout the project phases.

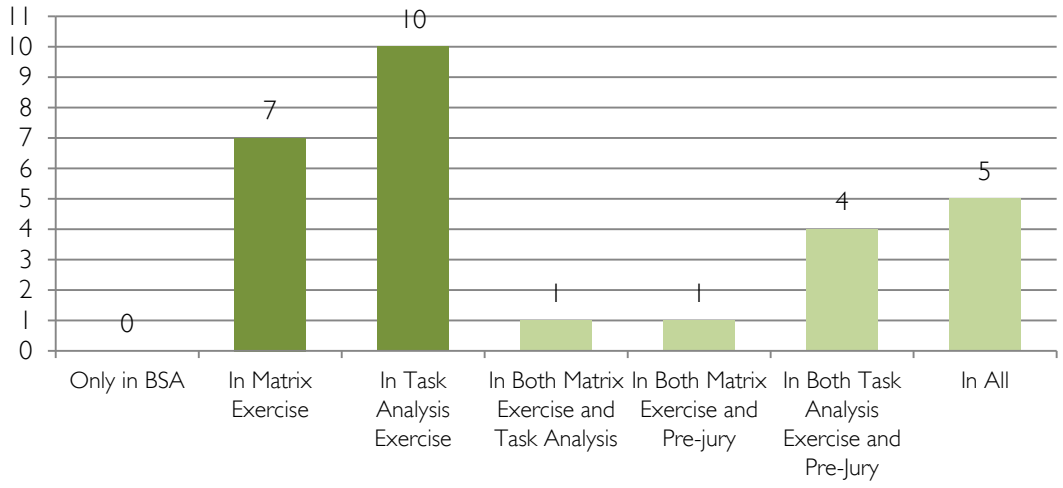

Figure 4.9 – The incorporation of biomimicry into the project phases for Group 1.

As shown in Figure 4.9 (above), 7 out of 11 students used biomimicry in the Matrix exercise, and 10 out of 11 students used it in the Task exercise. Considering that both of these exercise had different purposes of their own at the idea-generation phase, high-rate use of biomimicry within these exercises supported the influential effects of the biomimicry approach on the project, which the Group 1 students pointed out. Apart from that, considering the number of students who use biomimicry being higher in the Task Analysis Exercise than in the Matrix

Exercise, the biomimicry approach appears to be used more in the individual assignments. The reasons of this are explored, in 'Other Results' section.

According to Figure 4.9, nearly half of the Group 1 students (5 out of 11) have used the biomimicry approach in all of the phases. This is important in the sense that, it suggests the adoption and the use of the biomimicry approach right after the BSA, throughout the design process. Figure 4.10 shows the Group 1 students' use of the biomimicry approach throughout the design process individually.

Figure 4.10 – The individual use of biomimicry in the project phases for Group 1.

As can be seen from Figure 4.10, there are five students (1, 6, 7, 10, 11) who used the biomimicry approach - either their own results of the BSA exercise or another source - throughout the project phases. Another interesting data here was that one student (Student 5) presented an outcome inspired by nature, even though he/she did not use biomimicry in the pre-jury phase of the project. The reasons for this change are explained in the 'Student Cases' section.

As shown in both Figure 4.9 and Figure 4.10 more than half of the Group 1 students used biomimicry throughout the whole project phases and all of them incorporated the biomimicry approach into the most of the project phases. Yet, the nature of this incorporation or the sources of inspirations the students use are not presented in these figures (4.9 and 4.10).

When asked if they used any other inspiration sources from nature, the majority of Group 1 students (7 out of 11) mentioned they also sought other natural inspirations during the design

process (Figure 4.11) The mentioned other natural inspiration sources were generally sudden ideas originated from individual experiences, thus they lacked the observation stage of the BSA.

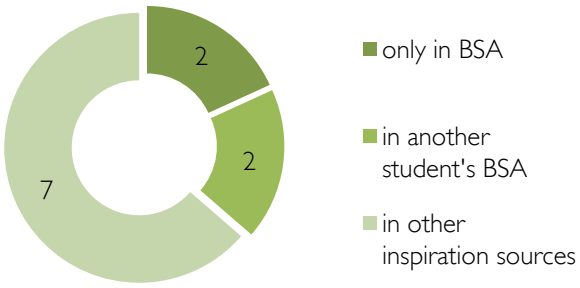

Figure 4.11 - Seeking Natural Inspirations throughout the Design Process for Group 1.

While, on the other hand, only 2 out of 11 the Group 1 students sought for natural inspirations from only the BSA exercise (Figure 4.11). This suggests that, Group 1 students sought for more than the results of the BSA exercise and adopted the biomimicry approach throughout the all project phases, which supported the initial result of *they simply asked for more*. This apparent high-rate adoption of the biomimicry approach, not only in BSA exercise but also among all other project phases, was not an unexpected result for Group 1, since it fit perfectly with the group's definition: the students who found the biomimicry approach helpful and developed a design project inspired from nature.

While the Group 1 students sought for other inspirations in nature, their final designs were mostly originated from their BSA outcomes. Figure 4.12 shows the results of the question regarding the origin of the inspirations used in their project outcomes.

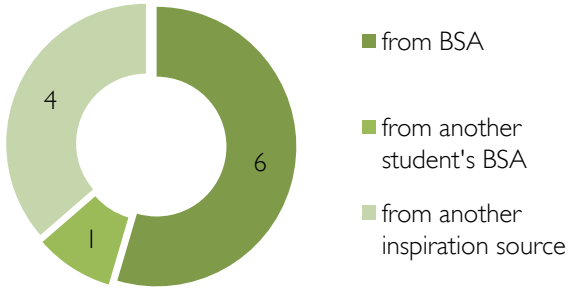

Figure 4.12 – The origins of natural inspirations for the final designs of Group 1.

As can be seen in Figure 4.12, more than half of the outcomes of Group 1 students' projects (6 out of 11) are originated from their own BSA results, while 4 out of 11 of them have resulted from other inspiration sources that the students have found, observed and inspired from during the design process. Only one of the students pointed out that he/she incorporated another student's BSA result into his/her project (Student 5). In this regard, the BSA exercise was found to be influential in the adoption of the biomimicry approach for the Group 1 students. Nearly half of the students developed project outcomes from other inspiration sources from nature considering the design problem at hand, even though they did not reach those initial design ideas during the BSA exercise.

With respect to the stages of the BSA exercise - observation, analysis and transfer - the Group 1 students were generally content with each stage and exercise as a whole. One of the students (Student 5) mentioned that: "The stages of the BSA exercise were already interrelated, and led us to a process that was supposed to be." Yet, Group 1 students mentioned the problem of time management and their lack of biology knowledge in two stages (i.e. observation and transfer). The observation stage was thought to be difficult to utilize, since, at the beginning of the exercise, they did not know what to look for in nature and the necessity of exploring that aspect put them in a tight schedule. This also affected the quality of the analysis and the inspiration source to transfer it into the design project.

Conclusions for Group 1 Students

Group 1 students emphasized various positive effects of the biomimicry approach and the BSA exercise - i.e. creating a starting point, number of diverse ideas developed, awareness towards the project needs and design considerations, and awareness of nature as an inspiration source. The high-rate adoption of the biomimicry approach not only in the BSA exercise but also throughout the project phases, and the use of other inspiration sources from nature suggest that the BSA exercise has presented them a fresh perspective on using nature as model and means on how to do that. According to the Group 1 students, the stages of the BSA exercise were applicable and logical, yet the necessity of more time was mentioned by all of them, affecting the quality of the BSA outcomes and the incorporation of the approach into the project phases.

4.2.3.1.2. Interview Results of Group 2 on Usage of Biomimicry

The Group 2 students responded to the implication of biomimicry for the idea-generation phase of the project similar to Group 1 students. They found the implication of it useful in

regard to *creating a starting point, the number of ideas developed, awareness towards the project needs* and *awareness of nature as an inspiration source*. On the other hand, the students also pointed out that the implications of biomimicry would be more appropriate in a conceptual design project, since inspiring from nature in a future projection would be more fruitful. Although the implications of biomimicry were considered as useful and influential by the Group 2 students, it should be noted that none of these students have produced an outcome or developed a design project from a natural inspiration source. In this respect, the students have mentioned the *misinterpretation of the exercise* and *the necessity of a fresh start as a strategic decision.*

Creating a Starting Point: The majority of Group 2 students mentioned that the biomimicry approach at the idea-generation phase provided them with a new perspective. They stated that the bathroom tiles and bathroom accessories had been explored to a great extent by industrial designers, and developing diverse and fresh ideas in such a saturated sector was a hard task for the design students. One of the students stated that: "Ceramics was a done area, and with biomimicry we could look at the project from outside" (Student 21).

The Number of Ideas Developed: The students mentioned the pool of ideas generated as a result of the assignment was influential. Even though, the Group 2 students did not utilize the biomimicry approach for their final designs, they highlighted its potential for generating many ideas on a project and considered it as helpful and inspiring.

Awareness towards Project Needs and Design Considerations: The students mentioned the influence of the biomimicry strategies - e.g. attach-detach, adapt – that created an awareness on project needs and regarded the biomimicry approach as useful both in meeting the project's design considerations and in generating diverse ideas.

Awareness of Nature as an Inspiration Source: The majority of Group 2 students stated that they were not aware of nature as such an extensive source of inspiration, and they became more conscious of and interested in it through the integration of the biomimicry approach. This newly gained perspective on nature was important for the students, while, on the other, it was just a realization of a project phase and requirement, as well as an additional tool contributing to their skill sets.

Non-transferability between the BSA stages: The students also emphasized that they were not able to utilize their BSA results in their final designs due to the non-transferability between the BSA stages. The mentioned reasons for misinterpretations and non-transferability include

focusing on specific functions rather than systems in nature, and inability to abstract and transfer the inspiration sources.

Necessity of a Fresh Start as a Strategic Decision: Even though the biomimicry approach were influential and considered helpful for the Group 2 students, they generally referred to a point or stage during the design process where they left the biomimicry approach. The reasons for this were stated as not being content with the ideas generated in the BSA exercise, and feeling more comfortable with using the methods and tools they were familiar with to generate new ideas.

The above mentioned results the Group 2 students have provided are consistent with their use of the biomimicry approach throughout the design process. Figure 4.13 shows the extent the Group 2 students have used the biomimicry approach in the design process. Dark blue figures illustrate the number of the Group 2 students have used biomimicry in the Matrix exercise and/or the Task exercise. Light blue figures indicate the subgroups of Group 2, with respect to the use of biomimicry throughout the project phases.

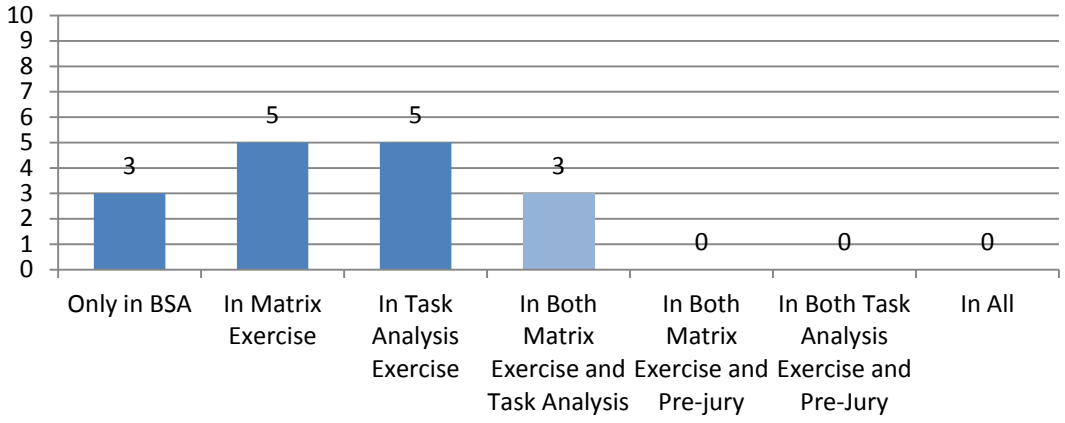

Figure 4.13 – The incorporation of biomimicry into the project phases for Group 2.

As can be seen in Figure 4.13 (above), none of the Group 2 students used biomimicry after the Task exercise and only half of them (5 out of 10) used biomimicry in the Task exercise. 3 out of 11 students left the biomimicry approach after the BSA exercise. Half of the students (5 out of 10) used the biomimicry approach in the Matrix exercise, 3 of which continued using it in the Task exercise as well. Regarding these results, it would be useful to see how the

biomimicry approach was used by the Group 2 students throughout the design process individually (Figure 4.14, below).

As can be seen in Figure 4.14 (below), half of the students (student 15, 17, 18, 19, 21) used biomimicry until the Task exercise, and only three of those students (student 17, 19, 21) used the biomimicry approach in all phases of the design process until the pre-jury. The reasons for this are examined in the 'Student Cases' section.

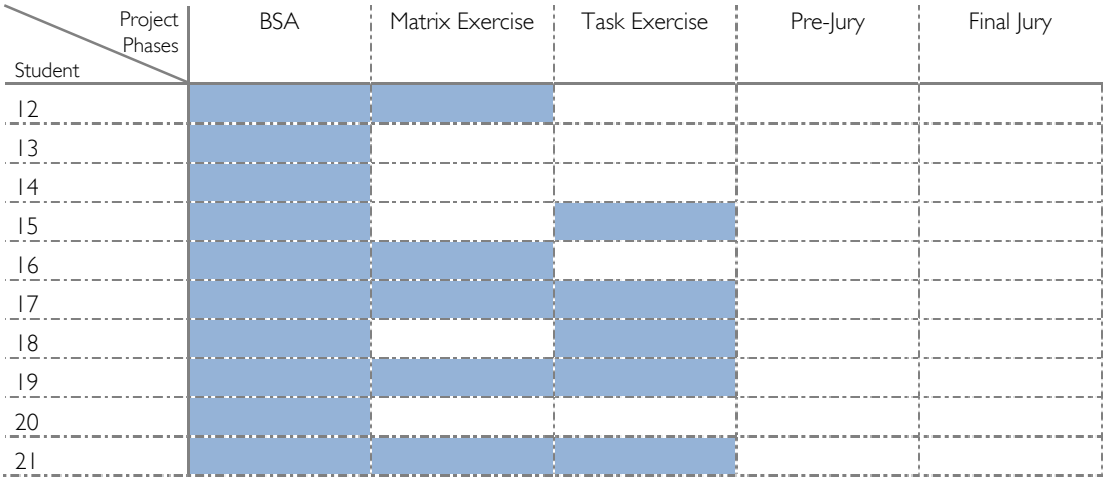

Figure 4.14 – The individual use of biomimicry in the project phases for Group 2.

When asked if the Group 2 students sought other inspiration sources, only 2 out of 10 stated that they looked for other inspiration sources (Figure 4.15). The exemplified other inspiration sources were water drops and shapes of leaves. Yet these two students stated that they were not content with the transfer of these other inspiration sources into generating design ideas as well, thus left the biomimicry approach as a result.

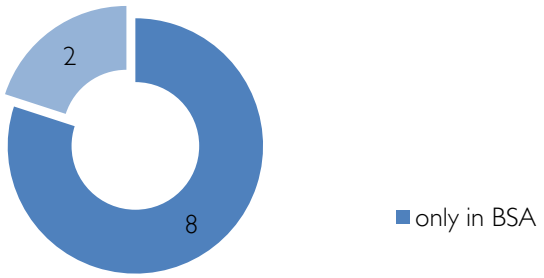

Figure 4.15 - Seeking natural inspirations throughout the design process for Group 2.

Regarding the stages of the BSA exercise, the Group 2 students were content with the first two stages of the exercise that were observation and analysis respectively. They found the strategies 'productive' with respect to limiting such an extensive and rich inspiration source - nature - and emphasized their positive effects on the observation and the analysis stages. Yet, they found the transfer stage particularly challenging due to various reasons - i.e. time management, constraints of the project, inability of abstracting. Only one of the students was satisfied with the stages of the exercise (Student 16). She stated that the transition between the stages was easy to follow, and the results were "trust-worthy" since she knew where the ideas came from and how they emerged.

Conclusion for Group 2 Students

The Group 2 students found the biomimicry approach useful for various reasons - i.e. creating a starting point, number of ideas developed, awareness towards the project needs and awareness of nature as an inspiration source, yet they were not able to utilize it affectively in the BSA exercise, which might be related to the fact that they did not generally seek other inspiration sources. 8 out of 10 students did not continue looking for other inspiration sources in nature, and moved towards other presented and incorporated idea-generation tools that they were familiar with, as a strategic decision. 7 out of 10 students tried using the biomimicry approach in the following phases of the project, yet did not pursue those ideas for their final designs. The general comment on the transfer stage of the BSA is emphasized by the students as challenging, which suggests that the stages of the exercise need to be developed further to make it easier for the students to adopt.

4.2.3.1.3. Interview Results of Group 3 on Usage of Biomimicry

The Group 3 students present interesting results in regard to the context of this research. This group did not find the integration of the biomimicry approach helpful for the idea-generation phase, yet they produced a project outcome and developed a final design solution informed and inspired by nature. They mentioned the exercise provided them with an *awareness of nature as an inspiration source*, yet they were not content with the outcomes of the BSA exercise initially. *The number of ideas developed* as a result of the exercise was mentioned influential, yet this also constituted a negative aspect for the students as well in terms of dealing with numerous design ideas emerged from the exercise. *Disbelief in the usefulness of the biomimicry approach* was another aspect mentioned in the interview sessions. Another reason

why this group did not find the biomimicry approach useful, was the *perception towards the BSA exercise*, which was considered as a warm-up session before the idea-generation phase.

Number of Ideas Developed: Although a number of students mentioned the integration of the biomimicry approach was helpful in generating numerous ideas, but regarded as more than they could handle. The group highlighted the problems in focusing on particular results to develop them further at first. These comments on the number of ideas developed were found worth mentioning, in the sense that the Group 3 students presented a final design project originated from a natural inspiration source. It might be also useful to propose a means of analyzing and using these numerous ideas within the context of the project for the students.

Awareness of Nature as an Inspiration Source: The Group 3 students mentioned they gained a new perspective about nature regarding its potential as an inspiration source, yet in the BSA exercise they were not able to utilize this aspect of nature, and explained their understanding of biomimicry as inspiring from nature not in depth, and not focusing on its systems and organism. One of the students mentioned this inspiration within the context of this project, might even be called symbolic rather than a thorough observation and transfer of the source of inspiration (Student 22).

Disbelief in the Usefulness of the Biomimicry Approach: The majority of the Group 3 students mentioned that they did not perceive the biomimicry approach as a solid approach at the idea-generation phase. They believed, either from personal point-of-view or due to some insights from unmentioned sources, the biomimicry approach was not worth focusing on.

Perception of the BSA Exercise: All of the Group 3 students mentioned that they saw the BSA exercise as a warm-up session for the idea-generation and did not expect any useful outcomes from it. This may have resulted from, or have resulted in, all the comments mentioned above.

These insights from the Group 3 students are mainly not matching with their use of the biomimicry approach throughout the project phases. As presented in Figure 4.16, the Group 3 students used the biomimicry approach in the design process. In Figure 4.16, dark figures show how many of the Group 3 students have used biomimicry in the Matrix exercise and/or the Task exercise. Light yellow figures indicate the subgroups of Group 3, with respect to the use of biomimicry throughout the project phases.

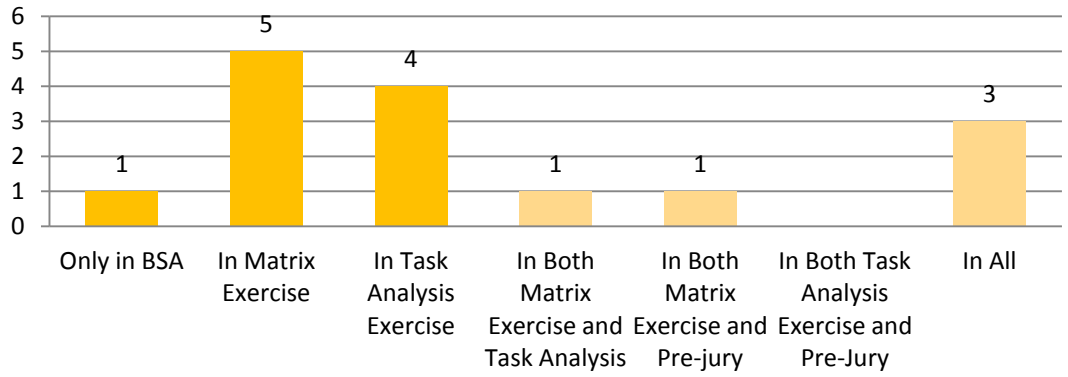

Figure 4.16 – The incorporation of biomimicry into the project phases for Group 3.

As can be seen it Figure 4.16 (above), 5 out of 6 students used the biomimicry approach in the Matrix exercise and 4 out of 6 students used it in the Task analysis exercise. There was only one student who used the biomimicry approach only in the BSA exercise prior to his final design. There was also one student that used the biomimicry approach in both the Matrix and Task exercises, and one student that used in both the Matrix exercise and the pre-jury. Half of the Group 3 students (3 out of 6) used the biomimicry approach throughout the project phases. To better understand the use of biomimicry in project phases, Figure 4.17 illustrates the individual use patterns for the Group 3 students.

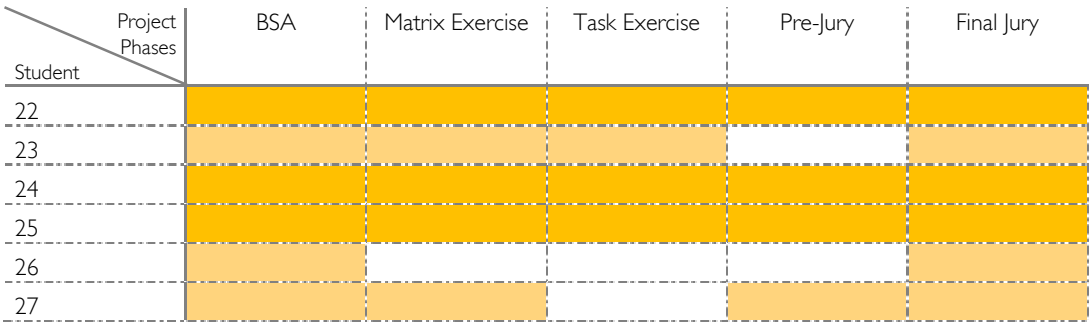

Figure 4.17 – The individual use of biomimicry in the project phases for Group 3.

As can be seen in Figure 4.17, the Group 3 students generally adopted the biomimicry approach in this project. Student 22, 24 and 25 used the biomimicry approach in all of the project phases. The use of biomimicry of Student 26 is significant, in the sense that s/he has not

used the biomimicry approach in any of the project phases, except for the BSA exercise and the final jury. The reasons for this are explored thoroughly in the 'Student Cases' section.

As shown in both Figure 4.16 and Figure 4.17, the Group 3 students generally used the biomimicry approach in most of the project phases, and presented a final design originated from a natural inspiration source. Yet, the nature of this incorporation or which inspirations they used could not be evaluated in these figures. Figure 4.18 (below) reveals the origin of the natural inspirations used for their project outcomes.

Figure 4.18 (below) shows that half of the Group 3 students (3 out of 6) have presented their final designs originated from other inspiration sources (Student 23, 26 and 27). This result was interesting due to the fact that the Group 3 students found the biomimicry approach not useful enough, yet sought inspirations from other inspiration sources. 2 out of 6 students pursued their BSA results in the following phases of the project. Only one student used another student's BSA result in his/her final design (Student 24). The reasons for these are further explored in 'Student Cases' section.

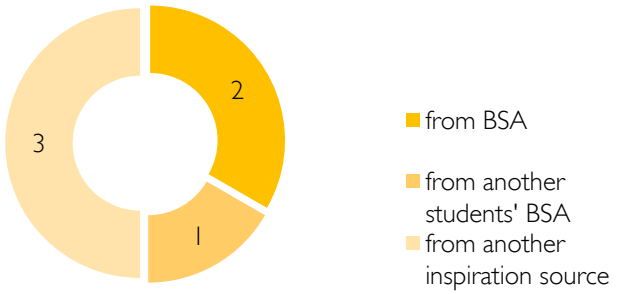

Figure 4.18 – The origins of natural inspirations for the final designs of Group 3.

When asked about the stages of the exercise, the majority of the Group 3 mentioned the last stage (i.e. transfer) was hard due to the project constraints, especially the ceramics as the main material. They had problems in transferring their analysis of the inspiration sources into eligible ideas for the project. The students in this group also mentioned the lack of time in the analysis stage caused rather shallow analysis of the observed inspiration sources, which might have affected the outcomes of the BSA exercise negatively. One student mentioned the outcomes of the BSA exercise had the potential to be utilized later on, even though they were "unrefined and raw" due to the transfer stage (Student 23).

Conclusions for Group 3 Students

Although the Group 3 students found the biomimicry approach not useful enough, they produced a final design with a natural inspiration source, and even half of them adopted the approach throughout the all project phases. What was more interesting for Group 3 that, more than half of them sought for and utilized natural inspirations not present in their BSA results. This might be due to various reasons, such as using a natural inspiration could be found useful in the assessment of their final designs based on the design considerations or a sudden realization of advantages of a natural form or function throughout the design process. The fact that they have not found the biomimicry approach useful enough may be resulted from their discontent in the transfer stage of the exercise.

4.2.3.1.4. The Interview Results of the Group 4 on Usage of biomimicry

The Group 4 students did not found the biomimicry approach useful and did not produce a project outcome with a natural inspiration. The *non-transferability between the BSA stages* was a common issue among the Group 4 students. In addition to that, the *lack of critiques* and the *perception of the exercise* were also stated during the interviews.

Non-transferability between the BSA stages: The majority of the Group 4 students mentioned that they focused on specific functions in nature, thus they were not able to transfer their observations into such a multi-faceted project. One of the students even stated that s/he did not think that s/he generated any useful idea, due to this reason (Student 30).

Perception of the Exercise: The exercise was perceived as a warm-up session for the idea-generation phase by the Group 4 students as well, and was thought as obligatory for these students. The majority of the Group 4 students did not perceive the exercise as a solid idea-generation tool, and completed the exercise on this basis.

Lack of Critiques: One of the Group 4 students stated that the critiques were not enough for the exercise to be useful (Student 28). S/he stated that the lack of critiques resulted in the misinterpretation of the exercise as a warm-up session.

These insights of the Group 4 students fall in line with their use of biomimicry throughout the project phases. Only one of the students (Student 28) mentioned s/he used the biomimicry approach in the Task exercise, and others did not use biomimicry in any of the following project phases.

On the stages of the BSA exercise, the majority of the Group 4 students mentioned they could not handle the transfer stage. They stated that the results of their BSA were not eligible for the project at hand, due to the incompetency of the transfer stage. While limiting the natural inspirations by the strategies were considered as a help in the observation stage of the exercise, they generally expressed there should have been more strategies to be presented in the BSA exercise.

Conclusions for Group 4 students

The Group 4 students have found the biomimicry approach not helpful and they did not use it in the design process. They highlighted three negative aspects regarding the implications of biomimicry for the design process which are: the *non-transferability between the BSA stages,* the *misperception of the exercise* and the *lack of critiques*. They found this integration of the biomimicry approach into idea-generation phase of the design project as not meaningful.

4.2.3.1.5. General Conclusions for All the Groups

Aforementioned sections present the results from the thematic coding and analysis (see Section 3.3.4.3) and aims to enlighten some of the categories for the content analysis mentioned in Section 3.3.4.2. The Groups of students show major similarities and differences, and Table 4.3 aims to illustrate these similarities and differences according to the comments made during the interviews classified through the categories emerged from the content analysis. The results are color coded according to the groups - green, blue, yellow, red - and categories - light gray and dark gray.

Table 4.3 – The Similarities and the Differences among the Four Groups of Students.

		Group 1	Group 2	Group 3	Group 4
Biomimicry Exercise in Design Process	Creating a starting point				
	Number of ideas developed				
	Awareness towards the project needs				
	Awareness of nature as an inspiration source				

Table 4.3 – The Similarities and the Differences among the Four Groups of Students. (continued)

	Necessity of a Fresh Start as a Strategic Decision				
	Disbelief in the Usefulness of the Exercise				
BSA Exercise	Misperception of the exercise				
	Non-transferability between the BSA stages				
	Lack of Critiques				

As can be seen in Figure 4.3 (above), Group 1, 2 and 3 students mentioned *number of ideas developed* and *awareness of nature as an inspiration source* as positive aspects of the implications of the biomimicry approach for the design process. The Group 1 and 2 students also mentioned this approach created a starting point at the idea-generation phase and raised awareness towards the project needs. Only the Group 2 students mentioned *a necessity of a fresh start* arose during the design process as they were not able to generate ideas that they were content with through using the biomimicry approach. Only the Group 3 students stated a *disbelief in the usefulness of the exercise* in generating ideas at first, yet they used the biomimicry approach in the following phases.

In the sections above, the use of the biomimicry approach throughout the design process was shown for each student with respect to the groups of students. Within the context of this research, it is significant to see the use of biomimicry throughout the design process for each student for all groups. Figure 4.19 illustrates the use of biomimicry throughout the design process, color coded according to the groups. Group 1 is shown with green, Group 3 with yellow, Group 2 with blue, and Group 4 with red.

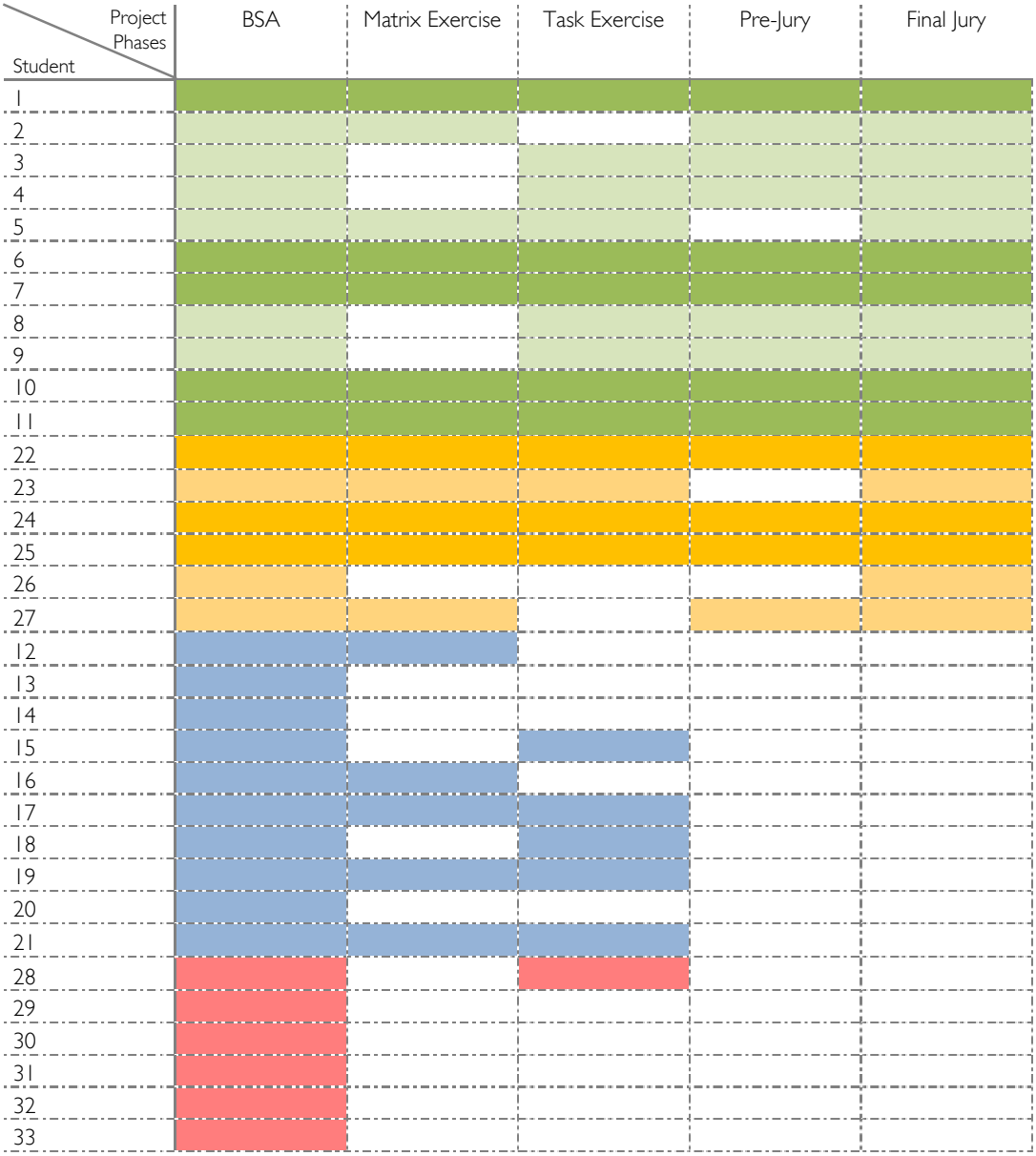

Figure 4.19 – The individual use of biomimicry in the project phases for all groups.

As presented in Figure 4.19 (above), 17 out of 33 students developed a final design originated from a natural inspiration source (Group 1 and 3), nearly half of which (8 out of 17) used the biomimicry approach throughout the all phases of the design process. In total, 17 out of 33 students used the biomimicry approach in the Matrix exercise and 20 out of 33 used it in the Task exercise. The number of the students who has used biomimicry in the Task exercise is higher than those who used it in the Matrix exercise, which suggests an interesting result with respect to the Task exercise conducted individually in comparison to the Matrix exercise conducted in student teams. This is discussed in Section 4.3.3.2.3.

Regarding the BSA exercise and its stages, Figure 4.19 (above) indicating that, the Group 3 and 4 students share a *misperception of the exercise*, and regarded it as a warm-up session for the idea-generation phase of the project rather than an important phase of the project. The Group 2 and 4 students mentioned the *non-transferability between the BSA stages* with respect to focusing on or seeking specific functions instead of systems and relationships in nature, which affected the quality and usefulness of their BSA results. Only the Group 4 students mentioned the *lack of critiques*. Considering that they did not adopt the biomimicry approach throughout the design process, this might suggest that this group of students were the ones that needed the critiques the most, or the ones that instructors were not able to provide critiques, which affected their BSA results and the way they explored and understood the biomimicry approach. With respect to the stages of the BSA exercise - i.e. observation, analysis and transfer – the Group 1 members expressed their content with the exercise phases, yet all the other groups mainly emphasized and found the transfer stage as challenging, and they provided two main reasons: time management and inability to abstract for the project. These reasons are explained in the next section, along with the other results from the interviews.

4.2.3.2. Other Results

In this section, other results from the interviews conducted with the students are presented. The content analysis was used to analyze the interview transcripts in general and the results that would not apply to each specific group of the students, developed through thematic coding and analysis, were derived. These results are presented as follows.

4.2.3.2.1. The Effects of the Research Phase on the Design Process

The research phase of the design process was the only phase before the implication of the BSA exercise, and it consisted of the literature search and the field observations phases. The aim for this research was to explore further the project dimensions stated in the project brief. Considering this, the students were asked if the research phase affected their BSA exercise and its outcomes.

The results appeared to be significant to understand the implications of that phase for the design process in general. The findings revealed that the majority of the students were not able to utilize the outcomes of the research phase, not only in the BSA exercise but also in any other phase of the design process. The reasons mentioned for this were the quality of the

presentations, and the reluctance to attend the research presentations made by the student groups. Consequently, the BSA exercise and other following phases were considered as separated from the research phase, thus the effects of the research phase on the BSA exercise and on the implications of it for the biomimicry approach could not be assessed thoroughly. At the same time, this would not indicate that the research phase did not affect the BSA results and/or project outcomes at all.

Only eight students mentioned the utilization of the research outcomes in the BSA exercise, and only two of them were able to give an example of this utilization - i.e. soap holders getting soap stains, (Figure 4.20) and ceramics as a brittle material (Figure 4.21).

Although these eight students represent a small group in the sampling and an in-depth exploration of the issue cannot be made, the comments of these students have been found worth mentioning for further insights. The outcomes of the research phase that was utilized by these students were as follows:

Personalization: It was mentioned that the exploration of the design consideration, namely personalization within the context of the bathroom environment affected their idea-generation phase in general, yet they were not able to give a specific example to that.

Cleaning: The students have mentioned that the research phase has helped them realize how important the cleaning of the bathroom environment is. The field observations have provided them with insights into where and which objects require frequent cleaning and why these places or objects get dirty in the first place. Only one student was able to give an example of this aspect affecting his/her BSA results (Figure 4.20). He stated that by inspiring from the rubber tree leaves on draining the water accumulated on them, he was able to provide a solution for the soap holders to prevent them from getting soap stains.

The Use of Ceramics Material: The students also mentioned that the research phase provided them further insights into the use of material - ceramics - selected for the project and the pros and cons of it (e.g. ceramic tiles being slippery when they get wet, ceramics as a brittle material, etc.) Only one student was able to provide an example (Figure 4.21) and he stated that he tried to provide a solution for reducing the break of ceramic bathroom accessories through creating a locking mechanism inspired by whiskers of the catfishes helping them lock onto each other.

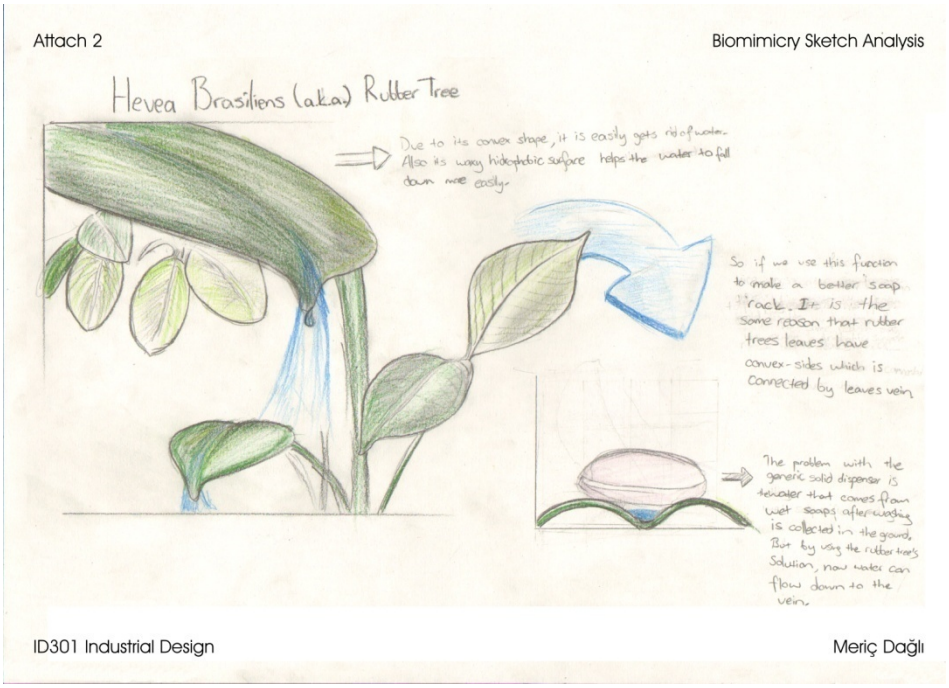

Figure 4.20 - An example of the research outcomes - i.e. soap holders getting soap stains – incorporated in the BSA exercise presented by Meriç Dağlı.

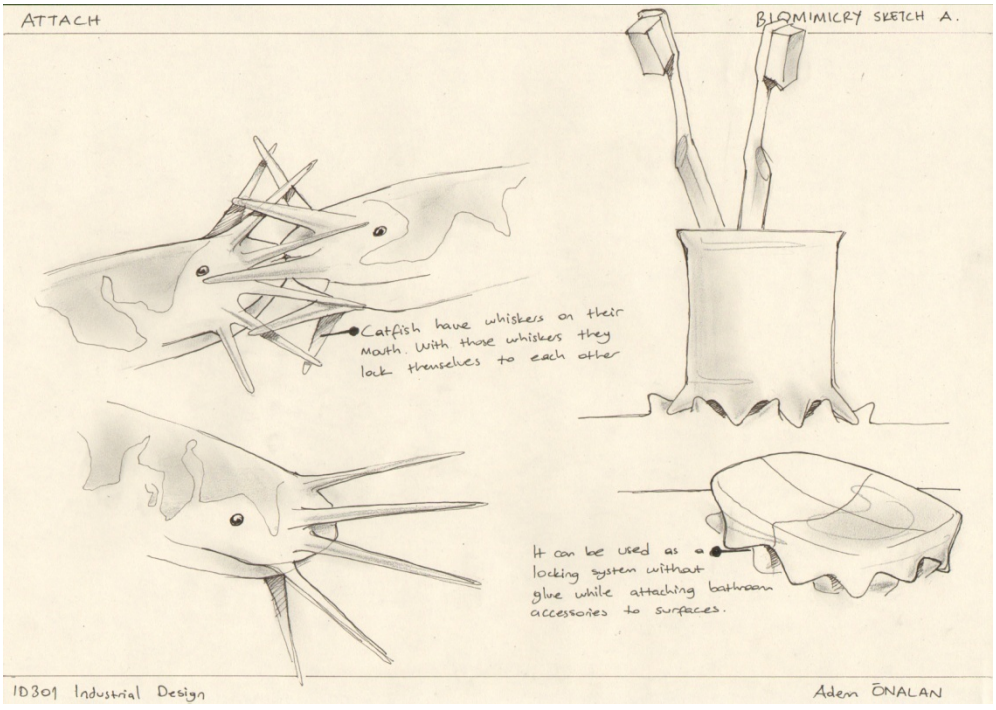

Figure 4.21 - An example of the research outcomes - i.e. ceramics as a brittle material – incorporated into the BSA exercise presented by Adem Önalan.

As mentioned before, the students considered the research phase separated from the idea generation phase, since the findings and conclusions for the effects of the research phase on the BSA exercise were not comprehensive, due to the general attitude of the students towards the research outcomes.

4.2.3.2.2. The Biomimicry Presentation and its Effects

The third-year students have stated various aspects of the biomimicry seminar developed and presented before the BSA exercise by the researcher. On the structure of the presentation, the majority of the students mentioned that the *introductory knowledge on the biomimicry approach* was helpful in providing a better understanding about the use of biomimicry in product design and the *strategies from nature* selected for the project were explained thoroughly. A few of the students emphasized the *necessity of more examples* on current applications of biomimicry in relation to the strategies. In general, the students have used the presentation as *a guide to look back to* that aided them to *acquire a critical perspective* to use nature as an inspiration source. These aspects will now be explained in more detail.

Introductory Knowledge on Biomimicry: The majority of the students stated that the presentation provided them with necessary basic information about biomimicry and how it was utilized around the world. The students also acknowledged that the biomimicry approach was introduced clearly and they understood what the approach was about. They mentioned the examples of the current applications helped them understand how it was implemented around the world, and gave them an idea of what kind of outcomes to expect from the BSA exercise.

Strategies from Nature and Their Effects: All of the students stated that the strategies given for the BSA exercise - i.e. attach-detach, and adapt - were helpful to limit the inspiration sources present in nature. It provided them with a guide to observe nature, and helped them start the BSA exercise right away. Through the strategies they were able to understand how they could use the biomimicry exercise for sustainable design considerations explained in the brief. The students also mentioned that, even though the strategies were helpful in leading them towards the inspiration sources, there should have been more strategies given for the project, and they stated that by giving only two strategies, to a certain extent, the potential of the biomimicry approach within the context of this project was limited.

Necessity of More Examples: The students underlined that even though the examples helped them understand the strategies - i.e. attach-detach, adapt - thoroughly, they stated that more

examples on the strategies would have helped them even further at the observation stage of the exercise. They stated that the examples in general helped them focus on inspiration sources with the similarities that the examples and the found inspiration sources shared. Thus, with more examples they could have found out more inspiration sources. Also, one of the students mentioned that an example should have been explained with its environment and the system it were in. This is an insightful comment, since the examples are mainly given with the explanation of the functions that those organisms respond to the environment and/or the systems they are in, but not with an overview and analysis of those environment and/or systems.

Guide to Look Back to: The majority of the students regarded the presentation as a source guide to revisit, and used it as a tool whenever they found anything unclear or confusing about the BSA exercise and the biomimicry approach. They mentioned the knowledge and the examples in the presentation were helpful during the BSA exercise and they were able to understand some aspects of the BSA exercise, the biomimicry approach, and the strategies from nature that they could not understand completely at first. This suggests that giving the presentation file to the students was found to be supportive for providing them an open-source on biomimicry.

Acquiring a critical perspective: The students mentioned that the presentation was influential in the sense that the application examples showed them what biomimicry could achieve and the examples for strategies along with explanations provided them the 'critical perspective' on nature, and, its systems and models to achieve similar results. This was an important outcome for the presentation as it aimed to prepare the students for the biomimicry approach through conveying them this 'critical perspective'.

The comments on the biomimicry presentation were mostly positive, and it was generally mentioned as well-structured to provide basic information on biomimicry and how it would be utilized in the design project at hand.

4.2.3.2.3. BSA Exercise as an Individual Assignment

The students were mostly content with the BSA being conducted as an individual exercise and mentioned various positive aspects such as, *easier application of the exercise, different perspectives of the individuals, owning the outcomes individually, number of ideas developed* and *gathering of various inspiration sources*. On the other hand, a few of the students mentioned

possible pros of the group work, such as, *outcomes of better quality* and *relieving the workload*. The comments on these aspects are presented below.

Easier Application of the Exercise: The majority of the students mentioned that the individual conduct of the exercise eliminated the necessity of compromising among the members of a group, thus every stage of the exercise was performed and later assessed individually and easily. The students stated they were able to utilize their time in working on the stages of the exercise more in depth, instead of discussing these stages with the group members.

Different Perspectives of the Individuals: It was mentioned by most of the students that individual work allowed different perspectives on inspiring from nature to be presented. They stated that everybody had a unique perspective towards their environment and as a result of that different BSA outcomes might emerge inspired from the same inspiration source. To compare this aspect between individual and group work, the students pointed out that it would have been hard for groups of students to inspire from nature in a collective manner and outcomes of the BSA exercise done by a group of students would have followed a more reductionist approach rather than a productive and inspiring one.

Owning the Outcomes Individually: The majority of the students stated that the outcomes of the BSA exercise belonged to the individual students. Furthermore, it was also stated that, this process led to an emotional connection towards their outcomes. The students also emphasized that, if the exercise was done by a group of students, the ideas would not belong to anybody and it would have resulted in dropping most of the ideas developed during the BSA exercise in the following phases of the exercise. This result appeared to be significant, since showing that why many of the students did not utilize other students BSA results (*see* Section 4.2.3.1). This result also illustrated that, if the exercise was conducted by groups of students, the results might not have been utilized in the following phases of the design process.

Number of Ideas Developed: All of the students mentioned that the individual conduct of the exercise resulted in presenting many ideas. Developing that many ideas (118 BSA outcomes were presented, to be exact) was considered as a positive aspect for the incorporation of the biomimicry into the design process that inspired the students by creating a pool of initial ideas for the following phases of the design process.

Accumulation of Various Inspiration Sources: In addition to the number of ideas developed, the students mentioned that the outcomes of the BSA exercise presented lots of different inspiration sources in their close environment, and this was directly related to the number of ideas developed. It was also stated that, seeing a wide-range of inspiration sources just in their

environment, encouraged them to look for more inspiration sources in their environment as well as in the online databases.

Outcomes of Better Quality: It was suggested that group work would have resulted in more detailed analysis and transfer of the inspiration sources, and brainstorming would have helped them achieve better quality results. The students also mentioned that, since they lacked certain knowledge in biology, the group work would have provided them with an opportunity to compensate for each others' short comings during the analysis stage. Others stated that, through brainstorming, the analysis of the inspiration sources would have been transferred into ideas that would be more detailed and more appropriate for the project at hand.

Relieving the Workload: A few students emphasized that the BSA exercise required too much effort to be handled individually. These students mentioned that, among the assignments of the other courses they were taking, the BSA exercise required too much physical effort - e.g. observing nature, going to the zoo or the botanical garden, etc. - and the group work would have relieved this workload. This aspect was mentioned by a few students, yet it appeared to be important regarding the future planning and applications of the BSA exercise.

The above mentioned results show that there are pros and cons regarding BSA exercise being an individual assignment. Although the pros suggested that the assignment was developed in a right way and should have been individual, other aspect - i.e. outcomes of better quality and relieving the workload - should also be considered further.

4.2.3.2.4. Perceived Aim of the BSA Exercise

The aim of the BSA exercise was perceived among the students from various perspectives. They mainly acknowledged that the aim of the biomimicry exercise was to *increase the awareness on biomimicry approach*. Other perceived aims mentioned were *conveying a critical perspective*, *learning how to use the biomimicry approach, triggering idea generation* and *enhancing the idea-generation phase*. Two students stated that they had *no idea* about the aim of the exercise. These perceived aims are explained in an order according to the number of times these perspectives have been mentioned. It is important to state that these perspectives are categorized using the gathered responses of the question on the aim of the assignment (*see* Section 3.3.4.1). The number of times these perspectives were mentioned might add up to more than the number of students as they were free to state more than one aim of the exercise.

Increasing the Awareness on the Biomimicry Approach (mentioned by 15 students): The students stated that this exercise was aimed to introduce an idea-generation method for product design. They thought that this was a newly-developing method for idea-generation and they believed the main reasons for integrating it into the early stages of the design process were to inform students about this method and let them experience the biomimicry approach. These students also mentioned that this was achieved with the BSA exercise. This perspective on the aim of the exercise suggested that these students did not make the connection between biomimicry and sustainability, even if they utilized the biomimicry approach for the design considerations for sustainability, or not.

Conveying a Critical Perspective on Nature (mentioned by 10 students): These students mentioned they gained a critical perspective on nature and its organism and systems. They mentioned that the analysis of natural models and systems might lead towards innovative ideas, and to do this analysis stage right, it was crucial to get the critical perspective on nature. These students stated that this aim was achieved, through the biomimicry approach and they were able to experience with the BSA exercise.

Learning How to Use Biomimicry for Sustainability (mentioned by 7 students): These students stated that the BSA exercise was integrated into the idea-generation phase to develop ideas with respect to the sustainable design considerations outlined in the brief. They also emphasized that, through the strategies, they were able to generate ideas for sustainable design considerations and it was simply logical to use biomimicry with the purpose of sustainability. These students stated that this aim was achieved, and, in the end, they had an idea on how to use biomimicry for sustainability, whether they utilized the biomimicry approach throughout the design process, or not.

Enhancing the Idea-generation Phase (mentioned by 5 students): This group of students stated that the BSA exercise was integrated into the idea-generation phase with the purpose of generating innovative or distinct ideas in the sector of highly-explored ceramics bathroom tiles and accessories. They mentioned that this exercise could have been useful in generating new design solutions with respect to various aspects - e.g. the ceramics material, the integration of the bathroom tiles and accessories, creating design solution with a natural feel, etc. Some of these students mentioned that BSA exercise achieved this aim, while others stated that the incorporation of the BSA exercise was unable to achieve this aim.

Triggering Idea Generation (mentioned by 3 students): These students stated that, the BSA exercise was used to lead students towards the idea-generation by providing them with an

inspiration source - nature - and goals in the form of strategies. By doing this, the BSA exercise was able to provide with many different ideas and prevent creative clogs during the design process. They mentioned that the BSA exercise achieved this aim, and it helped them generate ideas in line with the project's considerations.

Regarding the results mentioned above on the perceived aim of the assignment, the BSA exercise helped raise the students' awareness about the biomimicry approach and acquire a critical perspective on nature, with respect to using nature as a model. Yet, only 7 out of 33 students stated the BSA exercise led them towards using the biomimicry approach for sustainable design considerations. This finding suggested that the relation between the strategies from nature and sustainable design considerations should have been conveyed and presented more clearly for the students.

4.2.3.2.5. Using the BSA Exercise in the Future

When asked if the students came across any tool like the Biomimicry Sketch Analysis (BSA) before, only one of the students gave an example of sketches inspiring from a bug to design a vehicle, yet could not point out an exact source for this experience. Thus, it may suggest that these students have not seen anything like the BSA exercise, and in this section, the students' thoughts on using the BSA and the biomimicry approach in their future works are explored. It was also stated that the students would adopt *the biomimicry approach, not the BSA exercise*, for the idea-generation. Others pointed out the pros and cons of the exercise and stated that they would *adopt the BSA exercise* for their future works. Only 3 out of 33 students have specified that they *would not use the biomimicry approach* in their future works.

Adopting Biomimicry Approach, not the BSA Exercise: Nearly half of the students (14 out of 33) mentioned the pros and cons of the biomimicry approach for various aspects - e.g. nature as a wide-range inspiration source, providing a critical perspective to observe nature, a trend in product design, etc. - and stated that they would adopt the biomimicry approach for their future works. Yet they also stated that they would not utilize the BSA exercise for various reasons. They expressed their preference on biology to design approach in the context of biomimicry, implying that biomimicry should be adopted spontaneously rather than systematically. They would also prefer to focus on the analysis of the inspiration sources instead of immediately transferring them into an idea, etc. Regarding these reasons for not using the BSA exercise, it may be suggested that these students will not utilize the biomimicry

approach as their first choice of a tool for the idea-generation phase of a project. They generally stated that if there was a model or system as inspiring in nature, they learned how to analyze and transfer it in their future projects.

Adopting the BSA Exercise: Over one third of the students (13 out of 33) stated that they would use the biomimicry approach for the same reasons with the aforementioned group, yet they would use with the BSA exercise, as it provided them with a systematical approach for inspiring from nature and led them towards finding solutions considering the design project. These students believed that by using the exercise, they would be able to observe nature and find inspiration sources that could be utilized for the design considerations at hand. The students also mentioned the BSA exercise as an effective tool for the analysis of natural models and systems, as sketching would already be considered as a familiar tool to explore design solutions.

The aforementioned results present a very high rate (30 out of 33 students) of the adoption of the biomimicry approach in the future. 13 of these 30 students stated that they would use the BSA exercise and 14 out of 30 stated that they would utilize the biomimicry approach without the BSA exercise. The remaining three students revealed that they would use the biomimicry approach, yet they did not specify how they would. An interesting outcome about the adoption of the biomimicry approach in the future was that 5 out of 30 students stated that the biomimicry approach was useful *only in some design projects*, thus they would use it on those projects.

Only in Some Design Projects: These students mentioned the pros and cons of the biomimicry approach and the BSA exercise, yet they stated that they would use the biomimicry approach only for the design projects they would think biomimicry would be useful. These students were not able to give an example of these design projects, yet they stated that the educational project was found suitable due to the perception of ceramics being as a natural material, and the idea generation phase required for developing a system or a family of objects for the bathroom environment. This would suggest that systems thinking and material selection could be two of the reasons to utilize biomimicry in any future project.

Considering the aspects on the future utilization of the BSA exercise, the students perceived the biomimicry approach as a potential idea-generation method, yet there were various perspectives on how they would utilize it. On the one hand, the BSA exercise was found useful with respect to a systematical approach for biomimicry, while on the other hand, some students were against the 'challenge to biology' approach altogether. It was also a significant

result that a perspective about the type of the projects that biomimicry would be useful or not was emerging based on the interview results.

4.2.3.2.6. Suggestions for and Insights into Improving the BSA Exercise

In this section, the insights of the students on improving the BSA exercise and its integration into the design process are presented. There are various aspects mentioned by the students and these aspects are divided into three categories - *observation and analysis*, *transfer*, and *design process*. The 'Observation and Analysis' category explains various aspects regarding the improvement of the first two stages of the exercise - i.e. allocated time, inspiration sources, and class exercise. The 'Transfer' category points out possible modifications that can be made on the BSA exercise to improve the quality of the outcomes - i.e. group work, number of outcomes and critique sessions. Design Process category provide suggestions for the incorporation of the biomimicry approach and the BSA exercise into the design process - i.e. biomimicry presentation, the nature of the BSA exercise, biomimicry focused project, 'biology to design' approach.

Observation and Analysis

The majority of the students mentioned that the allocated time for the observation and analysis stages of the BSA exercise were not enough to explore natural models and systems, and to conduct a detailed analysis about them. This lack of time resulted in recurring of inspiration sources by different students and limiting the possible results that could have been found during the analysis stage of the exercise.

It was also mentioned that, even though limiting the observation stage with their close environments provided the student with a chance to analyze the inspiration sources that they found in more detail, the use of other sources (e.g. online databases, documentaries, biology books, etc.) should have also been allowed. It was also stated that especially the use of audio-visual materials - i.e. documentaries - would have allowed them to find more inspirations that could have been utilized more easily.

It was suggested the observation and analysis stages could have been done as a class as in the form of a field trip or gathering all the photos taken by the students and analyzing these visual documentations as a class. Accordingly, this collective analysis would have enabled a more detailed analysis stage, and improved the transfer stage of the exercise.

Transfer

On the transfer stage of the assignment, it was stated that the group work would have enabled brainstorming and resulted in better quality outcomes, thus a transfer stage of the exercise would have done by a group of students, after the observation and analysis stage. On the other hand, some students mentioned that the transfer stage should always be done individually, as it allowed different outcomes from the same inspiration source and its analysis. These opposing ideas on group work and individual exercise fall in line with the results mentioned in Section 4.2.3.2.3, as well.

A few of the students mentioned the necessity of more intervention of the instructors in the form of critiques during the transfer stage, since they were not able to utilize the results of the analysis of the inspiration sources affectively, and more critique sessions would have helped them in achieving outcomes of better quality.

It was emphasized that asking for three BSA outcomes from each student led towards lower-quality outcomes as they were not able allocate enough time for the transfer stage considering the duration of the project. It was suggested that presenting one outcome originating from a more detailed observation and analysis stage, and transferring into a solution for the project at hand more in detail would have been more influential and beneficial.

Design Process

Regarding the integration of the BSA exercise into the design project, a relocation of the biomimicry presentation upfront at the very beginning of the project was suggested by the students, which would better prepare them for the implications of biomimicry for the design process. Prior to the BSA exercise, an additional presentation on the strategies was also suggested.

A few students suggested that a biomimicry focused project would have been more influential for them with regard to the incorporation of this approach into the design process. It was suggested that instead of a pre-defined project and a design brief, 'biology to design' approach would be easier and more influential for them, and the results would have been developed more in detail and the biomimicry approach would have been explored further.

These insights into improving the BSA exercise fall in line with the other results of the interviews results presented earlier, and the suggestions of the students present certain potential, as some of them shows similarities with the approaches on design education and

biomimicry (see Section 2.4.1) - e.g. observation and analysis as a class exercise, using multiple sources to find inspirations, etc. Within the context of this research, it is highly significant to consider these suggestions and insights for the future adaptations and applications of the biomimicry approach and the BSA exercise.

In this section, the results of the semi-structured interviews are explored in-depth and a general conclusion for all of them is presented in the *Overall Conclusions of the Primary Research* section. (Section 4.2.6)

4.2.4. Student Project cases

In this section, the aim is to explore and understand the implications of the biomimicry approach and the BSA exercise for the design process, by presenting the use of biomimicry in the project phases and the results from the interviews for the selected project cases. For each student, their project phases and how they utilize the biomimicry approach are explained in 'The Use of Biomimicry in the Project Phases for Student X' parts and the overall results for the students - i.e. the interview results and the analysis of the outcomes of the BSA exercise with respect to the project phases - are presented in 'Results for Student X' parts.

The selected and presented cases here are for Student 21 (Group 2), Student 9 and 11 (Group 1) and Student 22 and 24 (Group 3). These students were selected as cases, since they would show the differences in different groups of students (i.e. the BSA outcomes utilized, the project phases that they were utilized in, how the BSA results were developed or changed throughout the design process) and present various aspects stated in the previous section (Section 4.2.3) in the content analysis categories - i.e. biomimicry in the design process, the BSA exercise and future projection.

4.2.4.1. The Case for Student 21

Oliver Whittaker was in Group 2, and he utilized his BSA outcomes until the Task exercise (see Section 4.2.3.2). After the Task exercise, he left the biomimicry approach and his final design idea focused on a bathroom environment tailored to dorm students. How he uses the biomimicry approach in the Matrix exercise and the Task Exercise, and his insights into the integration of the BSA exercise are presented below.

The Use of Biomimicry in the Project Phases for Oliver Whittaker

To understand and explore his use of the biomimicry approach in the project, it is important to see all his BSA outcomes first (Figure 4.22, 4.23 and 4.24). He presented one BSA outcome for the 'attach-detach' strategy and two for the 'adapt' strategy.

Before explaining his BSA outcomes, it should be noted that Oliver developed a distinctive way of adapting the BSA format. He put the visuals of the inspiration sources at the centre, explained how he inspired from it via text, and the sketch analysis took place around them. It was not a linear form of analysis and it seemed to be more in tune with the BSA exercise.

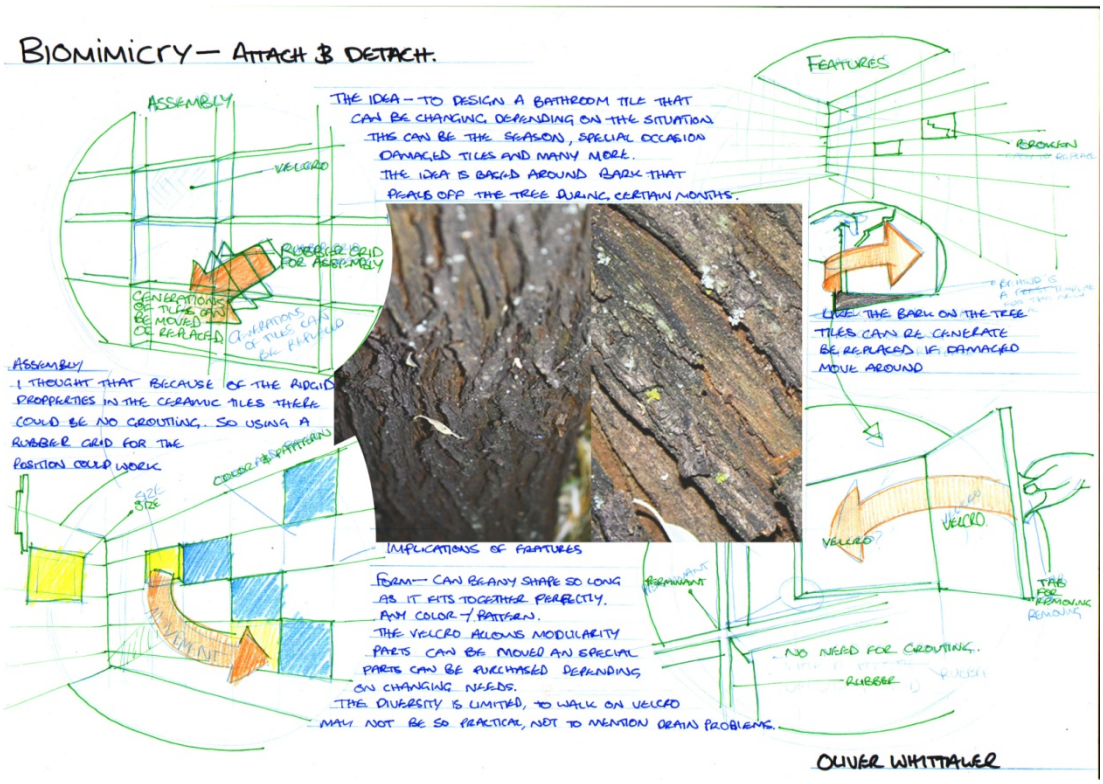

Figure 4.22 - BSA exercise outcome 1 presented by Oliver Whittaker.

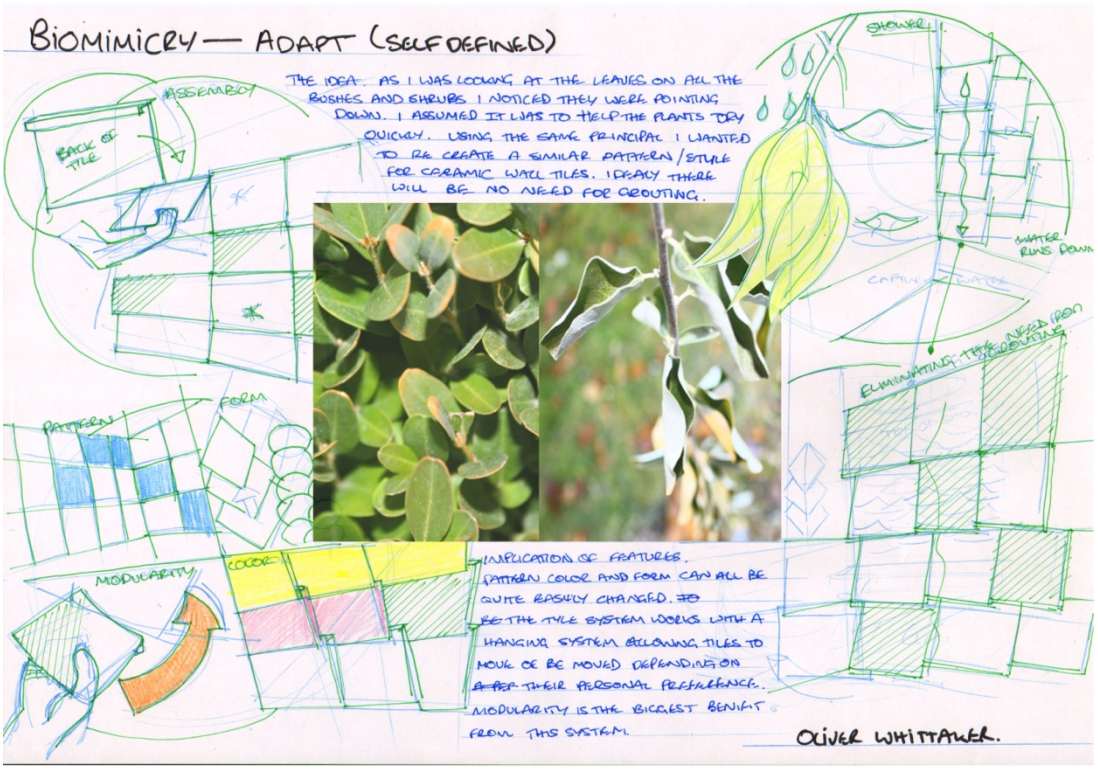

Figure 4.23 - BSA exercise outcome 2 presented by Oliver Whittaker.

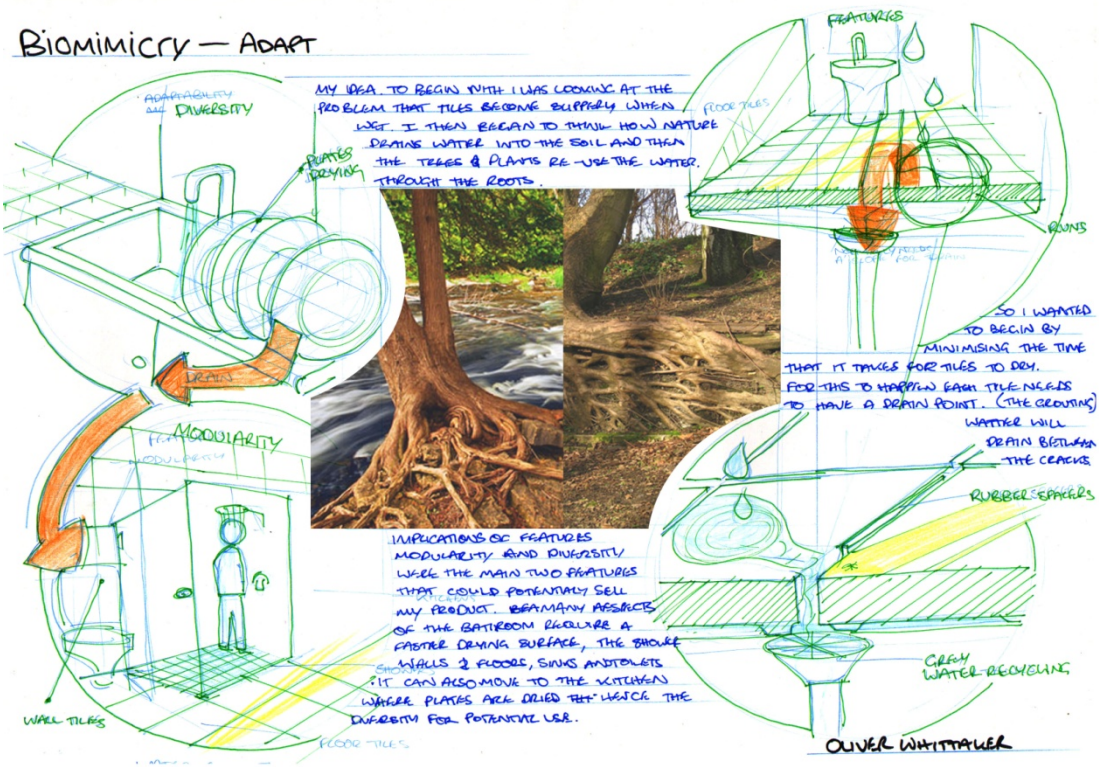

Figure 4.24 - BSA exercise outcome 3 presented by Oliver Whittaker.

As can be observed in Figure 4.22, he is inspired by tree bark and the changing and adapting texture on it that can renew itself to the changing seasons. Thus, he developed a solution constituting of easily detachable bathroom tiles that could be repositioned or replaced when damaged.

In Figure 4.23, he was inspired by the leaves of plants in general and their direction - pointing downwards - to drain the water accumulated on them. He developed a system of bathroom tiles that were not fixed, but hanged in a layered fashion to prevent water marks on bathroom tiles, offer both personalization and post-use - i.e. maintenance, repair and upgrade - more easily.

In Figure 4.24, he observed soil and roots of trees, and the means of re-using water, and developed an idea to reuse the water spilled on the bathroom floor, by creating openings in between tiles to drain and reclaim the waste water.

In the Matrix exercise, he and his group used one of these outcomes - the water re-use system inspired by soil and tree roots (Figure 4.24). Figure 4.25 shows the Matrix outcome that the BSA outcome developed and utilized by Oliver.

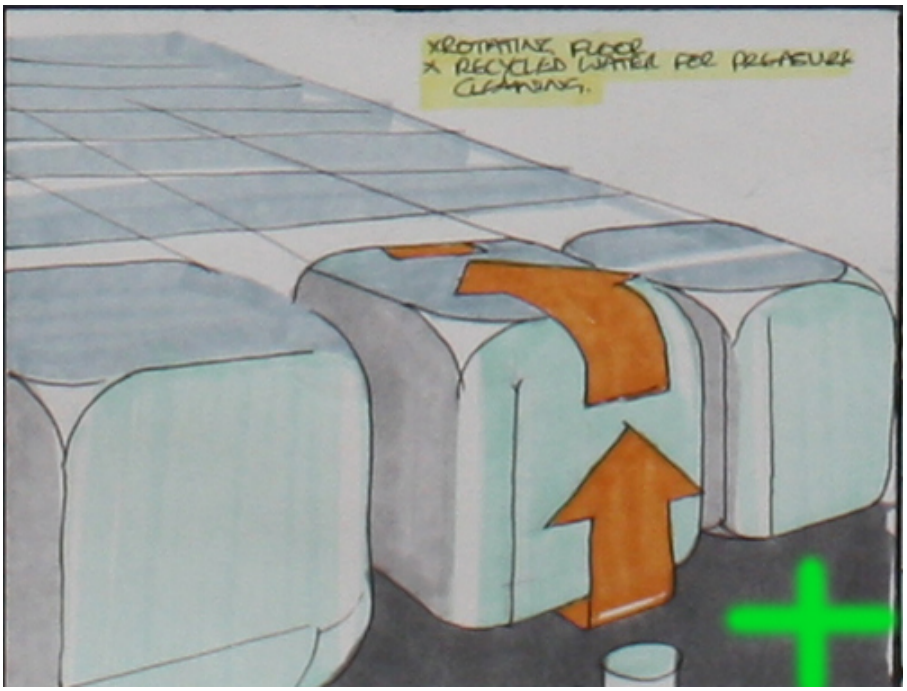

Figure 4.25 - Matrix exercise outcome presented by Ilgar Akbarov, Merthan Öztürk, Onurcan Önal, Oliver Whittaker and Selin Özden - the intersection of 'interchangeable' and 'clean contact'.

As can be seen in Figure 4.25, the idea is developed into a system of tiles that re-uses the water on the spot, for the purpose of self-cleaning of tiles. The idea has been developed further and incorporated into the Matrix exercise.

However, he has used a different BSA outcome in one of his Task exercise outcomes. He has developed his easily detachable bathroom-tile system inspired from tree bark, and presented it for interchangeable - free Lego zone intersection in the Task exercise (Figure 4.26). The Task exercise outcome offers a detachable bathroom-tile system, that can be re-assembled in different combinations of patterns - i.e. personalization - and form - e.g. stool for children.

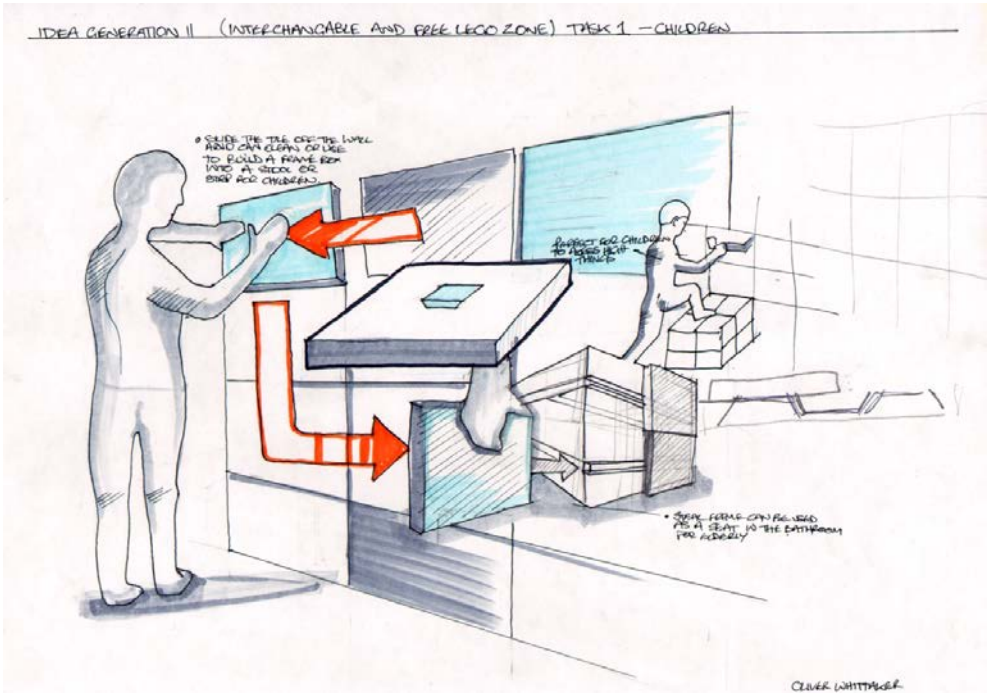

Figure 4.26 - Task exercise outcome presented by Oliver Whittaker - for the first task, 'making it a product family which empowers kids'.

After the Task exercise, Oliver left the biomimicry approach and did not utilized it for the pre-jury or the final jury. When asked, why he took such a decision, he stated that he was inspired by the attach-detach strategy itself, and he developed his final design from that strategy inspired from nature, even though he did not inspire from a natural model (i.e. from a specific inspiration source) or system. Thus he developed an idea on bathroom tiles and accessories, in which every accessory was attachable and detachable.

Up to the Task exercise, Oliver developed his BSA outcomes regarding the strategies of attach-detach (i.e. tree bark and its renewal) and adapt (i.e. soil and tree roots) further to incorporate various design considerations (e.g. re-using water, personalization, self-cleaning, empowering kids, etc.)

Results for Oliver Whittaker

The interview results, along with the results of the analysis of the project phases are presented in Table 4.4, summarized according to the content analysis categories and sub-categories.

Table 4.4 – The Overall Categorized Results for Oliver Whittaker.

		Insights of the student
Biomimicry in Design Process	Research Phase	Considered the research phase as not effective and the BSA exercise as a separate exercise.
	Idea-generation Phase	Considered the BSA exercise as creating a starting point for the idea-generation phase, was content with the outcomes.
	Design detailing Phase	Used the outcomes of the BSA exercise up to the Task Exercise. Developed the BSA outcomes further through incorporating design considerations.
	Final Jury	Presented a final design solution without a natural inspiration source.
BSA Exercise	Biomimicry Presentation	Thought it conveyed introductory knowledge and a critical perspective on nature.
	Strategies from Nature	Stated that the strategies were helpful and influential at the idea-generation phase.
	BSA stages	Stated that the transfer stage was challenging, due to the project constraints and time management.
	Individual Assignment	Emphasized that it was important to see different perspectives of the individuals for the BSA exercise.
	Perceived Aim	Perceived as conveying a critical perspective on nature and enhancing the idea generation phase.
	Outcomes	Presented the design outcomes on two strategies - attach-detach, and adapt.
Future Projection	Influence of Biomimicry Approach	Mentioned he would use the biomimicry approach for his upcoming projects.
	Insights on Further Development of the Assignment	Generally being content with the exercise, just mentioned the lack of time.

As presented in Table 4.4, student was generally content with the BSA exercise integrated into the idea-generation phase, yet he did not present a final design specifically inspired from

nature. He stated that the BSA exercise created a starting point for the idea-generation and mentioned the strategies were helpful and influential throughout the design process. He perceived the aim of the assignment as conveying a critical perspective on nature and enhancing the idea-generation, suggesting that he was not aware of the sustainability aspect of the assignment.

4.2.4.2. The Case for Student 9

Onurcan Önal was in Group 1, and he incorporated his BSA outcomes into all the project phases, except for the Matrix exercise (see Section 4.2.3.2). He developed and altered one of his BSA outcomes through the design process, and presented a final design originated from it. The means of using the biomimicry approach through the design process and his insights into the integration of the BSA exercise are presented below.

The Use of Biomimicry in the Project Phases for Onurcan Önal

To understand and explore his use of the biomimicry approach in the project, it is important to see all his BSA outcomes first (Figure 4.27, 4.28 and 4.29). He presented one BSA outcome for the 'adapt' strategy, one for 'attach' strategy, one for 'dispense' strategy - which was self-defined.

For the 'adapt' strategy (Figure 4.27), he was inspired by cacti and the patterns created by its spine groups. He abstracted that pattern to create a bathroom tile system integrated with modular accessories, constituting of replaceable tiles that could be replaced or repositioned when damaged.

In Figure 4.28, he was inspired by the serrated edges of leaves in general and the way things get stuck on these edges. He proposed a design solution for a system of accessories including such serrated edges that could hold toothbrushes, towels, etc.

For his last strategy - dispense - (Figure 4.29), he found and analyzed a fruit that he was not able to provide a name for, consisting of many pocket-like structures with nectar in them. Through analysis, he found out these pockets were able to act as dispensers of the nectar when damaged or torn. This inspired him to create a liquid soap dispenser in the form of a soap bar.

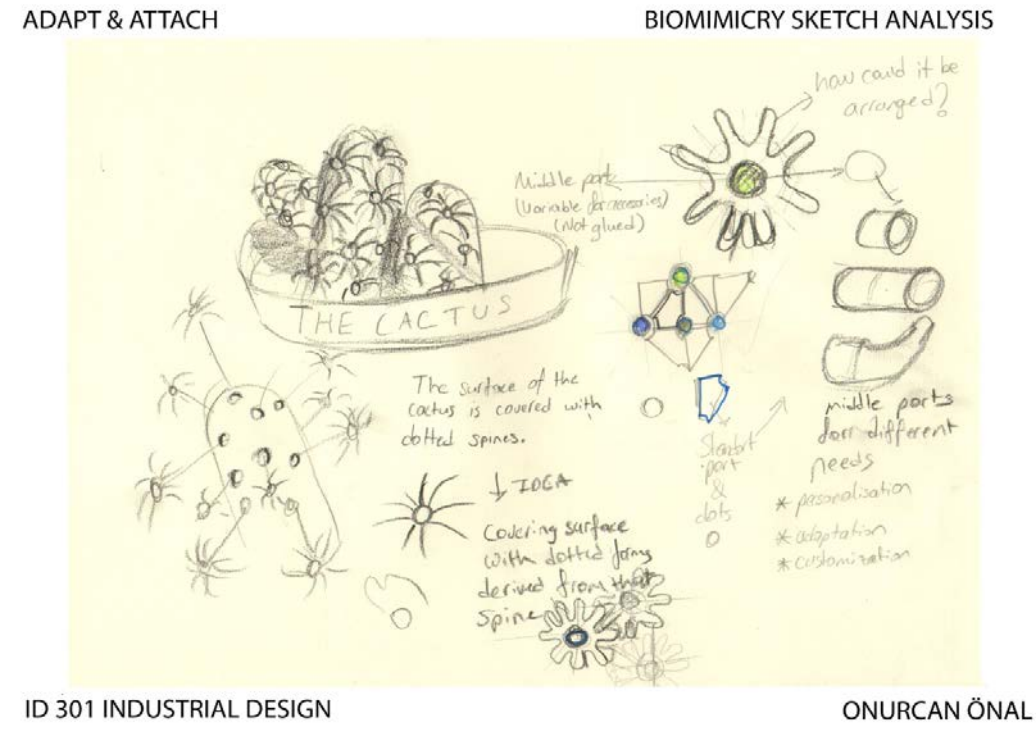

Figure 4.27 - BSA exercise outcome 1 presented by Onurcan Önal.

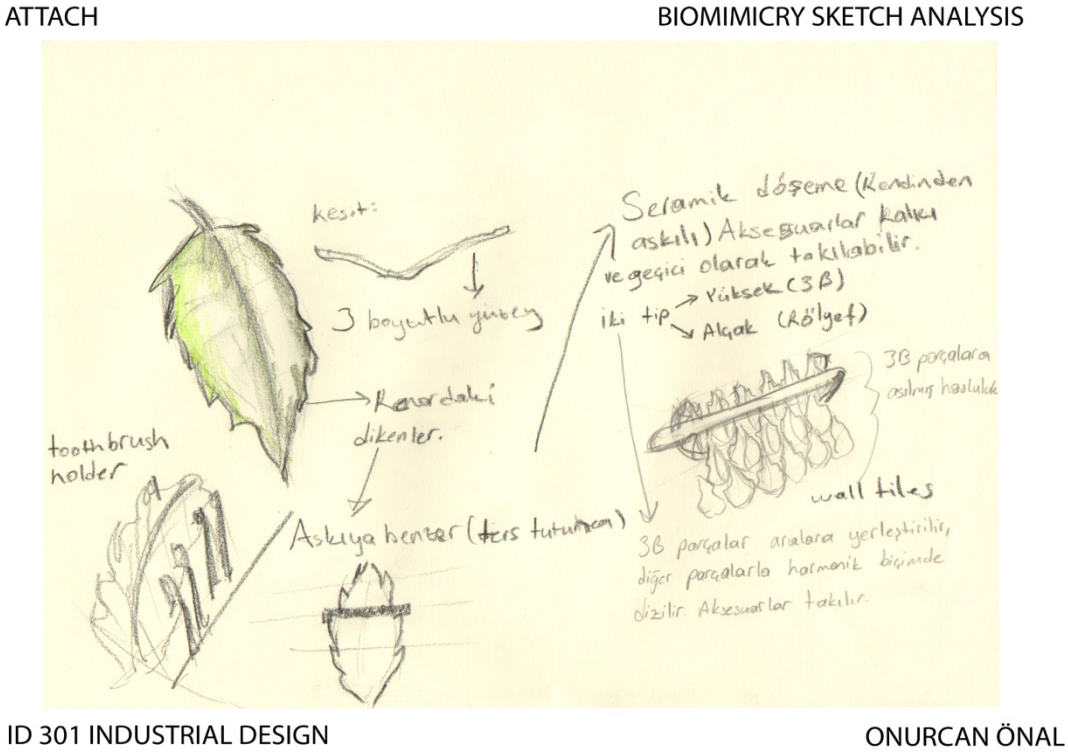

Figure 4.28 - BSA exercise outcome 2 presented by Onurcan Önal.

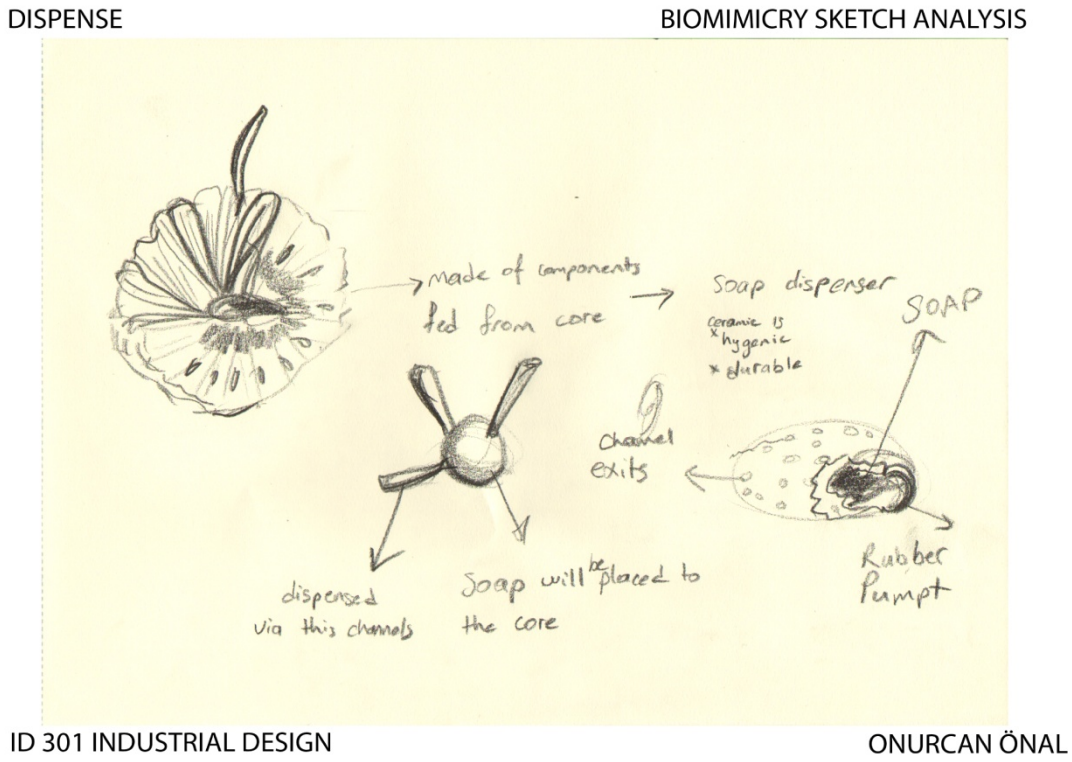

Figure 4.29 - BSA exercise outcome 3 presented by Onurcan Önal.

Onurcan stated that, he and his group for the Matrix exercise decided not to use the BSA outcomes for the Matrix exercise as much as possible, as they wanted to increase the number of initial ideas they developed. Consequently, he did not utilize any of his BSA outcomes in the Matrix exercise.

For the Task exercise, he developed his BSA outcome on attach strategy - inspired by cacti - in one of his Task exercise outcomes, the intersection of interchangeable and free Lego zone (Figure 4.30).

For his Task exercise, he developed the idea allowing personalization to offer various accessories, and presented possible accessories for this concept. In this idea, the accessories can be placed in any intersection of tiles by removing the circular components and placing accessories in their place. Furthermore, Onurcan developed his idea originated from his BSA outcome, further for the pre-jury (Figure 4.31) and the final jury (Figure 4.32), and presented a final design incorporating personalization as his main design consideration.

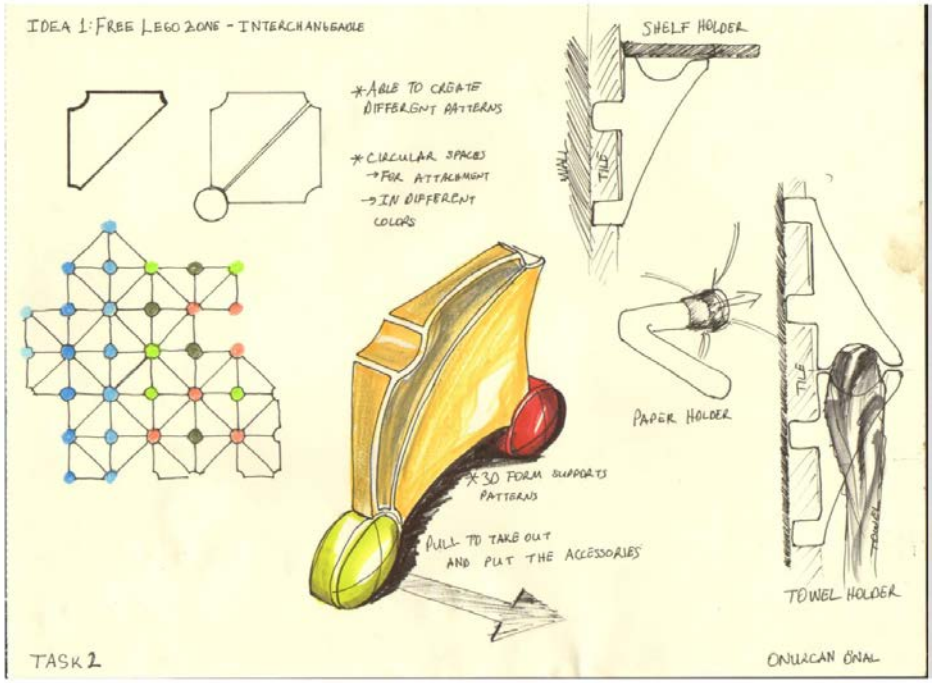

Figure 4.30 - Task exercise outcome presented by Onurcan Önal - for second task, 'making it a product family which allows personalization'.

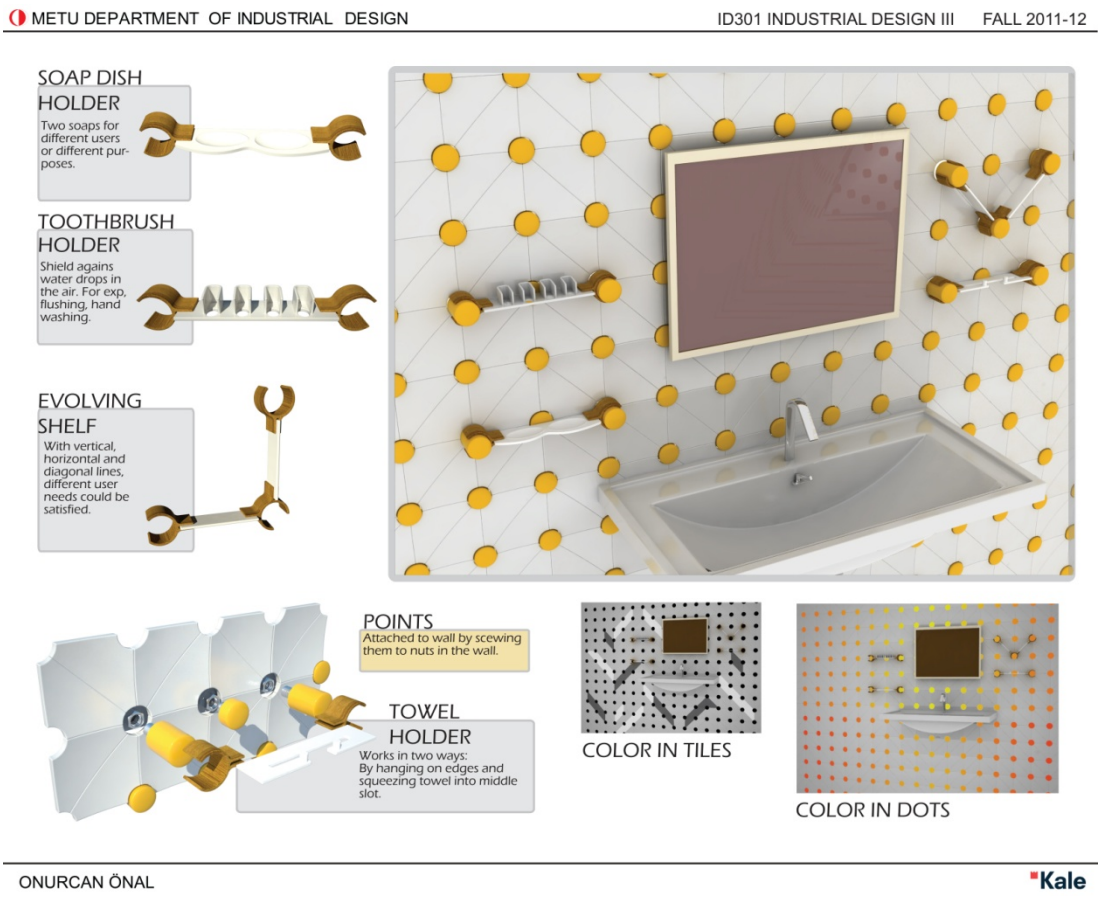

Figure 4.31 - Pre-jury presentation board by Onurcan Önal.

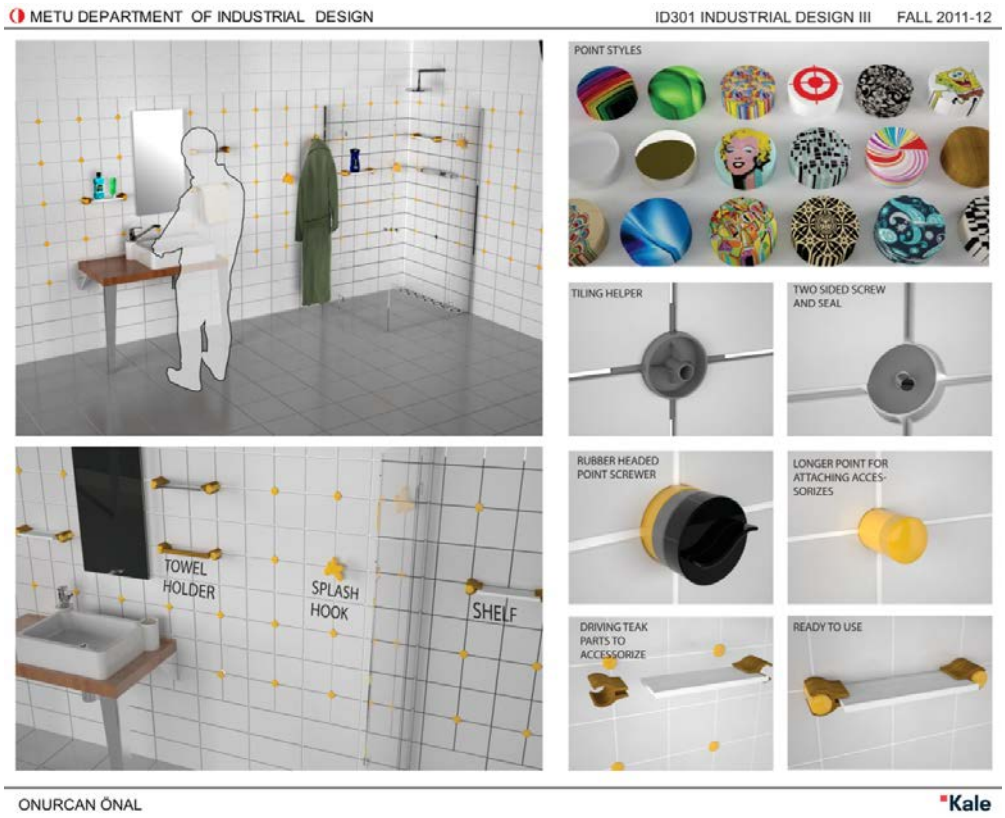

Figure 4.32 - Final Jury presentation board by Onurcan Önal.

Throughout the project phases, Onurcan utilized his BSA result in every phase except for the Matrix exercise. As mentioned before, his aim for not using the BSA outcomes in the Matrix exercise was to generate more ideas for the project. In the end, he developed and changed his BSA outcome towards a product family consisting of bathroom tiles and accessories to offer personalization in the bathroom environment.

Results for Onurcan Önal

The interview results, along with the results of the analysis of the project phases are presented in Table 4.5, summarized according to the content analysis categories and sub-categories.

Table 4.5 – The Overall Categorized Results for Onurcan Önal.

		Insights of the student
Biomimicry in Design Process	Research Phase	It did not affect the BSA exercise.
	Idea-generation Phase	Considered the BSA exercise as a starting point for the idea-generation and was content with the outcomes even though the results did not appear to be as they were inspired from nature.

Table 4.5 - The Overall Categorized Results for Onurcan Önal. (continued)

Biomimicry in Design Process	Design detailing Phase	Used the outcomes of the BSA exercise in every project phase, except for the Matrix exercise.
	Final Jury	Presented a final design originated from his BSA.
BSA Exercise	Biomimicry Presentation	Thought that it conveyed introductory knowledge on biomimicry, and mentioned it was helpful to understand the biomimicry approach.
	Strategies from Nature	Stated that the strategies were useful for understanding how to utilize the biomimicry approach for the project.
	BSA stages	Stated observation and analysis stages were challenging due to the lack of time.
	Individual Assignment	Stated the individual work led towards owning the outcomes, yet on the other hand, mentioned the group work might have helped in achieving the outcomes of better quality.
	Perceived Aim	Emphasized as triggering the idea-generation phase for the students.
	Outcomes	Presented the outcomes on three strategies - attach-detach, adapt and dispense.
Future Projection	Influence of Biomimicry Approach	Mentioned he would use the BSA exercise to analyze and transfer the inspiration sources he would find.
	Insights on Further Development of the Assignment	Stated the need for more time in the observation and analysis phases, and potentially, in the form of a group work.

As indicated in Table 4.5, Onurcan was generally content with the BSA exercise and the implications of the biomimicry approach for the design process. He mentioned that the aim of the BSA exercise triggered his idea-generation phase and it was helpful since the strategies were explained in the context of the project at hand, conveying how they should be utilized for the idea-generation. He stated the stages were generally in relation with each other and easy-to-follow, yet mentioned there needed to be more time for these two stages - i.e. observation and analysis. He stated that he would use the BSA exercise in the future as well to observe the nature and analyze its models and organisms.

4.2.4.3. The Case for Student 11

Yasemin Canik was in the Group 1 and have she used the biomimicry approach and the same inspiration source throughout all the project phases (see Section 4.2.3.1). Even though she

used biomimicry for the sustainable design considerations (e.g. personalization, diversity within unity) throughout the design process, after the pre-jury she had a strategic decision to use simply the patterns she inspired from nature. The means of using the outcomes of the BSA exercise and his/her insights into the use of the biomimicry exercise are as follows.

The Use of Biomimicry in the Project Phases for Yasemin Canik

To understand and explore her use of the biomimicry approach in the project, it is important to see all the phases she has incorporated the biomimicry approach. Figure 4.33, 4.34 and 4.35 show her BSA outcomes for the 'attach-detach', 'adapt' and 'cleaning' strategies.

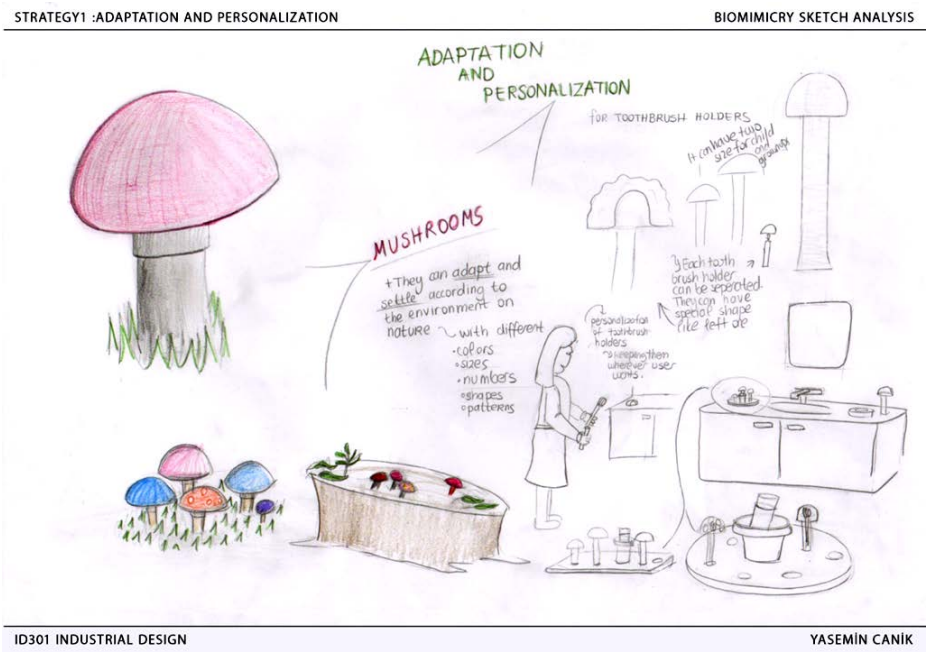

Figure 4.33 - BSA exercise outcome 1 presented by Yasemin Canik.

As illustrated in Figure 4.33, she was inspired by mushrooms tailored to different environments and the variety in color, size, shape, etc. they presented. She transferred that into personalized bathroom accessories for each household member.

In Figure 4.34 (below), she was inspired by the horse chestnut and its relation with the ground, and transferred it into a soap holder to solve the issue of soap stains left on the surface where the soap holder placed.

In Figure 4.35 (below), she was inspired by the cracks on the soil ground and created a form produced by the attachment of small pieces together to prevent the soap stains in the soap holder.

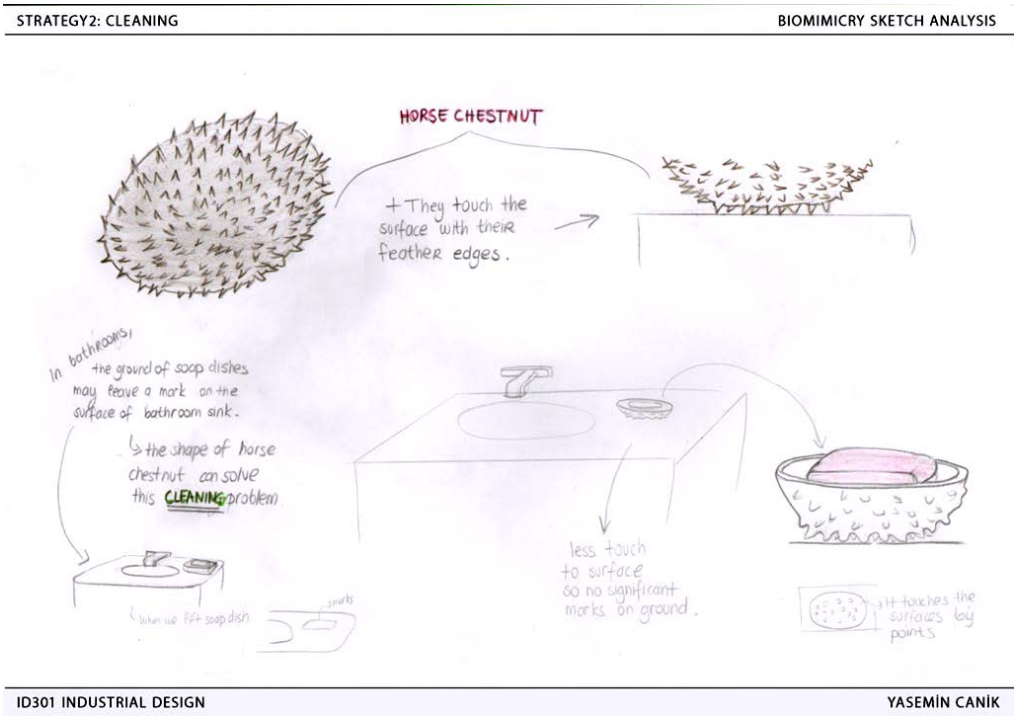

Figure 4.34 - BSA exercise outcome 2 presented by Yasemin Canik.

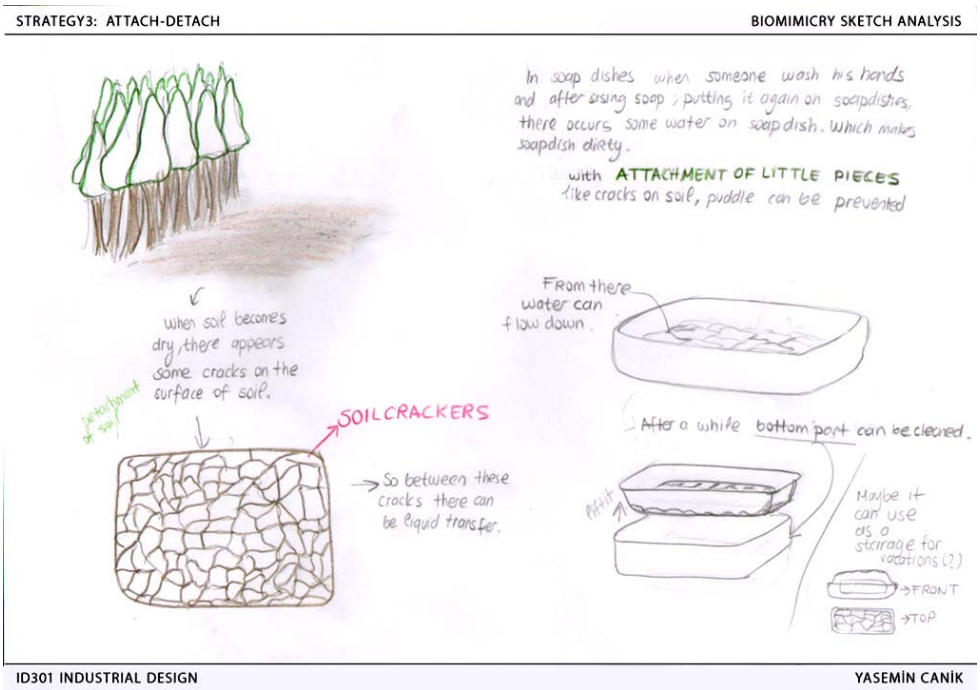

Figure 4.35 - BSA exercise outcome 3 presented by Yasemin Canik.

In the Matrix exercise, she and her group used two of these outcomes inspired from mushrooms and horse chestnut. Figure 4.36 and 4.37 shows the cells of the Matrix exercise that they have used the outcomes emerged from her BSA exercise.

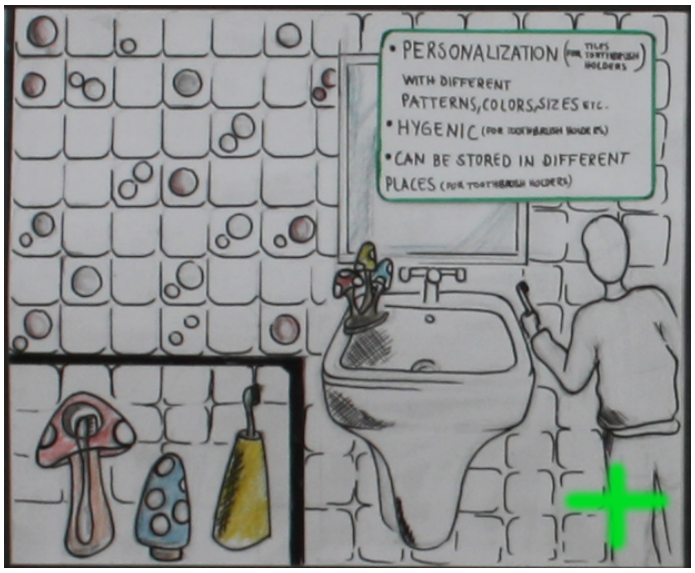

Figure 4.36 - Matrix exercise outcome 1 presented by Ceren Balcı, Derya Adıyaman, Gökçe Evren, Medina Bekteşeviç and Yasemin Canik - the intersection of 'inclusive' and 'my instant extended family'.

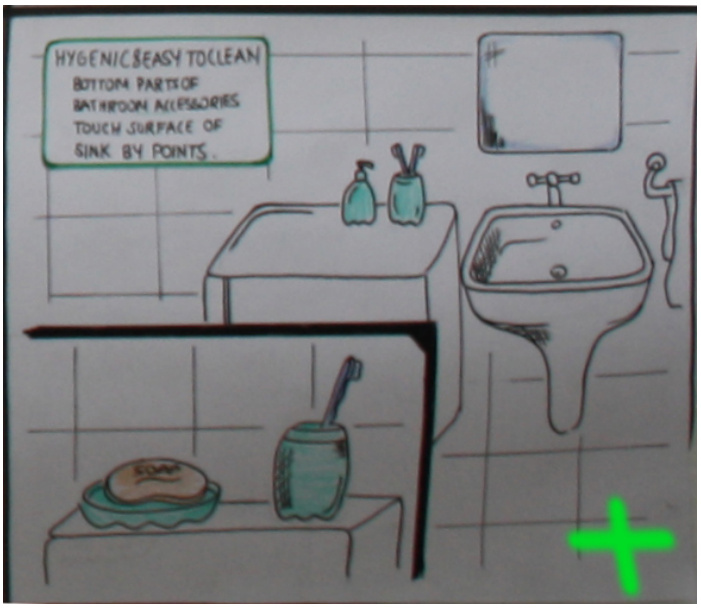

Figure 4.37 - Matrix exercise outcome 2 for Ceren Balcı, Derya Adıyaman, Gökçe Evren, Medina Bekteşeviç and Yasemin Canik - the intersection of 'adapting' and 'clean contact'.

In Figure 4.36, the student stated that she decided to use the BSA outcome originated from mushrooms in the intersection of 'inclusive' and 'my instant extended family', because that outcome presented the potential for *personalization* and *unity in diversity*, and it was found appropriate for that intersection.

In Figure 4.37 she stated that her BSA outcome originated from horse chestnuts was already providing a solution, and she figured out that the form was tailored to the surface to prevent the soap stains on the surface the soap holder. Consequently, she decided to use the idea on the intersection of 'adapting' and 'clean contact'.

In the Task exercise (Figure 4.38), she developed her idea from the BSA outcome originated from mushrooms further and used it for the second task (i.e. make it a product family allowing personalization). However, she developed the idea for a different project dimension and theme intersection - free Lego zone and evolving - than s/he initially positioned in the Matrix exercise.

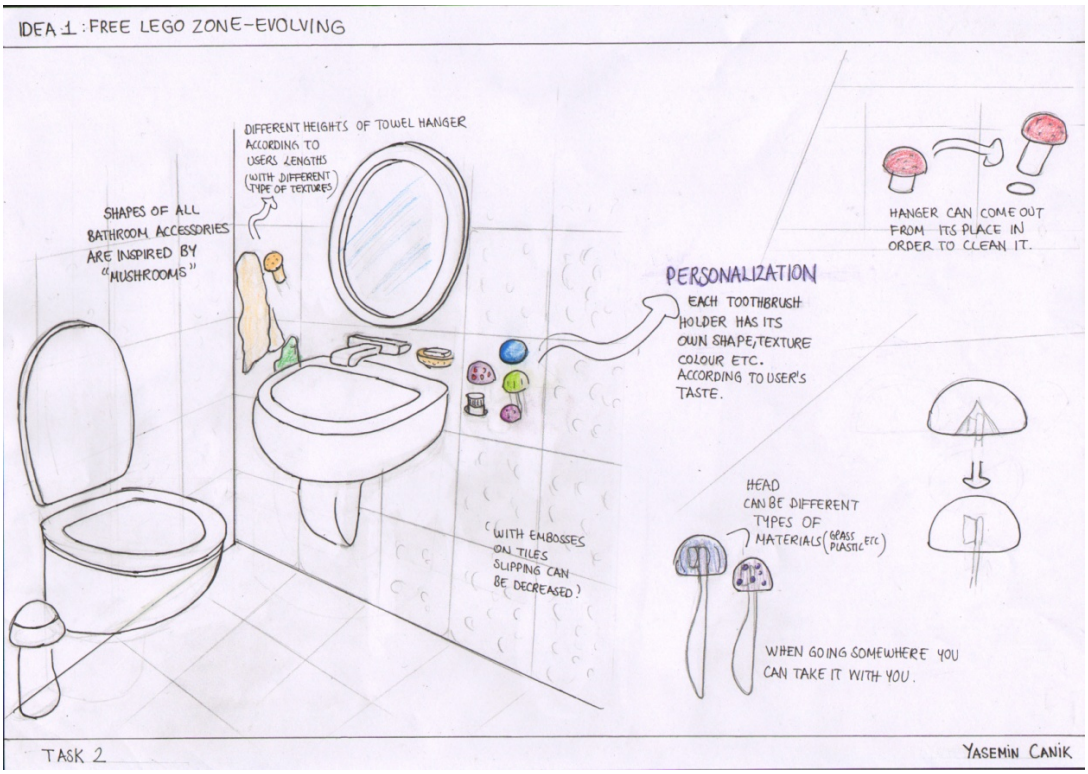

Figure 4.38 - Task exercise outcome presented by Yasemin Canik - for the second task, 'making it a product family which allows personalization'.

For the pre-jury, the student developed the idea further by redefining the bathroom environment through transferring the pattern existing on the other side of the mushroom and integrated the transferred pattern into the bathroom tiles (Figure 4.39).

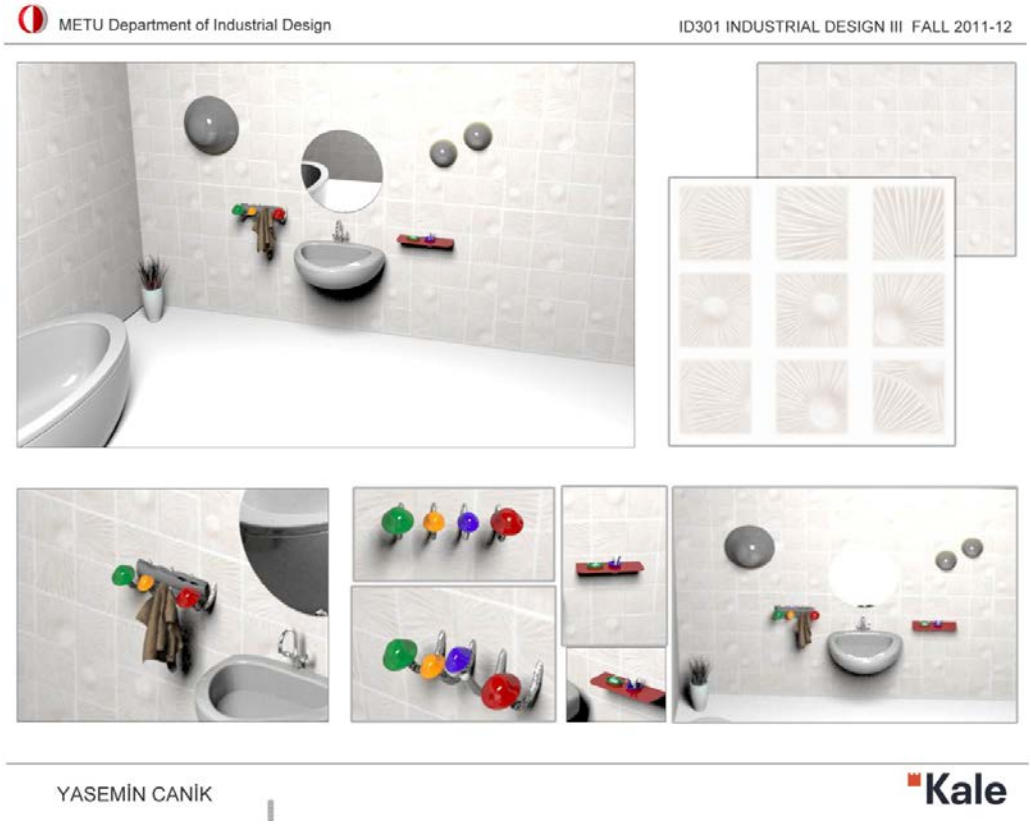

Figure 4.39 - Pre-jury presentation board by Yasemin Canik.

For final jury, the student stated she left the idea of accessories abstracted from the mushroom form, and developed final design with patterns emerged from the other side of the mushrooms (Figure 4.40). When asked, why she took such a decision, she mentioned the critique sessions during the project course and comments made during the pre-jury led her towards such a decision.

Throughout the whole design process, Yasemin developed and changed her BSA outcome originated from the mushrooms. At some point, she changed the way she was inspired from the same inspiration source, and developed a final design with a more form-based inspiring from nature.

Figure 4.40 - Final Jury presentation board by Yasemin Canik.

Results for Yasemin Canik

The interview results, along with the results of the analysis of the project phases are presented in Table 4.6, summarized according to the content analysis categories and sub-categories.

Table 4.6 – The Overall Categorized Results for Yasemin Canik.

		Insights of the student
Biomimicry in Design Process	Research Phase	Affected the BSA exercise, by providing information on ceramics material and field observations.
	Idea-generation Phase	The BSA exercise provided the final inspiration source, and the student was content with the implications of biomimicry for the idea-generation phase.
	Design detailing Phase	Used the outcomes of the BSA exercise throughout the project phases by developing and adapting these outcomes.
	Final Jury	Presented a final design, originated from a natural inspiration source - mushrooms.
BSA Exercise	Biomimicry Presentation	Used the presentation as a guide to look back to and mentioned the necessity of more examples for strategies.

Table 4.6 - The Overall Categorized Results for Yasemin Canik (continued).

	Strategies from Nature	Stated that the 'attach-detach' strategy was easy to understand, yet the 'adapt' strategy was hard to grasp.
	BSA stages	The stages were easy to follow and the results were satisfactory.
	Individual Assignment	Stated the workload was appropriate for an individual assignment and the easier application of the exercise.
	Perceived Aim	To inspire from nature to achieve sustainable design considerations.
	Outcomes	Presented the design outcomes on three strategies - attach-detach, adapt and cleaning.
Future Projection	Influence of Biomimicry Approach	Mentioned that she would use it only in some design projects.
	Insights on Further Development of the Assignment	Not enough allocated time for the observation and analysis stages of the BSA exercise.

As can be concluded from Table 4.6, the student was generally content with the implications of the biomimicry approach for the design process. She developed and changed the outcome of the BSA exercise throughout the design process and presented a final design originated from the same inspiration source, yet transferred that into the final design differently. She perceived the aim of the BSA exercise as inspiring from nature to achieve sustainable design considerations, and believed that the exercise helped her to achieve towards this aim. On the incorporation of the exercise into the design process, the student mentioned that the BSA exercise was appropriate for individual use and its stages were easy to follow.

4.2.4.4. The Case for Student 22

Salih Berk İlhan was in Group 3, and he has developed his BSA outcomes throughout all the project phases (see Section 4.2.3.3). He elaborated on and developed one of his BSA outcomes through the design process, and presented a final design originated from it. How he used the biomimicry approach through the design process, and his insights into the integration of the BSA exercise are presented below.

The Use of Biomimicry in the Project Phases for Salih Berk İlhan

To understand and explore his use of the biomimicry approach in the project, it is important to see all his BSA outcomes first (Figure 4.41, 4.42 and 4.43). He has presented one BSA outcome for the 'adapt' strategy and two for the 'attach' strategy.

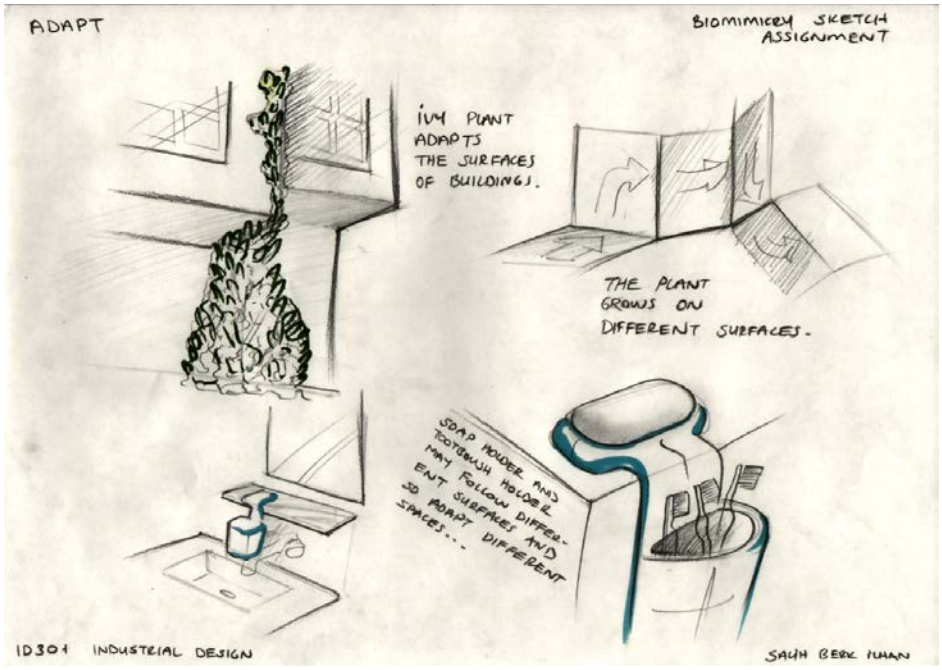

Figure 4.41 - BSA exercise outcome 1 presented by Salih Berk İlhan.

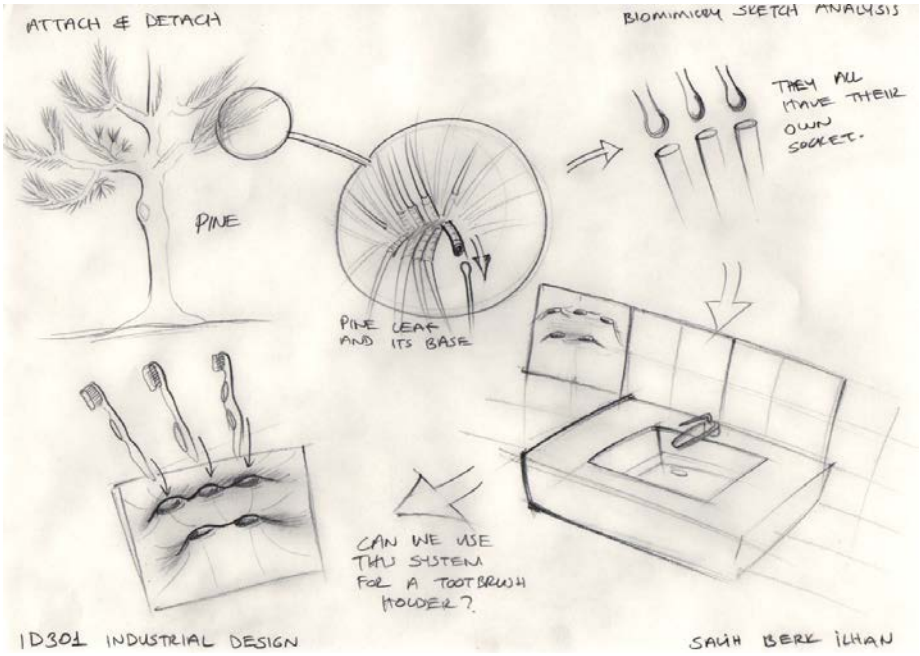

Figure 4.42 - BSA exercise outcome 2 presented by Salih Berk İlhan.

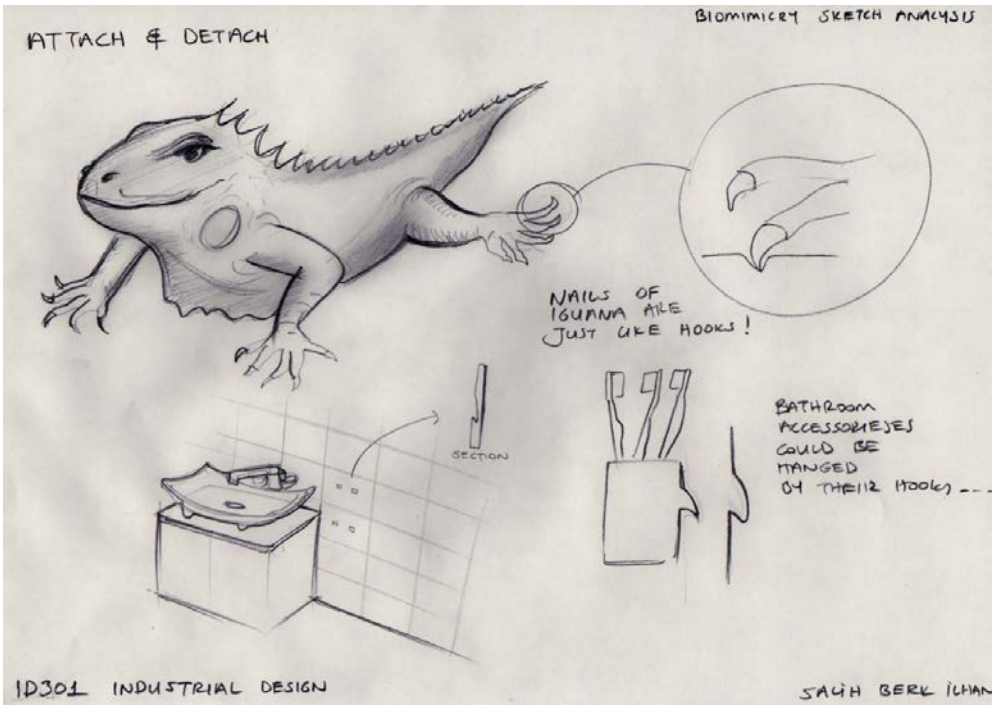

Figure 4.43 - BSA exercise outcome 3 presented by Salih Berk İlhan.

For the 'adapt' strategy (Figure 4.41), he was inspired by ivy plants and their adaptation to different angled surfaces. He figured out that the bathroom accessories should be like that as well, and developed an accessory that did not stand on a surface, yet could adapt to different surfaces.

In his second BSA outcome (Figure 4.42), he was inspired by pine leaves and the means of their attachment to the leaf base. He proposed a design solution for toothbrush holders working with the same principle - each brush has its own socket - and aiming to prevent toothbrushes touching each other or anywhere else for hygiene purposes.

For his last BSA outcome (Figure 4.43), he observes how iguana's interacts with the surfaces they move onto and how their nails are shaped to allow that. He used the same principle to create a system of tiles and accessories with dedicated hooks on accessories and holes in tiles.

In the Matrix exercise, Berk stated that he and his groups were inspired by his second BSA outcome - pine leaves and leaf base relation - and changed it completely towards a floor consisting of natural stones (Figure 4.44). This comment of Berk is interesting in the fact that, he believes the BSA outcome has inspired the idea, not the natural inspiration source.

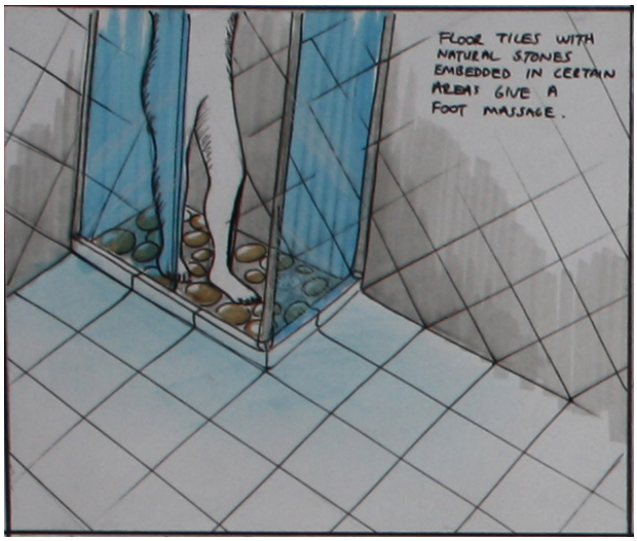

Figure 4.44 - Matrix exercise outcome 1 presented by Adem Önalan, Ahmet Burak Aktaş, Burak Söylemez, Salih Berk İlhan and Ümit Can Koralay - the intersection of 'cozy' and 'free Lego zone'.

In the Task exercise, he used his BSA outcome inspired from iguana and its relation to the surfaces through its movements, and further developed the 'attach-detach' mechanism to provide upgrading (Figure 4.45). He stated this Task exercise was in the intersection of 'free Lego zone theme' and 'evolving' consideration.

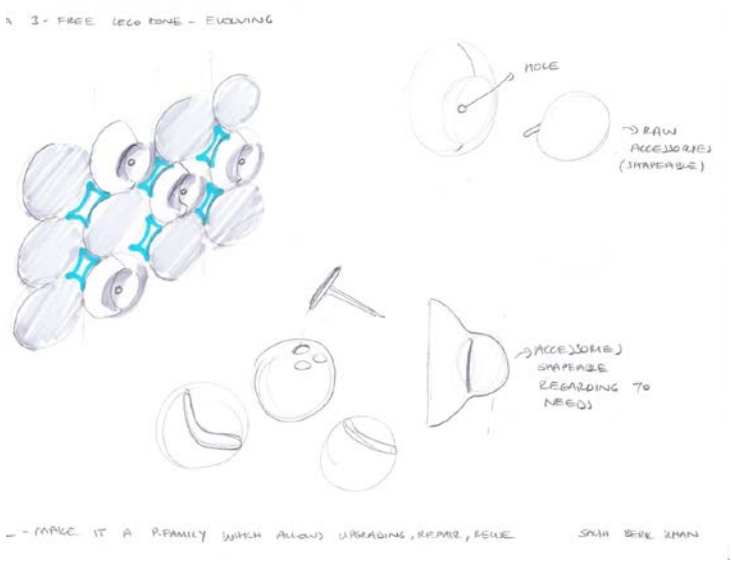

Figure 4.45 - Task exercise outcome presented by Salih Berk İlhan - for the third task, 'making it a product family which allows upgrading or repair or reuse'.

He developed and refined his Task exercise outcome further and presented it in the pre-jury (Figure 4.46), using the same attach-detach mechanism originated from his BSA outcome. For his final jury, he kept developing the same idea, yet in the end he left the attach-detach mechanism and used magnets instead. Figure 4.47 shows the final mechanism for the attaching the accessories on the bathroom tiles.

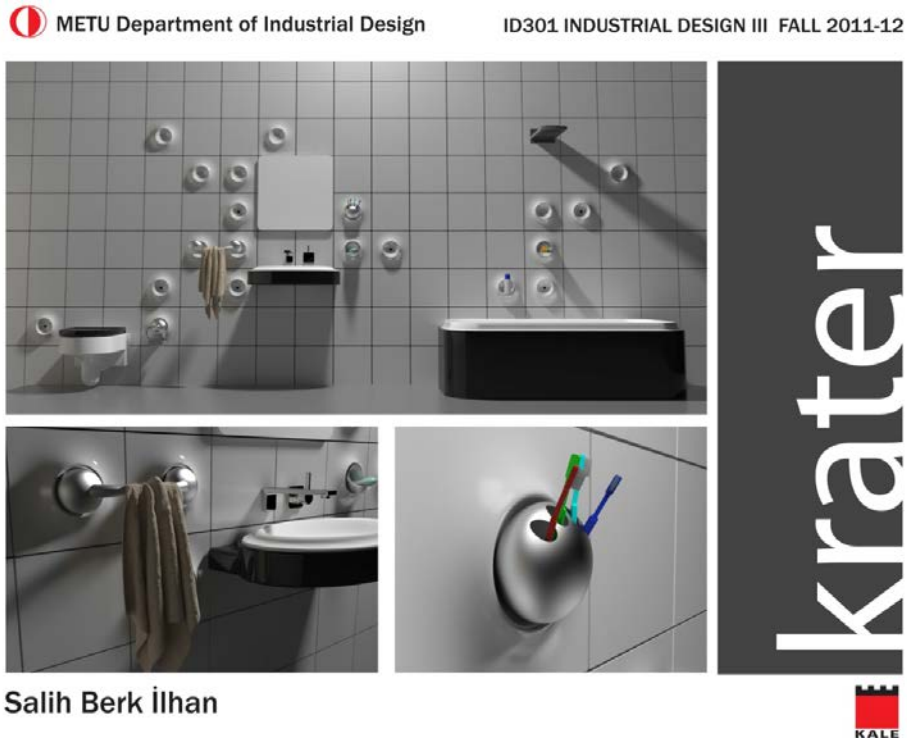

Figure 4.46 - Pre-jury presentation board by Salih Berk İlhan.

Figure 4.47 - A part of Final Jury presentation board by Salih Berk İlhan - showing the attach-detach mechanism.

Throughout the project phases, Berk developed the BSA outcome and completely changed the way he used it. At some point, he left the mechanism that was inspired from nature, yet kept developing the resulting idea of that inspiration. He utilized the BSA exercise to generate various ideas, and developed them further within the context of the project.

Results for Salih Berk İlhan

The interview results, along with the results of the analysis of the project phases are presented in Table 4.7, summarized according to the content analysis categories and sub-categories.

Table 4.7 – The Overall Categorized Results for Salih Berk İlhan.

		Insights of the student
Biomimicry in Design Process	Research Phase	Stated that the research presentation was not effective in terms of the project phases.
	Idea-generation Phase	Considered as ineffective, not an in-depth inspiring from nature.
	Design detailing Phase	Used the outcomes of the BSA exercise in each project phase, yet developed and changed them.
	Final Jury	Presented a final design originated from his BSA.
BSA Exercise	Biomimicry Presentation	Stated that it conveyed introductory knowledge on biomimicry, and explained the BSA stages effectively.
	Strategies from Nature	The stated strategies were easy to understand, and led him towards inspiration sources.
	BSA stages	Stated that the transfer stage was challenging, because of the lack of time, and the exercise being conducted too early in the design process.
	Individual Assignment	Stated that the individual work led towards easier application of the exercise, yet group work would have resulted in the BSA outcomes of better quality.
	Perceived Aim	To increase awareness on the biomimicry approach.
	Outcomes	Presented outcomes on two strategies - 'attach – detach' and 'adapt'.
Future Projection	Influence of Biomimicry Approach	Mentioned he did not know if he would use the biomimicry approach and the BSA exercise.
	Insights on Further Development of the Assignment	Emphasized the need for more time for the observation and the analysis stages, and more in-depth research in these stages.

As presented in Table 4.7, Berk did not consider the biomimicry approach as helpful enough throughout the project, however he presented a final design that was originated from one of his BSA outcomes. He developed and adapted that outcome further based on the design considerations of the project to the point that he changed the initially inspired attach-detach mechanism. He believed the biomimicry approach was generally ineffective at the idea-generation phase, as the observation and analysis stages of the exercise remained not-in-depth. Even though, he stated that the strategies from nature were clear and led him towards

inspiration sources, and there needed to be more time planned for the observation and analysis stages, so that they could be more in depth to develop projects of better quality.

4.2.4.5. The Case for Student 24

Fulden Dehneli was in Group 3, and she developed her BSA outcomes throughout all the project phases as well (see Section 4.2.3.3). She developed one of her BSA outcomes and then merged it with another student's BSA outcome at some point in the design process. Finally, she presented a final design, originated from both those BSA outcomes. How she used the biomimicry approach throughout the design process, and her insights into the integration of the BSA exercise are presented.

The Use of Biomimicry in Project Phases for Fulden Dehneli

To understand and explore her use of the biomimicry approach in the project, it is important to see all her BSA outcomes first (Figure 4.48, 4.49 and 4.50). She presented two BSA outcomes for the 'adapt' strategy and one for the 'attach' strategy.

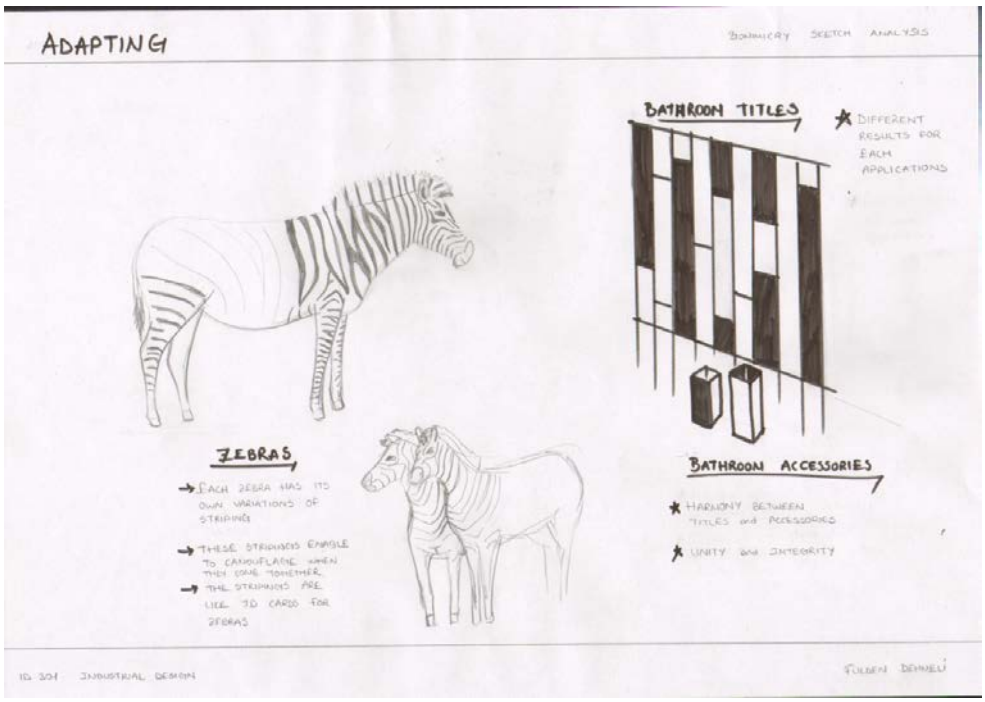

Figure 4.48 - BSA exercise outcome 1 presented by Fulden Dehneli.

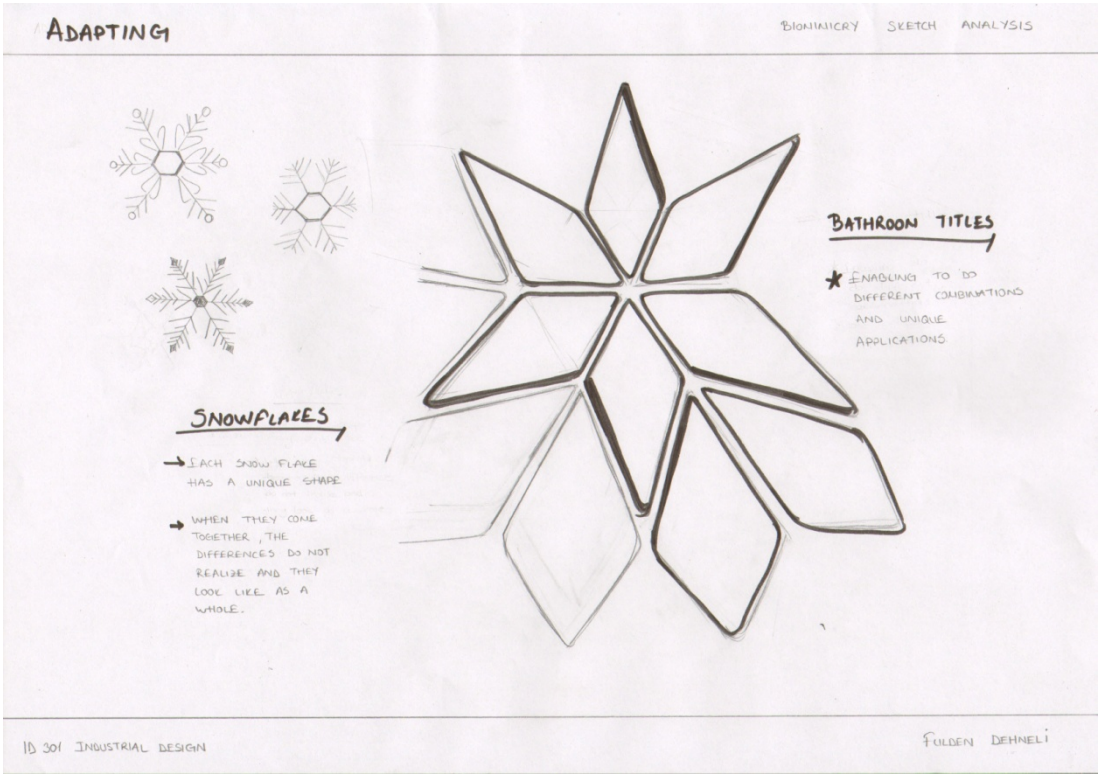

Figure 4.49 - BSA exercise outcome 2 presented by Fulden Dehneli.

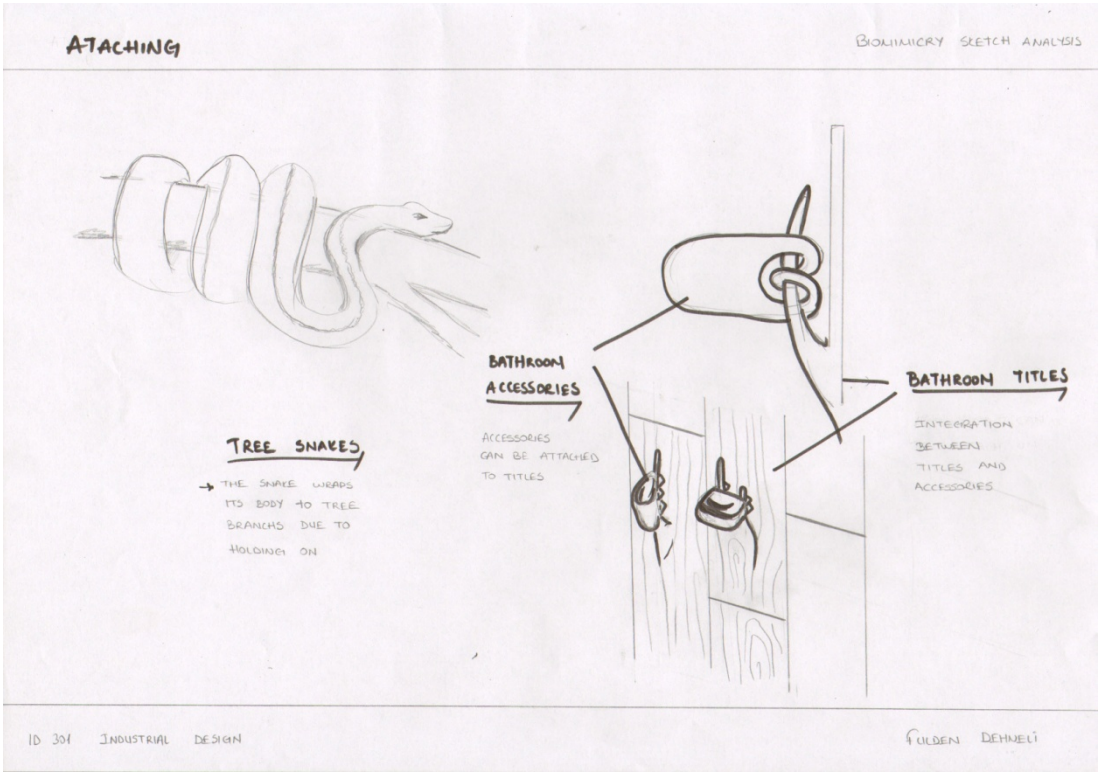

Figure 4.50 - BSA exercise outcome 3 presented by Fulden Dehneli.

In her first BSA outcome (Figure 4.48) she was inspired by zebras and their patterns constituting a survival strategy through making them appeared to be a bigger animal while moving together. Thus, she used the same strategy by abstracting the pattern to create a bathroom environment in which every component would seem like a seamless part of that environment.

For her second BSA outcome (Figure 4.49), she analyzed the microscopic structure of snowflakes and abstracted their shape to offer a modular system for bathroom tiles. She thought, by creating a modular unit to create different patterns in the bathroom environment would help her create personalized patterns for the bathroom environment.

For her last BSA outcome (Figure 4.50), she observed how snakes holding onto tree branches. She used that attaching strategy to create a system for accessories attaching to tiles through extensions.

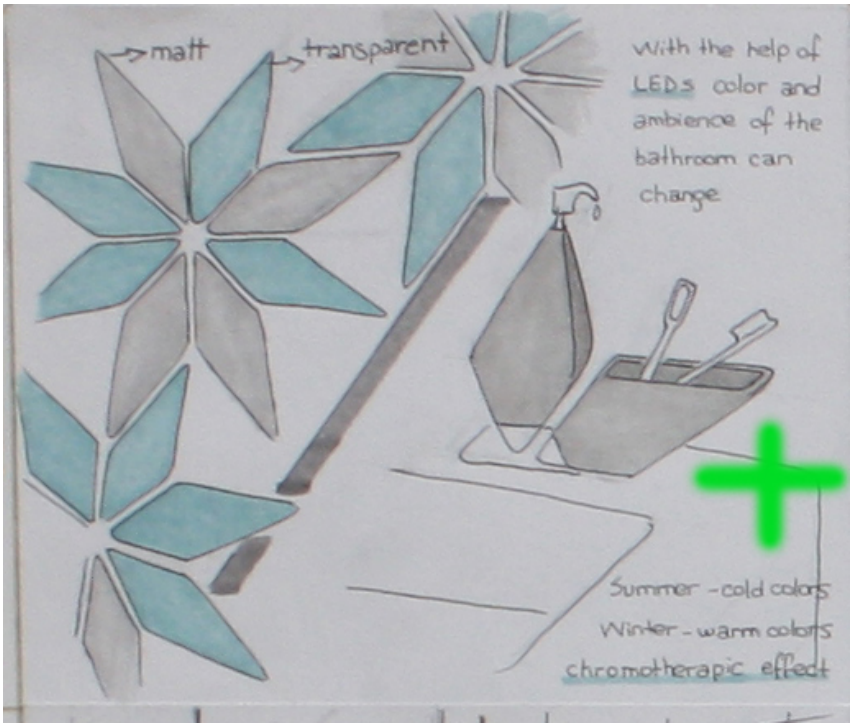

Figure 4.51 - Matrix exercise outcome 1 presented by Aylin Alpay, Çağrı Mercan, Ezgi Çetin, Fatma Köstekli, Fulden Dehneli, and Kaan Karaca - the intersection of 'cozy' and 'free Lego zone'.

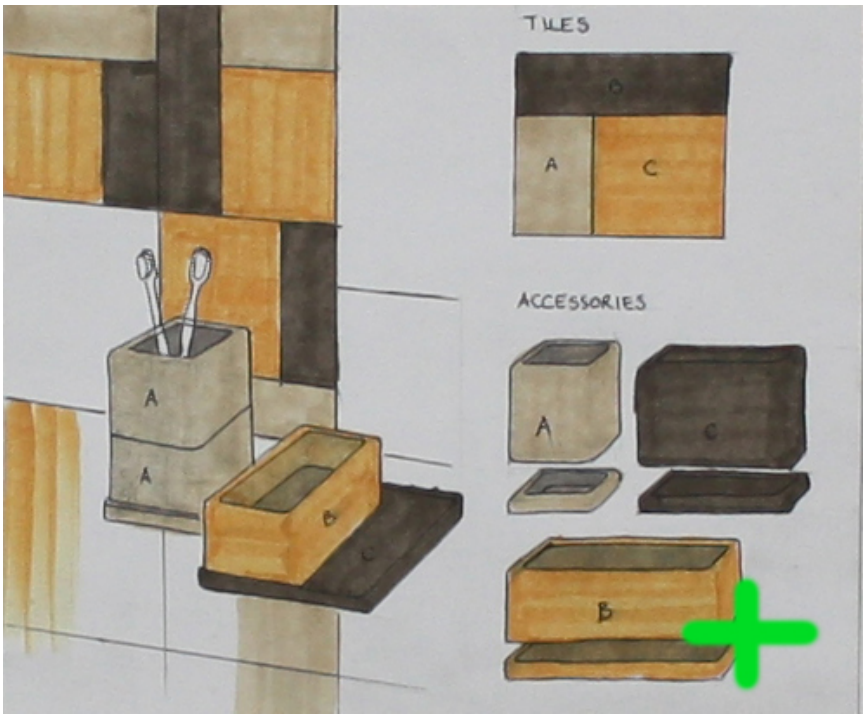

Figure 4.52 - Matrix exercise outcome 2 presented by Aylin Alpay, Çağrı Mercan, Ezgi Çetin, Fatma Köstekli, Fulden Dehneli, and Kaan Karaca - the intersection of 'interchangeable' and 'my instant extended family'.

In the Matrix exercise, Fulden and her group developed and used two of her BSA outcomes. Figure 4.51 shows the intersection of 'cozy' and 'free Lego zone' of their Matrix exercise incorporating her idea of snowflake-inspired pattern and developing it through designing accessories for the idea. Her BSA outcome, inspired by zebras and their patterns, was utilized in the intersection of 'interchangeable' and 'my instant extended family' of the Matrix exercise, offering flexibility in the use of accessories through blending these into the bathroom environment (Figure 4.52). Fulden stated that they used these ideas as a result of their personal attachment - i.e. they liked the ideas - and later realized they had considerable potential for the project considerations (i.e. personalization, evolving and upgrading).

In her Task exercise (Figure 4.53), she stated that she developed her BSA outcome originated from snowflakes, by bringing it together with another student's idea - originated from the leaf arrangement of a flower (Figure 4.54).

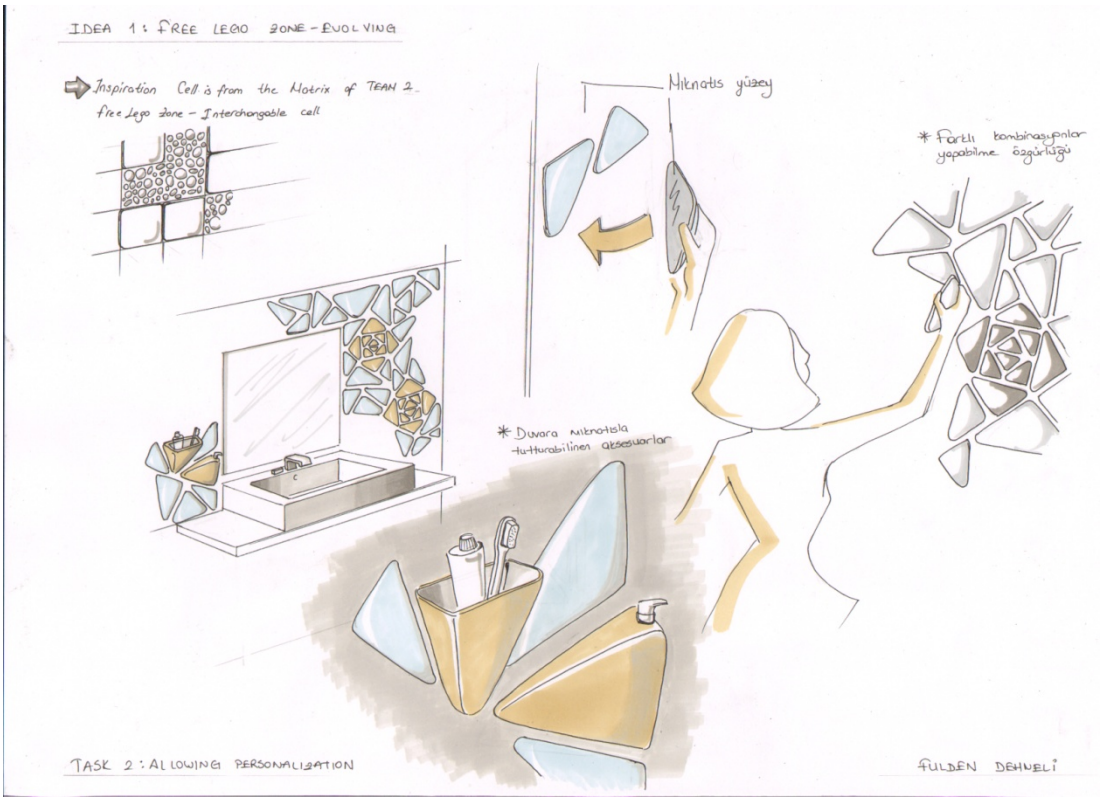

Figure 4.53 - Task exercise outcome presented by Fulden Dehneli - for the third task, 'making it a product family which allows personalization'.

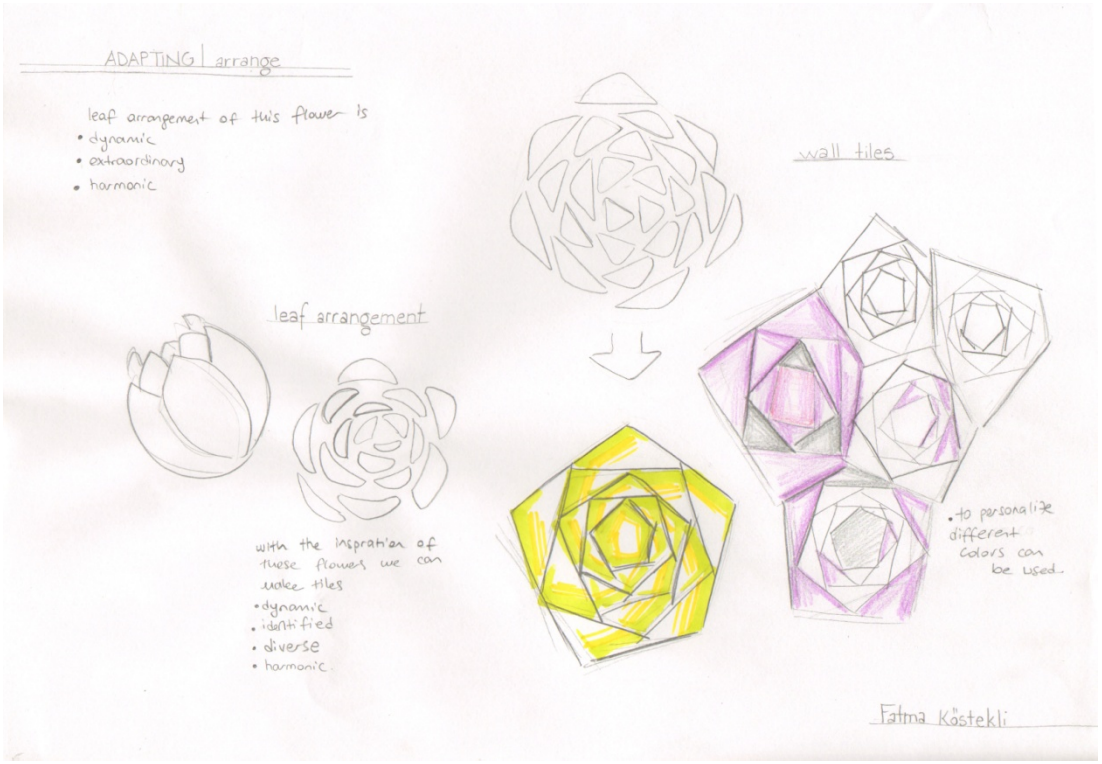

Figure 4.54 - BSA exercise outcome presented by Fatma Köstekli.

As presented in Figure 4.53, Fulden developed and incorporated her idea originated from snowflakes into the Matrix exercise with the addition of bathroom accessories, and developed that idea further considering the BSA outcome by Fatma Köstekli (Figure 4.54) which also constituted of similar modular components.

Through refining the patterns she developed throughout the project phases, she presented the idea in Figure 4.55 (below) for the pre-jury. She decided to use magnets for attaching different modular components, which could be arranged in many combinations to offer personalization.

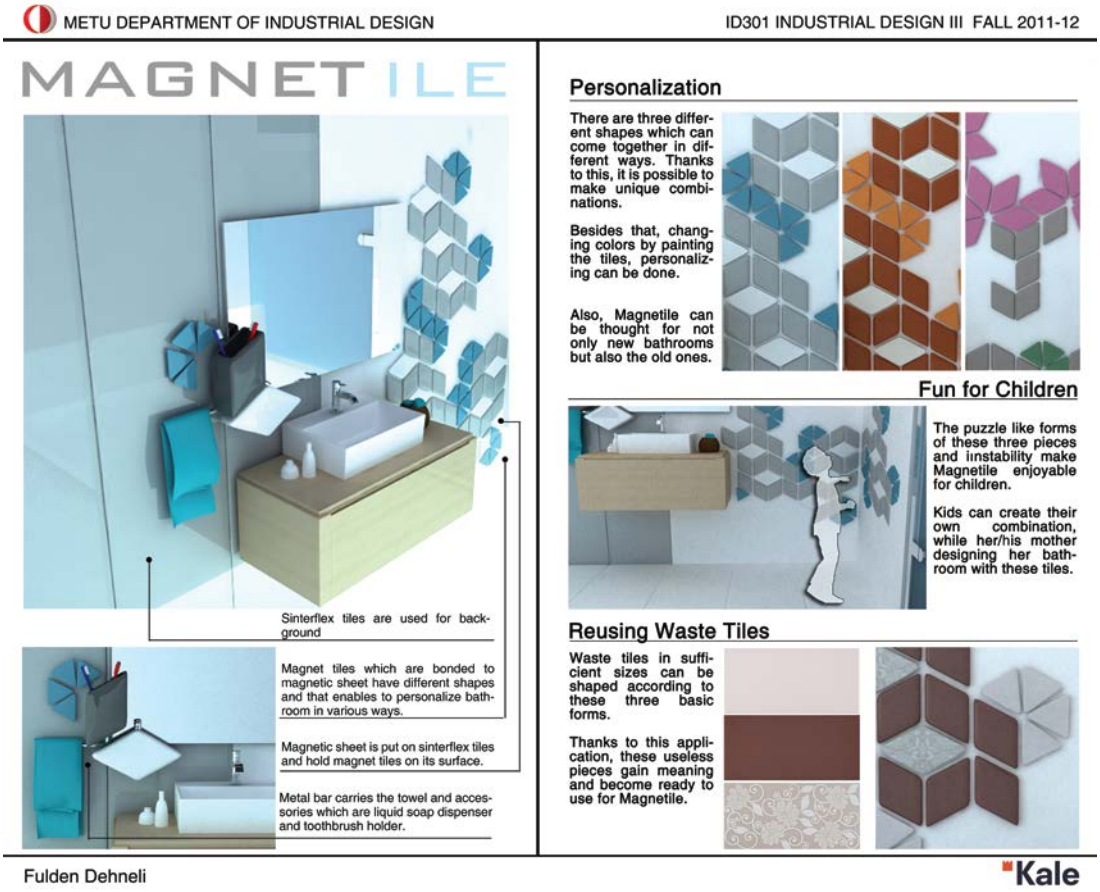

Figure 4.55 - Pre-jury presentation board by Fulden Dehneli.

For the final jury, Fulden refined the pattern inspired from nature even further to incorporate only one modular part, and presented the final design (see Figure 4.56). She focused on the personalization aspect throughout all the project phases, and her final design offered post-use aspects - i.e. maintenance, repair, upgrade and reuse - by offering a flexible system of bathroom tiles and accessories.

Figure 4.56 - Final Jury presentation board by Fulden Dehneli.

Throughout the project phases, Fulden developed her BSA outcome and brought it together with another student's BSA outcome (i.e. she compiled two ideas emerged from the BSA assignment). She focused on the same design consideration - i.e. personalization - from the BSA exercise to the final jury.

Results for Fulden Dehneli

The interview results, along with the results of the analysis of the project phases are presented in Table 4.8, summarized based on the content analysis categories and sub-categories.

Table 4.8 – The Overall Categorized Results for Fulden Dehneli.

		Insights of the student
Biomimicry in Design Process	Research Phase	Stated that the research phase was not helpful in general.
	Idea-generation Phase	Mentioned her disbelief in the usefulness of the biomimicry approach and regarded the quality of the BSA outcomes as being low.
	Design detailing Phase	Used the outcomes of the BSA exercise in every project phases, and compiled it with another student's BSA outcome.

Table 4.8 - The Overall Categorized Results for Fulden Dehneli (continued).

	Final Jury	Presented a final design originated from her BSA.
BSA Exercise	Biomimicry Presentation	Thought it conveyed introductory knowledge on biomimicry.
	Strategies from Nature	Stated that the examples for the strategies were helpful in understanding them, and were useful to lead her towards inspiration sources.
	BSA stages	Stated that transfer stage was challenging, due to the project constraints - i.e. ceramics material.
	Individual Assignment	Emphasized that the individual work increased the number of ideas developed from the different perspectives of the individuals.
	Perceived Aim	To increase awareness on the biomimicry approach.
	Outcomes	Presented outcomes on two strategies - 'attach-detach' and 'adapt'.
Future Projection	Influence of Biomimicry Approach	Mentioned she would use the biomimicry approach, not the BSA exercise, and only on some projects.
	Insights on Further Development of the Assignment	Stated the need for a different tool for the observation and analysis stages.

As concluded from Table 4.8, Fulden assessed that the BSA exercise and the biomimicry approach were not helpful enough for this project, and she indicated her disbelief in the usefulness of the biomimicry approach at first. Yet, she developed her BSA outcome throughout all the project phases, and even incorporated another student's BSA outcome. She perceived the aim of the exercise as increasing awareness on the biomimicry approach, as it appeared to be an idea-generation approach that the students could utilize in the future. She also suggested that there needed to be an alternative tool for the observation and analysis stages where the students had generally difficulty. However, she stated that she would us the biomimicry approach only in some projects in the future.

4.2.4.6 General Conclusions for Student Cases

In this section, five students' design processes were presented to explore and understand how students used the biomimicry approach and the BSA outcomes through the design process. There are various similarities and differences between their insights into the implications of the biomimicry approach for design project, which are presented in Table 4.9, color-coded according to the student groups (green - Group 1; blue - Group 2; yellow - Group 3).

Table 4.9 – Overall Categorized Results for the Selected Student Cases.

		Student 21	Student 9	Student 11	Student 22	Student 24
Biomimicry in Design Process	Research Phase	Not effective for the BSA BSA as a separate exercise	Not effective for the BSA	Effective in terms of further information on materials and user insights from user observations	Not effective for any project phase	Not effective and helpful for any project phase
	Idea-generation Phase	BSA as starting point for the idea generation phase Content with the outcomes	BSA as starting point for the idea generation phase Content with the outcomes	BSA effective for the final project Content with the outcomes and the implications of it	BSA ineffective for the final project Not an in-depth inspiring from nature	Disbelief in the usefulness of biomimicry Low quality outcomes of the BSA
	Design detailing Phase	BSA outcomes in Matrix exercise and Task exercise Developed them further	BSA outcomes in Task exercise, pre-jury, and final fury Developed them further	BSA outcomes in every project phase Developed and adapted them	BSA outcomes in every project phase Developed and adapted them	BSA outcomes in every project phase Combined with another students' BSA outcome
	Final Jury	Final design without a natural inspiration source	Final design originated from BSA	Final design, originated from BSA	Final design originated from BSA	Final design originated from BSA
BSA Exercise	Biomimicry Presentation	Introductory knowledge and critical perspective on nature	Introductory knowledge	Guide to look back to	Introductory knowledge and explanation of BSA stages	Introductory knowledge
	Strategies from Nature	Helpful and influential in idea-generation	Useful in utilizing the biomimicry approach	'Attach-detach' easy to understand 'Adapt' hard to grasp.	Easy to understand Leading towards inspiration sources.	Easy to understand Leading towards inspiration sources.
	BSA stages	'Transfer' challenging due to project constraints	'Observation' and 'Analysis' challenging due to lack of time	Easy to follow	'Transfer' challenging due to lack of time and early in the process	'Transfer' challenging due to project constraints

Table 4.9 - Overall Categorized Results for the Selected Student Cases. (continued).

		Student 21	Student 9	Student 11	Stundet 22	Student 24
BSA Exercise	Individual Assignment	Different perspectives of individuals	Owning the outcomes Group work for outcomes of better quality	Appropriate workload Easier application of the exercise	Easier application of the exercise Group work for outcomes of better quality	Number of ideas developed Different perspectives of individuals
	Perceived Aim	Conveying critical perspective on nature Enhancing the idea generation phase	Triggering idea-generation	Inspiring from nature for sustainable design considerations	Increasing awareness on the biomimicry approach.	Increasing awareness on the biomimicry approach.
	Outcomes	Attach-detach Adapt	Attach-detach Adapt Dispense	Attach-detach Adapt Cleaning	Attach-detach Adapt	Attach-detach Adapt
Future Projection	Influence of Biomimicry Approach	Biomimicry approach for future projects	BSA for future projects	Biomimicry approach for some of the future projects	Not BSA for future projects	Not BSA for future projects
	Insights on Further Development of the Assignment	Lack of time.	Lack of time and group work in 'observation' and 'analysis'	Lack of time in 'observation' and 'analysis'	Lack of time in 'observation' and 'analysis'	Different tools in 'observation' and 'analysis'

As presented in Table 4.9, the research phase was only mentioned as effective by Student 11 from Group 1, stating that it was effective on understanding more about ceramics material and bathroom environment. Others stated that, the research phase was generally ineffective for the design process, thus did not affect the BSA exercise as well.

About the effects of the BSA exercise and the biomimicry approach, Students 9, 11 and 21 (from Group 1 and 2) stated that they were content with the application in general with respect to creating a starting point and resulting in outcomes of good quality. On the other hand, Students 22 and 24 (from Group 3) stated that inspiring from nature remained not-in-depth and resulted in outcomes of low quality in general.

The students mentioned the biomimicry presentation provided them introductory knowledge on the biomimicry approach, and Student 11 (Group 1) even stated that it became a guide to look back to. The strategies from nature were stated as helpful in understanding what to look for in nature for the observation stage, and they were easy to understand. Only Student 11 mentioned problems in understanding the adapt strategy.

Students 21, 22 and 24 (Group 2 and 3) stated that *the transfer stage* of the BSA exercise was challenging due to project constraints, lack of time and positioning of the exercise. Student 9 (Group 1) mentioned that *the observation and analysis stage*s were challenging, as they needed more time to process these stages.

The students mentioned that individual application of the exercise resulted in presenting various perspectives of the individuals on the biomimicry approach, owning the BSA outcomes, easier application of the exercise and raising the number of ideas developed in the class. Student 9 and 22 (Group 1 and 3) stated that group work might have resulted in outcomes of better quality.

Student 22 and 24 (Group 3) perceived the aim of the BSA exercise as raising awareness on the biomimicry approach. Student 21 (Group 2) stated that the aim was to convey a critical perspective on nature and to enhance the idea-generation phase. Student 9 perceived the aim of the exercise as triggering idea generation for the project. Student 11 was the only one who was aware of the relationship between the BSA exercise and sustainable design considerations.

Student 9 was the only one stating that he would use the BSA exercise in his future projects, while others stated that they would use the biomimicry approach. Student 22 and 24 (from the Group 3) stated that they would not use the BSA exercise in their future projects.

The allocated time for the exercise was found insufficient, especially affecting the 'observation' and 'analysis' stages of the exercise. Even though the strategies were found useful in general, one of the students (Student 24) underlined the need for developing different tools for the 'observation' and the 'analysis' stages. Along with the challenges on each stage mentioned by the students, it may be suggested that each stage of the exercise should be developed further.

4.2.5. The Interview Results Presenting the Instructors' Insights

In addition to the semi-structured interviews with the student, an interview was conducted with one of the instructors of the third year studio course, Assist. Prof. Dr. Fatma Korkut, to get her insights into the implications of the biomimicry approach for sustainable product design education. The interview questions is presented in Appendix E, and its results according to the content analysis categories are as follows.

According to her, the reasons for the incorporation of the biomimicry approach into this particular project in the form of a sketch analysis, were that the biomimicry approach was thought to be helpful to enhance the idea generation phase considering the project theme - Reintegrating Bathroom Tiles with Bathroom Accessories. Furthermore, the BSA exercise was thought to be a good start, as this was the first time that approach was applied to an educational design project in the Department of Industrial Design at METU.

Biomimicry in Design Process

The main aim for the placement and planning of the BSA exercise at the idea-generation phase, prior to the Matrix exercise, was to prevent the BSA exercise getting greatly influenced by the Matrix exercise as a comprehensive idea generation method, which would have definitely affected the BSA outcomes. Thus, it was planned before the Matrix exercise, so that the BSA outcomes and their effects could be assessed later on.

It was also stated that the BSA exercise was effective at the idea-generation phase even though it was a short exercise. Creating a starting point for the idea generation phase was mentioned as very important for novice designers. As she explained, there were many final design projects presented by the students with an inspiration source from nature, or inspired from the strategies from nature, which appeared to be a significant finding from the research.

As stated by the students, she also mentioned the ineffectiveness of the research phase of the design process, as the aim of the research phase was to introduce students to the subject of

the project. According to her, the BSA exercise was too early in the process to be affected by the results of the literature review and field observations. The reason for that was explained as the students not being able to comprehend the subject of the project in detail just yet. Another reason for this would be that the students did not have the tools to make better use of the research phase and better connect this phase with the idea generation phase.

Biomimicry Presentation

She mentioned the aim of the biomimicry presentation was to provide students with *introductory knowledge on the biomimicry approach* and to prepare them for the application of the BSA exercise, by *conveying them a critical perspective on nature* through the examples of strategies and the biomimicry applications. Through the explanation of the biomimicry approach and the means of integrating it into the project, the sustainable design considerations (e.g. personalization, post-use, etc.) would be incorporated into the BSA exercise.

As she also stated, the aim for defining and selecting the strategies from nature was to better explore and incorporate the sustainable design considerations and project needs into the design project via the BSA exercise. The strategy 'attach-detach' was considered as important for personalization, upgrade, and repairing, so as 'adapt'.

BSA stages

It was mentioned that the strategies from nature helped the students find the inspiration sources and prevented them from getting distracted. Using photographs for the observation stage to document the inspiration sources and their environment was stated as useful in catching details that cannot be sketched and explored thoroughly, and capturing the inspiration source within its environment. For documenting, she suggested the use of audio-visual recording that would have been more interesting to analyze the inspiration sources.

For the analysis stage, she suggested alternative means for expanding the students' perspective (e.g. structural analysis, aesthetic analysis, etc.), which would have resulted in different BSA outcomes, and might have been more leading for the students.

The transfer stage was mentioned as a stage where the instructors' influence was limited to suggestions, and the students were basically generating new ideas originating from the analysis stage of the exercise and their own interpretation of that analysis.

Individual Assignment

She underlined the importance of different perspectives of individuals on nature which appeared to be important for this exercise, as the transfer stage was affected by individual perspectives. She stated that the assignment was conducted individually for increasing the number of ideas developed so that those outcomes could be assessed for understanding and exploring the implications of the biomimicry approach. Owning the outcomes by the students was also important, so that they would convey their unique perspective on nature individually, which was thought to be important to learn from the implications of the BSA exercise.

She also mentioned that the allocated time for the exercise was short, and the group work would have required a longer time period to be scheduled in the project, as this type of learning would need discussions and agreement upon every idea. On the other hand, she mentioned the group work might have resulted in the outcomes of better quality.

Improving the Assignment

She stated the application of the assignment was not transparent to her. She mentioned that the students completed the observation stage themselves, and even though they took photos of the inspiration sources, it was hard to understand in what ways they were influenced from the natural inspirations. Consequently, as she mentioned, the studio team might not be able to aid the students effectively enough throughout the BSA exercise. To prevent this, she suggested using a better documentation of the observation stage, in the form of logbooks where students would take notes on. Additionally, video recording of the observation stage itself would also make the process more visible and better provide the student's insights into how they inspired from a particular natural model or system. She also suggested that the guidance of experts might also be effective in the observation stage.

She stated that, at the analysis stage of the BSA exercise, the students needed to be reminded about the subject of the project frequently to approach to the inspiration sources accordingly, so that they would not get side tracked from the design considerations.

Future Projection

It was stated that 'biology to design' approach might be interesting to try out or to integrate into future educational projects, through which students would observe and analyze the inspiration sources they would find interesting more in depth and later incorporate it into a

design problem of their choice. She stated that this approach would be harder to utilize, yet the outcomes would be interesting.

She stated that the subject of the project this research was conducted upon - ceramics bathroom tiles and accessories - was suitable for integrating the biomimicry approach, yet could not mention any other project subjects for sure. She mentioned the biomimicry approach might be useful in inspiring for more technical functions, yet it should be tried out first to be able to provide comments on and suggestions for it.

Conclusions for the Interview Results

The interview with the instructor provided insights into the educator's perspective on the main research topic. Some suggestions of her match with the suggestions derived from the students' responses - e.g. observation as a class exercise, use of multi-sensorial mediums, the need for a longer period for observation and analysis, etc. She also stated the BSA exercise needs to be applied and developed with respect to each stage - i.e. observation, analysis, transfer - and additional tools that would aid the students throughout BSA exercise need to be developed. That was also suggested by the students.

4.3. Overall Results of the Research

This section presents an overview of the results of the primary research conducted with the third-year industrial design students regarding the implications of the biomimicry approach for the project phases, the BSA exercise and future research.

4.3.1. Biomimicry in Project Phases

With respect to the project phases individually, there were a few students (8 out of 33) who stated that the research phase (i.e. literature search and field observations) was helpful in any following project phase, and there were only two students who were able to give an example about its effects on the BSA exercise with respect to the design considerations, such as cleaning and ceramics material use in the bathroom environment.

The students were divided into four main groups in this research, according to their perspectives on the helpfulness of the biomimicry approach and the BSA exercise, and their use of this approach throughout the project phases (see Section 4.2.3.1). The integration of it

into the idea-generation phase with the application of the BSA exercise was found to be helpful mostly (21 out of 33 students - Group 1 and 2) and the following aspects of this application were stated as the reasons for its usefulness:

- Creating a starting point
- Number of ideas developed
- Awareness towards the project considerations
- Awareness of nature as an inspiration source

There were 17 out of 33 students who presented a final design originated from the biomimicry approach (Group 1 and 3). Among these students, eight of them developed, adapted and used their own BSA outcome, while two of them used or compiled other students' BSA outcomes. Consequently, 10 out of 33 students presented their final designs originated from the BSA exercise. For a three-days exercise scheduled in the nine weeks project, the overall effect of the project was significant, considering the fact that almost one third of the students were directly influenced by the exercise.

For the remaining 16 out of 33 students (Group 2 and 4), 10 of them stated that they did not develop the final design projects inspired and informed by nature, even though they found the biomimicry approach helpful for the idea-generation phase (Group 2). The reasons mentioned are as follows:

- Necessity of a fresh start as a strategic decision
- Non-transferability between BSA stages

In addition to these reasons above, the remaining six students who found the biomimicry approach not helpful enough were not inspired and informed by nature (Group 4), stated the following reasons:

- Misperception of the exercise
- Lack of Critiques

In general, the biomimicry approach was found helpful by two third of the students (Group 1 and 2), and affected the following project phases and the final design ideas of half of the students (Group 1 and 3). The BSA exercise affected the following project phases of one third of the students.

4.3.2. BSA Exercise

The aim of the BSA exercise was perceived as raising awareness on the biomimicry approach by the majority of the students, and only one fifth of the students (7 out of 33) emphasized that the aim was to explore and achieve sustainable design considerations (i.e. product maintenance, repair and upgrading). This low ratio suggested that the relationship between sustainability and biomimicry were generally not made by the students, and that connection should have been explained more in depth by the studio team.

The students stated various pros and cons of the BSA exercise steps, and offered some suggestions regarding its stages. The BSA exercise was integrated into the idea-generation phase with the following steps:

- Biomimicry presentation
- BSA exercise stages (observation, analysis and transfer)
- Presenting the outcomes through the BSA format

The biomimicry presentation given prior to the BSA exercise was mentioned to offer an introductory knowledge on biomimicry effectively. The presentation was considered as a guide to look back as it was comprehensive in explaining how the biomimicry approach could be utilized in the project at hand. The strategies from nature were mainly provided as a good guide in observing nature - a vast inspiration source - with respect to limiting the models and systems to look for. That presentation was found generally to be explanatory for the strategies from nature through the examples given for each of them. Yet some students highlighted the need of more strategies for the BSA exercise, as nature had more to offer within the context of the design project.

The majority of the students remarked that the allocated time for the BSA exercise was not enough with respect to conducting each stage - observation, analysis and transfer. For the observation stage, the need for other resources on where to look (e.g. online databases, documentaries, etc.) apart from their nearby environment was mentioned, even though some of the students suggested that limiting the places to look for the inspiration sources allowed them to analyze these sources more in depth. For the observation and the analysis stages, an exercise or a workshop carried out by the whole class together was suggested to achieve better analyses of the results for diverse inspiration sources. Similarly, the instructors suggested that there should be various methods of capturing the observed inspiration sources, like audio and video recording, so that they could be analyzed more effectively.

The transfer stage of the BSA exercise was stated as challenging for the students, since it required a better understanding of the project itself first at the onset of it. The allocated time for the exercise was an issue for this stage as well, to offer better quality outcomes from the BSA exercise. Yet the transfer stage allowed the students to present different outcomes even for the same inspiration sources, as the BSA exercise was an individual assignment and each student had their own perspective on nature.

4.3.3. Future Projection

30 out of 33 students emphasized the role of the biomimicry approach in their future projects, mentioning various pros and cons, like nature as a wide-range inspiration source, providing a critical perspective to observe nature, a trend in product design, etc. Yet only 13 of these students acknowledged that they would adopt the BSA exercise for their future projects, stating that the BSA exercise would provide them with a systematical approach in terms of inspiring from nature for the design considerations of potential or upcoming projects.

An interesting result derived was that some students (5 out of 33) mentioned that they would use the biomimicry approach only in some design projects. They were not able to give an example of these design projects, yet the ceramic tiles and accessories project was found suitable by these students. Regarding that, the biomimicry approach could be tried out in different projects to be able to explore the limitations of it in integrating it into various projects.

In this chapter, the results of the interviews with the students and instructors along with the analysis of the exercise outcomes in accordance with the project phases were presented in detail, to show the pros and cons of the biomimicry approach and BSA exercise integrated into the idea-generation phase of an educational design project for sustainability. The results were given in as much detail as possible to provide a better understanding for the integration and to explore the implications of the BSA exercise. In the next chapter, the conclusions drawn from these results will be presented.

CHAPTER 5

CONCLUSIONS

The research has shown that BSA exercise is a successful tool for the idea-generation stage of design process, regarding its effects on the final designs despite the short duration of it. Yet, each stage of BSA indicated pros and cons affecting the outcomes of the exercise. This chapter starts with revisiting the research questions considering the outcomes of the research, according to the results from the research conducted, and concludes with the implications of these conclusions and findings for, and insights into design process and further research.

5.1. Research Questions Revisited

What are the implications of integrating biomimicry into the idea generation phase of the design process based on a design education case for sustainability?

The primary research indicates that the integration of the biomimicry approach into the early stages of the design process has affected the following project phases. Even though the students were generally not aware of the relationship between the biomimicry approach and the sustainable design considerations, the final design solutions were affected by the strategies from nature that were decided upon by the instructors to fulfill these project considerations - i.e. product maintenance, repair, upgrading, and personalization.

The results from the pilot study supported the fact that the students were not mainly aware of the biomimicry approach before the incorporation of it into the design process. The Biomimicry Sketch Analysis (BSA) tool developed to explore the implications of this integration could be considered as successful with respect to this aim, as this analysis and idea generation tool provided awareness on the biomimicry approach, and created assessment criteria for the BSA exercise within the context of biomimicry and how it should be incorporated.

The students were able to assess the integration of the biomimicry approach with respect to its each step, yet there were not any objections against the way it was incorporated into the project schedule as a whole. All the suggestions made for improving the BSA exercise was about developing the steps of the exercise. This also suggested that the phases of this integration were how they should be, even though each step of the exercise could be potentially developed even further accompanied by their own tools. The students also indicated that each stage of the BSA exercise following the prior one systematically and logically, and that was mainly the reason that they would like to adopt the BSA exercise in their future projects.

What are the challenges that the industrial design students face during the incorporation of a biomimicry analysis and idea generation tool into a design project?

The students faced various challenges during the integration of the biomimicry approach, regarding the observation, the analysis and the transfer stages. However, prior to this the main challenge was the lack of knowledge on the biomimicry approach and the means of incorporating it into the design process. The biomimicry presentation given prior to the exercise aimed to eliminate this problem, by presenting the meaning of biomimicry and the ways of incorporating this approach into design projects around the world, and how it would be integrated into the design education project at hand. Through presenting definitions and diverse examples, the students mainly found the biomimicry presentation as comprehensive, since it provided them with the knowledge about the approach and showed what would be possible when this approach was applied to the design projects.

The second challenge was to lead the students towards observing the nature, through which the strategies from nature (i.e. attach-detach, adapt) was used to focus on particular aspects of nature and offer diverse features for the students to observe and elaborate on. The strategies from nature were predetermined by the instructors with respect to the sustainable design considerations (i.e. product maintenance, repair, and upgrading) and found useful by the students in the process of observing nature, as they knew what to look for in it. Yet, another challenge regarding the allocated time for the observation and the analysis stages was emphasized by the students that they needed more time to be able to find inspiration sources and analyze them to the point that these analysis would be better transferred into innovative design solutions. There arises the need for the development of new tools for these corresponding stages, as well as the allocation of more time.

The transfer stage was particularly stated as challenging as well. This stage is where the design considerations and the results of the observation and analysis stages are brought together to transfer these into developing initial design ideas. The stages of observation and analysis would require more time to allow more in-depth explorations and analyses of the inspiration sources. The positioning of the exercise was also found too early by the students, since they were not familiar with the project yet. Consequently, 'transfer' stage is where the problem arises, whether due to the lack of time in the observation and analysis stages, or the early positioning of the exercise at the idea-generation phase. The transfer stage is mainly concerned with combining various sets of knowledge acquired through different tools (i.e. literature review, field observations, BSA exercise) and developing a design idea that can be practically utilized. Thus, the inability of emulating (i.e. developing ideas and solutions based on natural models that are useful in the context of the project) was stated by the students as the most challenging part of the exercise, which was tried to be overcome through developing several and diverse design solutions emerged from the design considerations.

The BSA exercise was carried out individually by the third year students. This allowed different perspectives on nature and their transfers into the design ideas to emerge. However, presenting a better quality of outcomes was considered as necessary to make the assignment more effective in the design process. This was thought possible by carrying out the BSA exercise as a group work, and developing the ideas even further for the BSA outcomes. Yet, a group work would require more time for deciding upon ideas and developing them further, while at the same time eliminating individual perspectives to emerge, from which other students could inspire from. Another problem that the students highlighted regarding the group work was that the outcomes of the exercise would not be owned by the majority of the group members. The students emphasized that the project at hand was an individual one and everybody was expected to present a final design solution individually. Thus, the students found the development and the implementation of the BSA as an individual exercise as reasonable. Considering the findings from the interviews and the analysis of their projects, they developed the design solutions originated from their initial ideas that they would want to keep developing. This aspect suggested that the BSA exercise, or at least the transfer stage, should be carried out individually when integrated into an individual project. Additionally, the observation and the analysis phases could be partly applied as a group work to allow wider perspectives of the students and instructors to be included in the project through discussions and critiques which in turn help the students better understand and explore the inspiration sources from nature.

As a result, even though the BSA exercise provided a systematical approach for biomimicry and its integration into the idea-generation phase, its stages should be developed and detailed further considering these challenges that the students faced during its application.

What are the pros and cons of this integration in terms of the design process and design concepts?

The BSA exercise proposes an original perspective at the early stages of design projects as it constitutes both research (observation and analysis stages) and idea-generation (transfer stage) phases at the same time. In this manner, the students are led towards utilizing their findings in nature immediately by transferring them into design ideas for the project at hand at the initial stages of the design process. Looking at the bigger picture, from defining the strategies from nature to presenting design ideas, the BSA exercise provides a transition phase between the research and the idea-generation phases, in which the strategies from nature selected and defined in line with the design considerations to lead students towards the idea generation phase more effectively. This was stated by the students as the BSA exercise created a starting point at the idea-generation phase.

Half of the students with which this research was conducted (17 out of 33) presented a final design solution inspired and informed by nature. In addition to that, one third of the students (10 out of 33) found the biomimicry approach helpful for the idea-generation phase, yet were not able to develop design solutions inspired and informed by nature. In total, 17 out of 33 students used the outcomes of the BSA exercise in the following idea-generation exercise (i.e. Matrix exercise) and 20 out of 33 students used the biomimicry approach in the design detailing exercise (i.e. Task exercise). It should also be noted that the use of the biomimicry approach within the design process and for the final design solutions was left to the choice of the students.

The number of ideas developed as a result of the BSA exercise was also influential for the students as well. 118 design ideas were developed and presented in the BSA exercise, and that many ideas were stated by the students as influential throughout the design process. The outcomes were displayed on the white presentation walls of the studio for about two weeks, so that the students could examine this rich pool of ideas emerged from various inspiration sources, whenever they could not go further at the idea-generation and design detailing phases.

The perceived aim of the incorporation of the BSA exercise was interesting among the students. While nearly half of the students (15 out of 33) believed that the aim was to increase

awareness on the biomimicry approach, and one third of the students (10 out of 33) stated the aim was to convey a critical perspective on nature, and its models and systems, only 7 out of 33 students realized the relationship between sustainable design considerations and the incorporation of the exercise. Although the assignment aimed for all of these, its incorporation into the design process of the project mainly aimed to explore and integrate the sustainable design considerations (i.e. product maintenance, repair, upgrading, and personalization) from the start (i.e. idea-generation) via the biomimicry approach. This suggests that the relationship between sustainability and biomimicry should have been more clearly explained in the process, so that the students would better realize the aim of the exercise and make use of it.

Even though the students did not stated the relation between sustainability and biomimicry, the students incorporated the sustainable design considerations into their BSA outcomes. The patterns in natural models and systems abstracted were used for personalization, and the 'attach-detach' details used for product maintenance, repair and upgrading. Yet, the design considerations for the project, like the use of ceramics material, the bathroom environment, etc. affected the BSA outcomes. The students had to develop and adapt their ideas mostly, to be able to produce final design solutions that were in line with the project brief. Some of the final design solutions were originated from the BSA exercise; however they did not constitute or have reference to any inspiration source from nature. At some point, the BSA outcomes themselves were inspirational rather than the inspiration sources they were originated from.

As a result, it would be suggested that the integration of the BSA exercise into the idea-generation phase was influential for the design process, with regards to becoming a transition phase between the research phase and the idea-generation phases, and developing ideas for sustainable design considerations. Yet, on the other hand, the students were not limited by the biomimicry approach to develop their final designs. In addition to that, their final design solutions might not appear to be inspired and informed by nature, even if they were generated by the BSA exercise for incorporating the sustainable design considerations in the first place.

What are the instructors' points-of-view on the integration of biomimicry into an educational design project?

The instructors stated that the BSA exercise was a good start, as this was the first time the biomimicry approach was applied to an educational project in the Department of Industrial Design at METU. It was a short exercise to explore the implications of the biomimicry approach, and it was planned prior to the Matrix exercise to prevent its outcomes affecting the BSA exercise. However, the BSA exercise was mentioned as effective at the idea-generation

phase even though it was a short one. It created a starting point for the students; the development of initial ideas was underlined as a common problem for novice designers. Furthermore, the final design solutions were affected by the biomimicry approach, either by an inspiration source from nature of or by the strategies from nature.

Defining the strategies from nature upfront helped the students find the inspiration sources. Documenting these sources visually (i.e. taking photos) was considered as useful for the instructors to follow how the students were inspired by nature. Yet, it was also stated that just taking photos was not enough by itself, and alternative ways of documenting, like logbooks, audio and video recordings, etc., were also suggested to enrich the student experience on the biomimicry approach.

Presenting the individual perspectives on nature was stated as important for the transfer stage of the exercise. Yet, for the observation and analysis stages, group work or class exercises might lead towards outcomes of better quality. The problem was the allocated time for this exercise, as this type of learning would require more time.

For the future use of the BSA exercise, it was mentioned that the limits of the biomimicry approach should be explored within different subjects. The biomimicry approach was thought to have the potential for providing inspirations for technical functions in more complex design problems, and it could be integrated in future educational projects to explore this potential.

5.2. Implications of This Research for Improving the BSA Exercise

The BSA exercise was developed as an analysis and idea-generation tool to incorporate the biomimicry approach into the design process, and its stages were defined, keeping in mind the students skills and knowledge in that particular area (i.e. the lack of biology knowledge and inability to conduct micro level of observation of natural systems and models). It should also be noted that the research was conducted with novice designers, and their skills and needs are different from that of professional designers.

The exercise has three stages: observation, analysis, and transfer. For the observation stage, a more familiar form of observation was suggested and in this research, a hands-on observation was found suitable, instead of mainly using various databases and resources requiring inherent biology knowledge. Even though, this approach has allowed the students to observe natural systems and models within their contexts, and to figure out how different models and systems interact, the need for more advanced educational tools for novice designers arose. The reason

for that is, the strategies from nature, that were defined by the instructors according to the sustainable design considerations, and examples of these strategies presented in the biomimicry presentation were helpful in leading the students towards the inspiration sources. Yet, how and why they were inspired from that particular model or system were unclear to the instructors, which might have caused limitations on assisting the students, and, to the students, which might have resulted in a not-in-depth analysis stage.

For the analysis stage, the sketching and visualization skills of a designer were utilized. The students had to look closer and understand how the systems and models in nature work, in order to be able to sketch or visually analyze them in the first place. However, the students were not given any specific directions for the analysis stage, thus every student analyzed the natural models and systems according to their own choice of direction, and presented various analyses and explorations of forms, patterns, functions. By defining the directions of the analysis stage (e.g. aesthetic, structural, etc.), the outcomes of the BSA exercise can result in differently, and the direction of the analysis can be chosen or specifically detailed according to the project that the BSA exercise is integrated into.

For the transfer stage, a combination of the Matrix exercise and the BSA exercise was suggested by the students and the instructors, which might have resulted in various ideas that would be more in line with the design project. The Matrix exercise allows students to reassess the design considerations with respect to project themes and generate ideas accordingly. Yet, the use of such a Matrix for the BSA exercise could result in better understanding of the project considerations and outcomes of better quality regarding these considerations. Consequently, the relationship between the strategies from nature and the design considerations for the project would have been clearer for the students.

To conclude, the BSA exercise was used to incorporate the biomimicry approach into the idea-generation phase of the design process, and it offered a systematical approach for that integration. This thesis aimed to explore the implications of the biomimicry approach for sustainable product design education, and it attempted to do so via the BSA exercise. The ideas and the conclusions presented here aim to be inspirational instruments for students, educators, and designers who want to make use of the biomimicry approach in their works and researches.

5.3. Implications for Further Research

This thesis addresses two areas of further research related to the biomimicry approach for sustainable product design and education. Firstly, the integration of the biomimicry approach into the design education project in the area of ceramic tiles and accessories has effective results with respect to the sustainable design considerations (i.e. product maintenance, repair, upgrading, personalization), and the integration of it into the design projects of different product categories with more complex sustainability issues, such as consumer electronics, home appliances, in relation to electronic waste, is also worth investigating and exploring. Furthermore, the BSA exercise and the integration of the biomimicry approach into the idea-generation phase would have the potential to be developed further through supported analysis and observation tools, and the implications of them could be explored. Secondly, as a result of this research, the BSA exercise has the potential in achieving sustainable design considerations, and its development for the use of design professionals is an aspect that can be taken into account for further studies as well.

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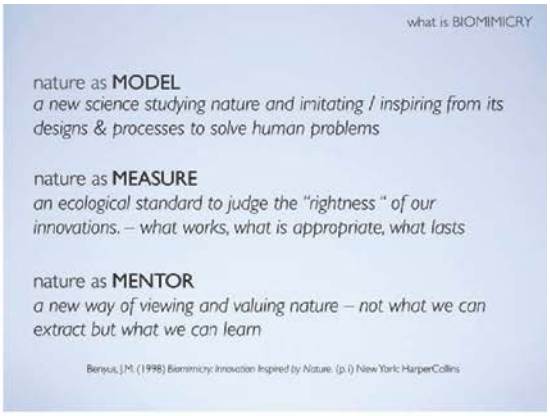
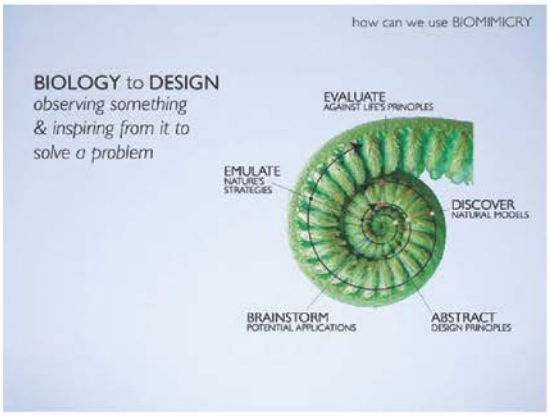
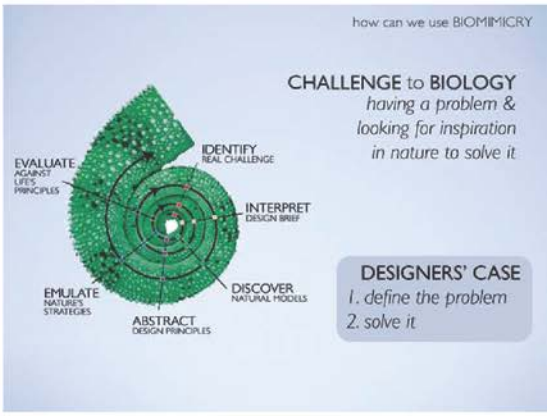
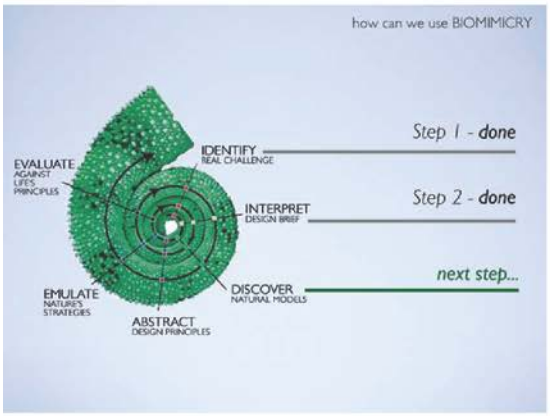
APPENDIX A

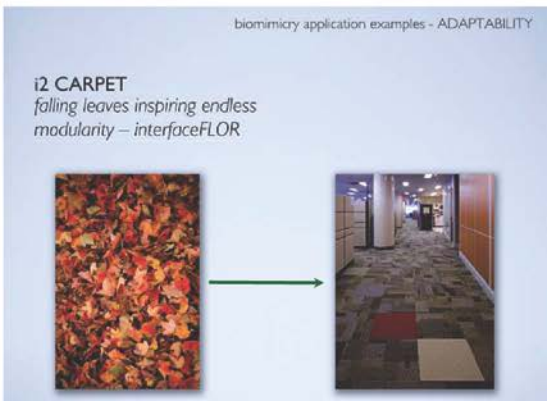
Biomimicry Presentation for the Third Year Design Students







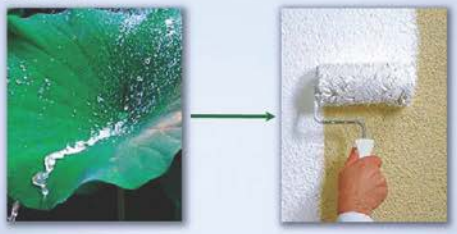




biomimicry application examples – SELF-CLEANING

EXTERIOR COATING

hydrophopic surface of sacred lotus inspiring self-cleaning paint – Lotusan Paint



POSSIBLE INSPIRATIONS for Kale Project

for attaching and adapting

possible inspirations - PERMANENTLY ATTACHING

MOUSEBIRD

- *Can perch without energy usage*
- *Has an anatomical **locking mechanism** at its feet*

possible inspirations - TEMPORARILY ATTACHING

REMORA

- *Can attach to sharks (3D forms) with partial vacuum*
- *Has **sucker-like structure** on top of its head*

possible inspirations - TEMPORARILY ATTACHING

BLACKBERRY

- *Can **hold onto and align** itself on different plant stems*
- *Has **backward-pointed structure** on its spines*

possible inspirations - TEMPORARILY ATTACHING

LEAF BEETLE

- *Can hold onto waxy leaves*
- *Has thousands of **bristles wetted with oil***

possible inspirations - ADAPTING | material use

HONEYCOMBS

- *Optimizes material use with **120°, three-way junctions***
- *Creates **perfect hexagonal** voids, that can be brought together without unused walls*

possible inspirations - ADAPTING | material use

TORTOISE SHELL

- *Creates a 3D form out of hexagonal surfaces*
- *Uses **hexagonal subunits** and **filler shapes** to connect hexagons*

possible inspirations - ADAPTING | arrange

SUNFLOWER

- *Fits numerous seeds in minimum space*
- *Arranges seeds in **spirals of Fibonacci numbers***

possible inspirations - ADAPTING | form and position

GUILLEMOT EGGS

- *Does not fall off cliffs*
- *Has **pear shape**, enabling **spin on spot** rather than rolling*

possible inspirations - CLEANING

PUMPKIN

- *Can resist adhesion of water and dirt*
- *Has **convex geometry** on its surface*

possible inspirations - CLEANING

EYE of MOTH / FLY

- *Reduces adhesion*
- *Has **corneal gratings** decreasing contact area*

possible inspirations - MAKE | resist force

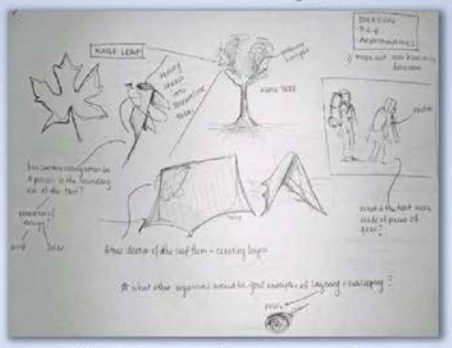
VINES

- *Has flexible branches resisting damage*
- *Branches has **soft-tissue components** and grow in a **ribbon shape***

ASSIGNMENT: **FIND INSPIRATIONS**

for attaching and adapting

assignment - FIND INSPIRATIONS



biomimicry sketch analysis example

possible inspirations - CLEANING

PLACES to LOOK FOR INSPIRATIONS

- *METU campus*
- *METU Botanical Garden*
- *The A.O.Ç. Zoo*
- *The Eymir Lake*
- ***everywhere...***


THANK YOU FOR YOUR ATTENTION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APPENDIX B (1)

Project Brief

Middle East Technical University Faculty of Architecture Department of Industrial Design

Fall 2011-12 ID 301 Industrial Design III

Asst. Prof. Dr. Çağla Doğan, Asst. Prof. Dr. Fatma Korkut, Part-time Inst. Selim Gençoğlu, Part-time Inst. Funda Özkan, Part-time Inst. Tuğba Ülker, Res. Asst. Sedef Süner, Res. Asst. Senem Turhan

Sustainable Design Solutions Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles in Collaboration with Kale Group

This project will be undertaken in collaboration with Kale Group, one of the major bathroom products and accessories producers in Turkey. The aim of the project is to develop sustainable design solutions, which demonstrate the potential of personalization and biomimicry in the area of ceramic bathroom accessories and tiles. Within the scope of this project, *a family of products* will be developed that reflects the sustainability vision of Kale through rethinking and reintegrating ceramic bathroom accessories with bathroom tiles. Ceramic bathroom accessories include soap dish holders, toothbrush holders, towel bars, soap dispensers, shelf fixtures, toilet brushes, toilet roll holders, etc.

- Personalization: Empowering and encouraging product-user relationship through personalization is one of the important sustainable design considerations. Personalization supports user's attachment to the product and enriches product-user interaction which, in turn, prolongs the product life span. We think that "half-way product" is a viable and promising personalization strategy which enables user intervention; the user can explore various possibilities to personalize her/his half-way or semi-finished product through integrating materials and skills at the local level. This will help develop a family of products allowing product diversity through personalization.
- Biomimicry: Biomimicry is an approach that encourages design solutions inspired by nature. In this project we will explore the implications of this approach in terms of integrating bathroom tiles and bathroom accessories through exploring strategies inspired by nature such as attach-detach, adapt, assemble, make modular, etc. The examples demonstrating nature's "knowledge" or ways of doing things will be incorporated into the idea generation phase of the design process.

The stages of the project

Part 1 – Literature Search, Field Observations and Project Dimensions

Conduct literature search on assigned topics, make user observations in private homes, and survey the existing bathroom accessories in the market. Based on the major conclusions you reached, propose project dimensions.

Part 2 – Initial Design Exploration

Work on project dimensions and develop initial ideas through the biomimicry exercise and MATRIX exercise to explore diverse design solutions.

Output: Diverse design solution areas for integrating bathroom accessories and tiles.

Part 3 – Concept Development and User Testing

Further explore the initial design ideas through the TASK exercise. In order to assess the potential of design solutions, build mock-ups and conduct interviews with potential users.

Output: Alternative design solutions, mock-ups and user testing results.

Part 4 – Final Design

Present the final design solution with real size appearance models of the whole product family.

Grading:
Literature search, field observations and project dimensions 15%
Preliminary Jury 30%
User testing results, and design details and sections 15%
Final presentation and deliverables 40%

APPENDIX B (2)

Project Research Brief

Middle East Technical University Faculty of Architecture Department of Industrial Design

Fall 2011-12 ID 301 Industrial Design III

Asst. Prof. Dr. Çağla Doğan, Asst. Prof. Dr. Fatma Korkut, Part-time Inst. Selim Gençoğlu, Part-time Inst. Funda Özkan, Part-time Inst. Tuğba Ülker, Res. Asst. Sedef Süner, Res. Asst. Senem Turhan

Project II: Sustainable Design Solutions Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles in Collaboration with Kale Group

Literature Search, Field Observations and Project Dimensions

Digital submission (Microsoft Office Power Point)

https://online.metu.edu.tr/ 15 November 2011 Tuesday 13:40

Presentation: 15 November 2011 Tuesday 13:40

1. Literature Search

Each team will cover one subject category for the literature review. Conduct a thorough **literature search** on the subject category assigned to your team:

Team 1	Kale Group - vision, mission, brand values; facts and figures; current products in the market; customer services, etc.
Team 2	Ceramic as a material; production processes and applications
Team 3	Ceramic decoration and surface finishing applications
Team 4	Bathroom accessories excluding ceramic ones (e.g. liquid soap dispenser, toothbrush holder, bathroom tumbler, tissue holder, etc.)
Team 5	Ceramic bathroom accessories and tiles
Team 6	Bathroom environments in relation to products and habits in different cultures
Team 7	Trends and directions for future bathroom environments
Team 8	Personalization, localization, half-way products, family of products

2. Field Observations

Visit private homes and retail stores, and document your observations with still images, video recordings, voice recordings, notes and sketches. Please ask for permission and use attached guideline before recording and/or taking any pictures. At your presentation we expect documentary evidence.

a. Domestic environments

Visit at least two private homes (and/or dormitories), and document the ways in which bathroom accessories and tiles are used. During your observations and in your presentations address the following issues and questions:

- What are the characteristics of the users? Take notes about age, gender, income level, neighbourhood and other important features.
- What are the difficulties/critical issues that the users encounter concerning the use of bathroom accessories and tiles?
- Which needs do these products fulfill?
- What functional and decorative qualities do these products embody?
- What types of accessories or elements do the participants add to the bathroom accessories to transform or personalize them?
- What is the environment/setting of these products?

b. Commercial environments

Visit at least two different types of stores and document your observations concerning ceramic bathroom accessories and tiles that we specified.

Specialized stores (e.g. Paşabahçe, Tepe Home, etc.) for bathroom accessories in general

Hardware stores (e.g. Praktiker, Koçtaş, Bauhaus, etc.) for bathroom accessories and ceramic tiles in general

- What are the characteristics of the bathroom accessories and tiles in terms of design, surface finishing applications, graphics and labelling?
- Are there special sets or family products for bathroom accessories?

3. Major Conclusions

As a team, discuss your **major conclusions/findings/insights** from the literature search and the field observations; provide at least three conclusions from each study.

4. Project Dimensions

Based on the conclusions reached, each team member will provide minimum four **project dimensions** which are critical for this project (examples: sustainable, natural, diverse, evolving, adaptable, transformable, local, personalised, integrative, empowering, modular, etc.). Make a complete list of all dimensions proposed by the team members. As a team discuss, choose and highlight at least four dimensions out of this list which you find critical for the project.

5. Presentation

Prepare a PowerPoint presentation documenting your literature search, field observations, major conclusions from the literature search and field observations, and the complete list of all dimensions along with the four selected dimensions.

You can adopt different strategies to carry out this assignment; but decide on the structure of your presentation together before conducting literature search and field observations. During the presentation, we expect each team member to contribute to the presentation.

Presentation format: 15 minutes team presentation.

APPENDIX B (3)

Biomimicry Sketch Analysis Exercise Brief

Middle East Technical University Faculty of Architecture Department of Industrial Design

Fall 2011-12 ID 301 Industrial Design III

Project II: Sustainable Design Solutions Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles in Collaboration with Kale Group

Biomimicry Sketch Analysis

Hard-copy submission: 25 November 2011, Friday 13:40

Digital submission (only JPEG or PDF, real size 200 dpi): https://online.metu.edu.tr/ 25 November 2011, Friday 13:40

For this assignment, you will observe, explore and document three different natural systems or organisms (e.g. animals, insects, plants, trees, seeds, etc.) that you find inspiring within your nearby environment (e.g. METU Campus, METU botanical garden, the A.O.Ç. Zoo, the Eymir Lake, etc.).

Biomimicry involves developing strategies inspired by nature. In this assignment, you are expected to explore and analyze at least the first two of the following strategies:

Attach and detach: permanent or temporary
Adapt: optimize space or materials; modify physical state such as changing form, color or position
Self-defined (optional): (self-)clean, resist forces, etc.

For each natural system or organism, prepare a detailed hand sketch analysis which describes and visualizes the following aspects:

The source of inspiration
Its unique feature(s) and component(s) in terms of the biomimicry strategies highlighted above
The implications of the feature(s) for this particular design project in terms of form, color, pattern, assembly, modularity, diversity, scale, etc.

Format: Individual submission, three A3 (landscape) sketch analyses along with photographs for the sources of inspiration on A4 paper (portrait) with a brief description including title, date, location.

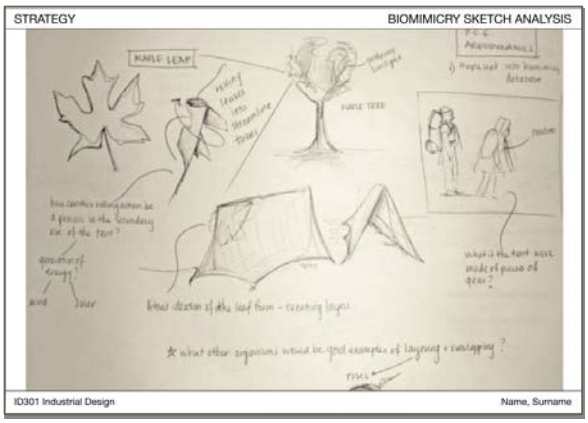


Figure 1: A Sample of Biomimicry Sketch Analysis

APPENDIX B (4)

Matrix Exercise Brief

Middle East Technical University Faculty of Architecture Department of Industrial Design

Fall 2011-12 ID 301 Industrial Design III

Asst. Prof. Dr. Çağla Doğan, Asst. Prof. Dr. Fatma Korkut, Part-time Inst. Selim Gençoğlu, Part-time Inst. Funda Özkan, Part-time Inst. Tuğba Ülker, Res. Asst. Sedef Süner, Res. Asst. Senem Turhan

Project II: Sustainable Design Solutions Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles in Collaboration with Kale Group

Matrix: Idea Generation Exercise (teamwork)

Submission and presentation: 29 November 2011 Tuesday 13:40

The aim of the Matrix exercise is to explore various dimensions of the project within the context of particular themes. The Matrix consists of project dimensions placed on the top of each column, and themes placed on the left of each row as described below. You will sketch concept ideas in each cell inspired by the themes and the dimensions provided.

The concept ideas should involve reintegration of tiles and bathroom accessories; bathroom accessories includes soap dish holders, toothbrush holders, towel bars, grab bars, soap dispensers, hooks, shelf fixtures, toilet brushes, toilet roll holders, etc. Since you are going to develop *a family of products* we recommend that you explore more than one accessory in each cell of the matrix. Try to come up with diverse ideas and diverse combination of accessories.

Project Themes/Project Dimensions	Cozy	Inclusive	Interchangeable	Evolving	*A self-defined dimension*
Free Lego zone					
My instant extended family					
InteracTiles OR Experience keeper					
Clean contact					

Phase I: By 25th of November, each team is expected to develop ideas for **five** cells in the matrix.

Phase II: By 29th of November, the teams will complete the remaining cells **15** cells of the matrix and present it.

Format: 70X100 cm white paper, orientation: landscape

APPENDIX B (5)

Task Exercise Brief

Middle East Technical University Faculty of Architecture Department of Industrial Design

Fall 2011-12 ID 301 Industrial Design III

Project II: Sustainable Design Solutions Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles in Collaboration with Kale Group

Task: Idea Generation Exercise II (individual work)

Submission: 2 December 2011 Friday 08:40

Digital submission (only JPEG or PDF, real size 200 dpi): https://online.metu.edu.tr/ 2 December 2011 Friday 24:00

Aim: The aim of this exercise is to develop and enrich the ideas from the matrix and the biomimicry exercises through considering the specific "tasks" described below. A "product family" includes bathroom tiles, and accessories fullfilling at least three functions.

Tasks:

1. Make it a product family which empowers and enables kids **OR** elderly.
2. Make it a product family which allows personalization.
3. Make it a product family which allows upgrading **OR** repair **OR** reuse

Procedure:

1. Focus on (or compile) **three** diverse ideas from the matrix or the biomimicry exercises.
2. For each idea, select one task (out of three) and apply it to the idea. Do not select the same task again.

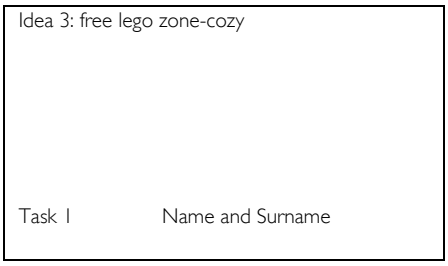
Format :

Use the exemplary layout given.

Use A3 size white paper

Orientation: Landscape

Exemplary layout



APPENDIX B (6)

Preliminary Jury Brief

Middle East Technical University Faculty of Architecture Department of Industrial Design Fall 2011-12
ID 301 Industrial Design III

Asst. Prof. Dr. Çağla Doğan, Asst. Prof. Dr. Fatma Korkut, Part-time Inst. Selim Gençoğlu, Part-time Inst. Funda Özkan, Part-time Inst. Tuğba Ülker, Res. Asst. Sedef Süner, Res. Asst. Senem Turhan

Project II: Sustainable Design Solutions Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles in Collaboration with Kale Group

Preliminary Jury 16 December 2011 Friday 08:40-17:30

Digital submission (only JPEG or PDF, real size 200 dpi): https://online.metu.edu.tr/ 13 December 2011 Tuesday 24:00

Presentation boards submission: 13 December 2011 Tuesday 13:40-17:30

Full scale mock-ups submission and preliminary jury: 16 December 2011 Friday 8:40

For the preliminary jury scheduled on December 9th, present two alternative design solutions. For each design solution, submit scenario snapshots communicating your design approach for reintegrating bathroom tiles with accessories. The snapshots should describe:

- The product family in context
- Proposed user interventions at various stages of the products' lifespan
- Design details enabling the integration of bathroom tiles and accessories

For one of the design solutions submit full scale mock-ups: Tiles, and accessories fullfilling at least three function

Examplary format:

Sample Board

Presentation Board
Physical size: 110 cm x 90 cm
Orientation: Landscape
Language: English
Resolution: 200DPI (CMYK or RGB), 8661 x 7087 pixels

HEADER
Background: White
Left Align: METU emblem, followed by "METU DEPARTMENT OF INDUSTRIAL DESIGN"
Right Align: "ID301 INDUSTRIAL DESIGN III FALL 2011-12"
Thin Horizontal Line

FOOTER
Thin Horizontal Line
Background: White
Left Align: "FIRST NAME SECOND NAME"
Right Align: Logotype of "Kale" (use the version provided)

APPENDIX B (7)

Final Jury Brief

Middle East Technical University Faculty of Architecture Department of Industrial Design Fall 2011-12
ID 301 Industrial Design III

Asst. Prof. Dr. Çağla Doğan, Asst. Prof. Dr. Fatma Korkut, Part-time Inst. Selim Gençoğlu, Part-time Inst. Funda Özkan, Part-time Inst. Tuğba Ülker, Res. Asst. Sedef Süner, Res. Asst. Senem Turhan

Project II: Sustainable Design Solutions Rethinking and Reintegrating Bathroom Accessories with Bathroom Tiles in Collaboration with Kale Group

Final Jury 06 January 2012 Friday (09:00-17:30) and 07 January 2012 Saturday (09:00-14:00)

Digital submission (only JPEG, real size 200 dpi): https://online.metu.edu.tr/ 07 January 2012 Saturday 24:00

Final Jury Requirements

For the final jury scheduled on January 6th-7th, present your finalized design solution:

- Full-scale orthographic views and dimensions of all components, sections as many as necessary, and design details for the integration of bathroom tiles and accessories (black and white print-outs are acceptable).
- Coloured drawings and renderings describing all critical features of the product family and their usage in context, and the proposed user interventions at various stages of the products' lifespan.
- Full-scale appearance models of tiles and accessories fullfilling at least three functions.

Presentation: For each presentation, 10 minutes will be allocated. 5 minutes for the student's presentation and 5 minutes for the jury members' comments. The order of presentations will be determined by drawing lots.

Sample Board	**Presentation Board** Physical size: 110 cm x 90 cm Orientation: Landscape Language: English Resolution: 200DPI (CMYK or RGB), 8661 x 7087 pixels **HEADER** Background: White Left Align: METU emblem, followed by "METU DEPARTMENT OF INDUSTRIAL DESIGN" Right Align: "ID301 INDUSTRIAL DESIGN III FALL 2011-12" Thin Horizontal Line **FOOTER** Thin Horizontal Line Background: White Left Align: "FIRST NAME SECOND NAME" Right Align: Logotype of "Kale" (use the version provided)

APPENDIX C

Semi-Structured Interview Questions for Students (Turkish)

I - Giriş Bölümü (Biyomimikri sketch ödevlerinin sonuçlarını göstermeden – genel olarak ödev ve süreçlerini değerlendirmek Q1-Q3)

Q1. Yaptığınız biyomimikri skeç analizi ödevini nasıl değerlendirirsiniz? Süreçleden bahseder misiniz?

Q1A. Ödev ve ilgili süreçler sizin için ne kadar açıktı?

Q1B. Biomimicry sunuşu, biomimicry stratejileri açısından, ödevi anlamanızda ve fikir geliştirme aşamasında ne ölçüde etkili oldu? Hatırladığınız ve etkilendiğiniz örnekler nelerdir?

Q1C. Fikir geliştirme sürecindeki yeri ve etkisini değerlendirir misiniz?

Q1D. Bireysel olması fikir geliştirme sürecini nasıl etkiledi?

Q1E. Bu ödevi ilham kaynağı, kaynağın analizi, ve bu analizin transferi aşamaları açısından nasıl değerlendiriyorsunuz? Bu analizleri fikir geliştirme sürecine ne ölçüde dahil edebildiniz?

Q1F. Bu ödev öncesinde yaptığınız kullanıcı, ürün ve literatür araştırması (projenin ilk aşaması), ilham kaynağı seçiminizi ve analizini etkiledi mi? Evetse, örneklerle açıklayabilir misiniz?

Q2. Sizce bu ödevin amacı veya amaçları neydi? Bunlara ulaşabildiniz mi? Hangi açılardan?

Q3. Bu ödevi geliştirmek için önerileriniz nedir? Ödev sırasında karşılaştığınız sorunlar veya zorluklar nelerdir? Bunların giderilmesine yönelik önerileriniz nelerdir?

II- Gelişme Bölümü (Biomimicry skeç ödevlerinin sonuçları üzerinden – süreç ve sonuçları değerlendirmek Q4-Q8)

Q4. Bu ödevin sonuçları projenin ilerleyen safhalarında nasıl etkiledi?

Q4A. Ödevdeki biomimicry analizlerini ve uygulamalarını *matrix* egzersizinde kullandınız mı? Evetse, nasıl kullandığınızı anlatır mısınız? Örnek verir misiniz ve sunuşlar üzerinden gösterir misiniz? Hayırsa, nedenini belirtir misiniz?

Q4B. Ödevdeki biomimicry analizlerini ve uygulamalarını *task* egzersizinde kullandınız mı? Bunları daha önce *matrix* egzersizinde kullandınız mı? Yoksa doğrudan sadece *task* egzersizinde mi kullandınız? Örnek vererek açıklar mısınız?

Q4C. Bu ödevde geliştirdiğiniz ilk fikirler, ön juri için geliştirdiğiniz fikirleri nasıl etkiledi? Örnek vererek açıklar mısınız?

Q5. Bu ödevin sonuçlarını projenin sonraki safhalarında nasıl kullandınız? Oldukları gibi mi? Geliştirerek veya değiştirerek mi? Birkaç sonucu birleştirerek mi?

Q6. Projenin sonraki safhalarında, bu ödevde ulaştığınız sonuçlar dışında biomimicry ilham kaynakları kullandınız mı? Evetse, kullandığınız ilham kaynakları nereden geliyor? (Proje süreçlerinde diğer öğrencilerin paylaştığı örnekler mi, yoksa başka ilham kaynakları mı?)

Q7. Bu analiz yöntemiyle daha önce hiç karşılaştınız mı? Evetse, kaynağınız nedir? Gelecekte yapacağınız projelerinizde yeri ve etkisi konusunda ne düşünüyorsunuz?

Q8. Biyomimikri analizlerinize tekrar baktığınızda bu sürecin geliştirmesine yönelik değerlendirme ve önerileriniz nelerdir?

APPENDIX D

Project Calendar

METU DEPARTMENT OF INDUSTRIAL DESIGN - ID 301 2011-12 FALL - KALE GROUP PROJECT CALENDAR

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	MONDAY
31-Oct	1-Nov	2-Nov	3-Nov	II. Project starts Introduction Literature Search User Observations Project Dimensions 4-Nov	5-Nov	6-Nov
7-Nov	8-Nov	9-Nov	10-Nov	Critiques for Literature Search User Observations Project Dimensions 11-Nov	12-Nov	13-Nov
14-Nov	Seminar by Tuğba Ülker Literature Search User Observations Project Dimensions presentations 15-Nov	16-Nov	17-Nov	Kale Factory visit (Çan) tile, bathroom sink, bathroom tub and water closet 18-Nov	19-Nov	20-Nov
21-Nov	Biomimicry seminar by Yekta Bakırlıoğlu and Biomimicry assignment 22-Nov	23-Nov	24-Nov	Matrix idea generation exercise 25-Nov	26-Nov	27-Nov
28-Nov	Matrix group sumission Task exercise 29-Nov	30-Nov	1-Dec	Task idea generation exercise submission 2-Dec	3-Dec	4-Dec
5-Dec	Design crits for preliminary jury presentations and mock- 6-Dec	7-Dec	8-Dec	Preliminary Jury presentations 9-Dec	10-Dec	11-Dec
12-Dec	Design crits 13-Dec	14-Dec	15-Dec	Design crits and Technical drawing seminar by Mustafa Hasdoğan 16-Dec	17-Dec	18-Dec
19-Dec	Design crits 20-Dec	21-Dec	22-Dec	Design details technical details submission 23-Dec	24-Dec	25-Dec
26-Dec	Design crits for final jury presentations and mock-ups 27-Dec	28-Dec	29-Dec	Design crits for final jury presentations and mock-ups 30-Dec	31-Dec	1-Jan
2-Jan	Design crits for final jury presentations and mock-ups 3-Jan	4-Jan	5-Jan	Final Jury End-of-classes 6-Jan	7-Jan	8-Jan

APPENDIX E

Semi-Structured Interview Questions for Instructors (Turkish)

Q1. Biyomimikri yaklasımını özellikle bu proje kapsamında kullanmanızın nedenlerini açıklar mısınız?

Q2. Biyomimikri yaklasımın projenin fikir geliştirme aşamasında bir skeç analizi ödevi seklinde vermenizin amacı veya amaçları neydi? Bunlara ulaşabildiniz mi? Hangi açılardan?

Q3. Biyomimikri skeç analizi ödevini projenin fikir geliştirme aşamasındaki yerini belirlerken göz önünde bulundurduğunuz etkenler nelerdir?

Q7. Biyomimikri skeç analizi ödevinin, projenin fikir geliştirme sürecindeki yeri ve etkisini değerlendirir misiniz?

Q4. Ödev ve ilgili süreçler belirlenirken, göz önününde bulundurduğunuz etkenler nelerdi?

Q5. Ödevle ilgili stratejileri (attach-detach ve adapt) belirlerken, göz önünde bulundurduğunuz etkenler nelerdir?

Q6. Biyomimikri sunuşunun hazırlanmasındaki temel amaç sizce neydi? Öğrencilerde nasıl bir farkındalık yaratılmaya çalışıldı?

Q8. Ödevin bireysel olması kararını alırken göz önünde bulundurduğunuz etkenler nelerdir?

Q9. Ödevin ilham kaynağı, kaynağın analizi, ve bu analizin problem alanına aktarılması aşamaları açısından nasıl değerlendiriyorsunuz? Bu aşamaların birbirleri arasındaki geçişte ve ilişkilendirmede eksik gördügünüz, geliştirilmesi gerektiğini düşündügüz yerleri var mı? Varsa, nedir?

Q10. Bu ödevin, öncesindeki proje safhalarından (lireratür araştırması ve kullanıcı gözlelemleri aşamalarından) ne derece ve nasıl etkilendiğini düşünüyorsunuz?

Q11. Bu ödevin, sonrasındaki proje safhalarının (Matrix ve Task fikir geliştirme süreçlerinin) nasıl etkilendiğini düşünüyorsunuz? Hatırladığınız proje örnekleri var mı?

Q12. Bu ödevin uygulaması sırasında karşılaştığınız sorunlar veya zorluklar var mıydı? Varsa, bunlar nelerdir ve bunların giderilmesine yönelik önerileriniz nelerdir?

Q13. Biyomimikri skeç analizi sonuçlarının devam ettirilmesi veya aktarılmasıyla sonlanan veya finalize edilen projeler var mıydı? Bu projelerden hatırladıklarınız hangileriydi?

Q14. Bu projelerde biomimicry'nin kullanımı hakkında ne düsünüyorsunuz? Sizin biomimicry'yi projeye dahil etme amaçlarınızla, gerçekte kullanım şekli örtüşüyor muydu? Yoksa, farklı amaçlarla kullanımı var mıydı? Varsa bunlar nelerdir?

Q15. Bu projelerde biomimicry'nin yaptığı katkıyı nasıl değerlendiriyorsunuz? Sonuçlar, en başta verilen sürdürülebilir tasarım ölçütlerine uygun oldu mu? Hangi açılardan değerlendirir misiniz? Biyomimikri bu sonuçlara ulaşmakta sizce ne kadar etkiliydi?

Q16. Stüdyo ekibi olarak benzer bir projeyi tekrar etmek isteseydiniz, Biyomimikri yaklaşımını sürece nasıl dahil ederdiniz? Projede ve biomimicry ödevinde ne tür değişiklikler yapardınız?

Q17. Biyomimikri ödevinin gelecekteki eğitim projelerinde uygulanmasına yönelik önerileriniz neler? Bu yaklaşımın ne tür projelerde uygulanması tasarım eğitimi açısından uygun ve etkili olurdu?

Q18. Biyomimikri yaklaşımının sürdürülebilirlikle ilişkisini nasıl değerlendirirsiniz? Biyomimikri yaklaşımı ve uygulamaları açısından sürdürülebilir ürün tasarımı alanı nasıl geliştirilebilir?

APPENDIX F

Consent Form for Students

CONSENT FORM

Research Project Title: The implications of biomimicry approach on design process

Investigator: Yekta Bakırlıoğlu, M.Sc. student, Middle East Technical University

I am a M.Sc. student in the Department of Industrial Design and I am carrying out a study which aims to investigate the implications of biomimicry approach for idea generation phase and semi-structured interviews with industrial design students to provide insights on design process. The research results will provide a basis for the development of papers for journal publications and for the completion of my Master's Thesis.

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

I wish to interview you because of your attendance and performance in the second project of the course Industrial Design 301. Your participation would involve answering questions in an interview, which is expected to take approximately 20-25 minutes. The interviews will be audio taped. Your participation is voluntary and you may withdraw from the study at any time, in which case your responses would not be used.

As the interview questions are related to your work performed during the project, I may request to observe visual representations of your ideas (i.e. sketches, renderings, 3D models, photographs etc.) during the interview.

☐ By signing this consent form, you will agree that your name may be used in the Master's Thesis and journal publications in connection with the information you provide and the visual representations. (i.e. sketches, renderings, 3D models, photographs)

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time. If you have further questions concerning matters related to this research, please contact:

Yekta Bakırlıoğlu, M.Sc. Student
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Middle East Technical University
Phone: 0 312 210 7033
E mail: yekta@metu.edu.tr

Assist. Prof. Dr. Çağla Doğan, Supervisor
Department of Industrial Design,
Faculty of Architecture
Middle East Technical University
Phone: 0 312 210 2247
E mail: dcagla@metu.edu.tr

Participant‘s name and signature
Date

Investigator‘s signature
Date

*A copy of this consent form has been given to you to keep for your records and reference