DEVELOPMENT OF BIOPHILIC DESIGN CONCEPT FOR EDUCATIONAL SPACES

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UTVECKLING AV BIOFILISKT DESIGNKONCEPT FÖR UTBILDNINGSUTRUM

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Abstract

As urbanization encourages more people to stay indoors for longer periods of time, there is an increased need to reconnect with nature, using design as a tool. The concept of biophilic design aims to do just this, by bringing natural elements into human spaces.

This industrial design project aims to create a product for educational workspaces that incorporates natural elements in a metaphorical way, so as to try and create a positive perception of such workspaces among humans. The project explores the different ways in which biophilia can be implemented in product design, and the factors and aspects that need to be considered in order to do so.

The project also tests the developed concept using a Virtual Reality setup and a questionnaire, which had 9 respondents. The results from the questionnaire showed that 89% of respondents felt the concept expressed natural elements, and 44% felt ‘Peaceful’ after observing the concept in Virtual Reality. The positive responses from participants indicate that the concept is successful both in incorporating natural elements and in transmitting a positive perception of workspaces where it is used.

Keywords:
Design, Industrial Design, Biophilic Design, Educational workspaces, Perception
Sammanfattning

Eftersom urbanisering uppmuntrar fler människor att stanna inomhus under längre perioder, finns det ett ökat behov av att återknyta kontakten med naturen med design som ett verktyg. Konceptet med biofil design syftar till att göra just detta, genom att föra in naturliga element i mänskliga utrymmen.

Detta industriella designprojekt syftar till att skapa en produkt för pedagogiska arbetsplatser som innehåller naturliga element på ett metaforiskt sätt, för att försöka skapa en positiv uppfattning om sådana arbetsplatser bland människor. Projektet utforskar de olika sätt på vilka biofili kan implementeras i produktdesign, och de faktorer och aspekter som måste beaktas för att göra det.

Projektet testar också det utvecklade konceptet med hjälp av en Virtual Reality-uppsättning och ett frågeformulär, som hade 9 respondenter. Resultaten från enkäten visade att 89 % av de tillfrågade ansåg att konceptet uttryckte naturliga element, och 44 % kände sig "fredliga" efter att ha observerat konceptet i Virtual Reality. De positiva svaren från deltagarna indikerar att konceptet är framgångsrikt både när det gäller att införliva naturliga element och att förmedla en positiv uppfattning om arbetsytor där det används.
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1 Introduction

1.1 Background

In recent times, natural elements have begun to be included in workspaces and urban living spaces, most commonly in the form of green plants and green walls. This inclusion is motivated by the belief that as human beings evolved over the years, they formed a deep genetic bond with nature, to the point that they feel comfortable and relaxed while in nature. Thus, it is the lack of this connection that is pushing us to include nature in our living spaces, and it is this concept that forms the basis for the field of design called Biophilic Design (Kellert S. R., 2008).

Many scientific studies have shown (M.S. Abdelal, 2019) that natural elements improve the well-being and productivity of people in workspaces. In many of these studies, the productivity and creativity of employees was shown to increase when plants and sunlight were introduced into their workspaces. Similarly, students’ connection with nature, and their overall emotional and physical health have been shown to improve with exposure to nature. While this is a strong motivation for products that include natural elements, in most cases this has involved the use of green plants and pictures of nature.

There is thus an increased need for creative industrial design that utilizes the principles and advantages of biophilic design. With scientific studies solidly showing that biophilic design comes with many benefits, more products have to be designed from the ground up incorporating biophilic principles. It is this gap that the master thesis tries to fill.

1.2 Objectives

This project will look into the various factors involved in the integration of natural elements in workspace products, specifically biophilic design and how it can be implemented, and using this knowledge, design a product suited for educational environments, such as universities and schools. The project will take the campus of Jönköping University as a basis for understanding educational spaces.

This project will go in depth into the implementation of biophilic design principles in industrial design, especially in educational environments. The aim is to create a product that is shaped by a deep understanding of biophilic design principles and how they can be implemented in the different stages of product development. Using a strong foundation of scientific studies to back the theory, the project will investigate how biophilic design can help to create positive perceptions in a workspace to improve the connection between users and nature. This is one of the major aims of the project. This will then be tested to verify and validate the concept.

As such, the goal of the project is to:
1. Design and develop a concept that integrates biophilic principles.
2. Understand how natural elements and biophilic design have been integrated into everyday products and how this can be approached in a different manner.
3. Try to create positive perceptions of the workspace using the designed product and nature as driving factors.

1.3 Research Questions

The research questions connected with this project are:

- What are the factors and motivations surrounding the integration of natural elements with traditional workspace products?
- How can workplace products integrating natural elements be designed in an educational setting?
- What methods can be used to show the resulting perception of workspaces with the introduction of the concept design?

1.4 Delimitations

The project will focus mainly on the specific biophilic principles that can be used with industrial design, and the implementation of this knowledge in the design of the product. As a result, manufacturing and production will not be focused on. The cost analysis of the final product will also be beyond the scope of this project. Further, due to the skills and motivations behind the project as a master thesis, the project will focus on products and not architectural features or design of workspaces as a whole.

1.5 Disposition

The project report is divided into multiple sections. The Introduction explains the project, introduces the problem and gives an overview of why the project is considered relevant. The Theoretical Background aims to give an understanding of the area of work, a brief about product development and about industrial design, design thinking, biophilic design theory and semantics and semiotics. The section on Method describes the processes involved in the project, while the section on Approach, Implementation and Results shows how the processes were carried out and conducted and reporting the results of the project. This is followed by the section on the Final Concept, which looks into the detailed design and CAD modeling and prototyping of the final concept, followed lastly by Conclusions and Discussions.
2 Theoretical Background

2.1 Product Development and Industrial Design

Ulrich (Ulrich K. T., 2017) defines Product Development as the systematic approach of creating new products or enhancing existing ones to meet customer needs and market demands. The process involves multiple steps such as problem identification, ideation, concept development, prototyping, testing, commercialization and product lifecycle management. These steps also need a strong foundation of relevant research and analysis to identify customer needs and requirements, understand the problem area and market, and to provide a basis for the product being developed.

Industrial design is a multifaceted field that involves the use of scientific research to create visually appealing and functional products that meet the needs and preferences of users. It can be described as the act of creating and developing concepts to optimize the aesthetics, value and functionalities of products with both the user and manufacturer in mind (Norman D., 2013). Contrary to popular belief, industrial design encompasses more than just appearances, involving aspects such as ergonomics, product performance, materials and production.

In the development of any product, there is always an interplay between industrial design and other aspects of product development such as manufacturing and product lifecycle management. This is essential in order to create products that are not only good looking and convenient to use, but are also easy to manufacture and behave in the required manner throughout their expected lifetime. There are also several challenges involved in managing any product development project, and these can include project planning, team dynamics, resource allocation and risk management. These further emphasize the need for effective coordination and collaboration between people involved in the different processes, in order to ensure a successful outcome (Ulrich K. T., 2017).

2.2 Design Thinking

Design Thinking is an iterative approach to problem-solving that places emphasis on empathy, creativity, and experimentation. Norman (Norman D., 2013) argues that design thinking should focus on the needs and goals of users, rather than just the technical aspects of a product. He suggests that designers should take a user-centered approach to design, starting with empathy for the people who will be using the product. Industrial designers frequently apply Design Thinking to generate innovative ideas, prototype concepts, and test products before releasing them into the market. The Design Thinking process consists of multiple phases, such as empathizing with users to gain insight into their needs and preferences, defining the problem, brainstorming potential solutions, prototyping, and testing the proposed solutions, and finally, implementing the most effective solution. Norman also emphasizes the importance of feedback in the design process. He suggests that designers should continually test and iterate their designs based on user feedback, to
ensure that the product meets the needs of users. By taking a user-centric design thinking approach in the industrial design process, designers can produce products that are not only functional but also enjoyable to use.

### 2.3 Semantics and Semiotics

Norman (Norman D., 2013) talks about semantics as the study of meanings. Semantics are powerful knowledge as they are based on what we know about the world and the context, giving us helpful insights into how to use products intuitively. Semantics can vary vastly with differences in culture, technology etc. Monö (Monö, 1997) on the other hand, talks about semantics as the message that is given by a product. This can be achieved in four different ways.

- **Description**: Describing a product through its purpose or function. This can be achieved through the title of the product.
- **Expression**: Expressing properties, attributes and feelings through the form or function of the product. This can be used to let the user know what kind of feeling the product will invoke when interacting with the user.
- **Exhortation**: Exhorting or eliciting responses and reactions from the user. These are commonly achieved through the use of signals, such as a vibration to indicate something important.
- **Identification**: Identifying the product through its attributes, such as its brand, origin, purpose and category.

Semiotics deals with the study of signs, and how they are used and interact with other signs. Monö (Monö, 1997) explains that the five senses are continuously used by a person to understand their environments and surroundings, and this can be used in industrial design to design products in such a way that it prompts the users’ senses to perceive the product in the right way. This can make the product easier to understand, and easier and more effective to use.

### 2.4 Emotional Well-Being and Industrial Design

Emotional well-being is a multidimensional construct that encompasses various dimensions such as positive emotions, life satisfaction, happiness, and fulfilment. Industrial design can have a significant impact on emotional well-being by incorporating design features that promote positive emotional experiences. According to research by Hassenzahl et al (Hassenzahl, 2003) emotional design, which involves designing products that stimulate positive emotional responses, can enhance user satisfaction and emotional well-being. Industrial designers can utilize emotional design principles by designing products that evoke positive emotions, such as joy, excitement, and contentment. For instance, the design of a
product can incorporate aesthetically pleasing features, such as vibrant colors, soft textures, and curved shapes, which have been shown to promote positive emotional responses (Norman D., 2004)

Moreover, the use of positive psychology in industrial design can further enhance emotional well-being. Positive psychology is a branch of psychology that focuses on the study of positive emotions and experiences. The application of positive psychology principles in industrial design can result in products that promote happiness and well-being. Industrial designers can apply positive psychology principles by designing products that foster positive emotions, such as gratitude, compassion, and kindness. For example, the design of a product can incorporate features that promote mindfulness, such as simple and intuitive interfaces, which have been shown to enhance emotional well-being (Lomas, 2017).

Incorporating emotional design and positive psychology principles into industrial design can have a significant impact on emotional well-being. By designing products that stimulate positive emotions and foster well-being, industrial designers can contribute to enhancing the emotional well-being of users and promoting positive experiences.

2.5 Industrial Design in Educational Environments

Industrial design plays a crucial role in the development of educational environments. Educational environments should be designed in such a way that they provide a conducive atmosphere for learning and create a positive impact on the students. According to research by Nair and Fielding (Nair, 2005), well-designed educational environments can help improve student performance and engagement. Industrial designers can use various design principles, including ergonomics, aesthetics, and functionality, to create effective educational environments.

2.5.1 Ergonomics

Ergonomics, which is the study of human factors and their relationship with the environment, can be used to design educational furniture and equipment that promote healthy posture and enhance learning experiences. Industrial designers can use ergonomics principles to design furniture that is comfortable, adaptable, and promotes movement.

2.5.2 Aesthetics

Aesthetics is another critical design principle that can be used to create effective educational environments. Aesthetically pleasing environments have been shown to improve students' cognitive processing and mood (Gifford, 2014). Industrial designers can use design elements such as colour, lighting, and texture to create visually appealing educational environments.
2.5.3 Functionality

Functionality is yet another critical design principle that should be considered when designing educational environments. The design should promote ease of use and accessibility. The design should also provide a positive user experience for students and teachers. For example, the design of educational technology should be intuitive, straightforward, and easy to use.

2.6 Biophilic Design

Biophilic design is an approach to architecture and interior design that incorporates elements of nature into the built environment, with the aim of enhancing people’s connection with nature and improving their well-being. The concept of biophilia, which suggests that humans have an innate affinity for nature, is at the core of biophilic design. According to Kellert et al. (Kellert S. R., 2008), biophilic design principles can be applied in a variety of ways, such as incorporating natural light and ventilation, using natural materials, and creating views of nature from indoor spaces. Research has shown that biophilic design can have a positive impact on human health and well-being, including reducing stress, enhancing cognitive function, and increasing creativity (Browning, 2014), (Jove, 2007). In the study "Nature connectedness and biophilic design", Richardson and Butler (Butler, 2022) talk about the potential that nature connectedness-focused biophilic design can have in shaping environments that benefit people, nature and the future by developing opportunities to increase interaction and engagement with nature in everyday spaces, such as work or at home. This suggests that biophilic design can be an effective way to promote nature connectedness and enhance well-being in indoor environments.

2.6.1 Biophilic Design Principles

In ‘The practice of Biophilic Design’, (Kellert S. &., 2015) Kellert talks about five main biophilic design principles that can be used to create a successful and satisfying experience of nature in buildings. These principles are:

- **Engagement –** Biophilic Design requires repeated and sustained engagement with nature
- **Adaptation –** Biophilic Design focuses on human adaptations to the natural world that over evolutionary time have advanced people’s health, fitness and physical well-being.
- **Attachment –** Biophilic Design encourages an emotional attachment to particular settings and places.
- **Interaction –** Biophilic Design promotes positive interactions between people and nature that encourage an expanded sense of relationship and responsibility for the human and natural communities.
Theoretical Background

- Interconnection – Biophilic Design encourages mutual reinforcing, interconnected and integrated architectural solutions. (Kellert S. &., 2015)

2.6.2 Biophilic Design and Well-being

A regularly discussed topic in the study of biophilic design is its effect on the physical and psychological well-being of users, particularly its benefits. This is all the more pertinent when it comes to educational environments. Students often report more than average levels of stress and anxiety and are diagnosed with depression (Verna DeLauer, 2022). The causes for these conditions can be varied, ranging from competitiveness in the grading system to low self-esteem. Studies have also found a relationship between stress and a range of negative behaviours like substance abuse, violence, suicidal tendencies etc.

At the same time, one of the commonly reported benefits of engaging with nature in urban spaces and in wilderness areas, is the effects it has on mitigating stress. Studies have shown that people experience a sense of calm and tranquil while being in nature, or even while looking at pictures of nature (Vining, 2008). The Psycho-Evolutionary Theory, a part of evolutionary psychology, talks about the effects of natural environments in reducing stress levels because such environments provide attributes that human beings consider important for survival, like water and open spaces (Ulrich R. S., 1991).

2.6.3 Biophilic Design in Educational Environments

Considering the stress and anxiety that persist among students in educational environments, there is a potential for biophilic design principles to help alleviate these conditions. Haidamous (Haidamous, 2022) talks about the effects that biophilic design can have on the productivity and psychological well-being of students and employees. He explains that offices and schools are spaces where the occupants can become stressed and tired working for long hours with heavy mental engagement. In such cases, their focus is also affected, which in turn impacts their productivity. Using biophilic design can help to maximise productivity, and at the same time improve the psychological well-being of occupants. Dzhambov et al (Dzhambov, 2021) also talks about the effects of having house plants in reducing depression.

Biophilic design can be incorporated into educational spaces in different ways. One of the common ways to do this is to design the built environment using biophilic principles, to increase engagement with natural elements and improve the interaction and connectedness with nature.
3 Method

3.1 Double Diamond Design Process

The project will be executed using the Double Diamond approach as a template. The Double Diamond is a very popular design approach that is widely used, and it consists of four phases – Discover, Define, Develop and Deliver. These phases are explained below.

- **Discover** – In this phase, the background regarding the project is collected. All relevant information, such as from surveys, observations, interviews and literature are compiled to get a better understanding of the problem area and the scope of the project.
- **Define** – In this phase, the specifics regarding the project are put down and defined. This includes the problem area, target audience, the scope and limitations, user requirements, functions and needs for the project and the specifications for the same.
- **Develop** – The Develop phase consists of the actual design of the product. This includes activities such as brainstorming, concept generation, concept selection and detailed design.
- **Deliver** – The last phase involves the presentation of the product, including physical and/or digital models such as prototypes and renders. (Design Council, 2007)

As part of the different phases, various activities and methods will be used for different purposes.

![Double Diamond Design Process](Design Council 2007)
3.2 **Gantt Chart**

A Gantt chart is a project management tool that displays the schedule of activities, their start and end dates, and their dependencies. It offers a comprehensive view of the project timeline, enabling project managers to track progress and make adjustments as needed. For this thesis, breaking down the work into individual tasks and mapping them onto the Gantt chart can help ensure timely completion. As a well-established tool, the Gantt chart has proven effective in various contexts, including academic research projects. Martin and Spolander (Spolander, 2012) recommend the use of Gantt charts for successful project management in social work and social care.

3.3 **Literature Review**

A literature review is a critical analysis and synthesis of existing research on a particular topic. In the context of a master thesis, a literature review serves to identify gaps and debates in the field, as well as establish the context and significance of the research question. A comprehensive review of relevant literature is essential for developing a research proposal that is grounded in existing knowledge and contributes to advancing the field. As noted by Fink (Fink, 2019), a well-conducted literature review can provide a framework for identifying research questions, designing studies, analyzing data, and interpreting results. Therefore, it is crucial for the literature review to be systematic, well-organized, and reflective of the current state of knowledge in the field.

The literature search in this project will use Google Scholar, Primo and Scopus to find scientific articles. Keywords have to be defined to help narrow the search results, and combinations of the keywords using the connectors AND, OR and NOT are created to clearly define the searches. The project will also use a method called snowballing, where a parent article is selected, and any relevant articles that have been used as references in it are then selected to be reviewed (K. Säfsten, 2020). Alternatively, one can also find where the parent article has been cited, and use those articles in the review process.

3.4 **Market Research**

Market research is a study of existing products and solutions in the market that are similar to or competing with the project at hand. It helps identify the immediate brandscape of similar brands, and allows the designer to understand the trends and patterns (if any) that are visible in the current market.

In this project, market research will be performed to get an overview of the types of products that exist in the market, and to identify trends in the design of biophilic furniture.
3.5 Observations

Observations are performed by the author during the Discover phase. They involve the author (observer) being in a relevant setting (for example, a classroom), and recording how people interact and behave in the setting, and how different aspects of the environment are. They can be done in structured, semi-structured and unstructured ways. In this project, unstructured observations will be used. The observations will performed in a non-participatory manner, with the focus being to observe and record the events happening in the environment. The observations will be twofold, one part being to observe the environment where the product is to be implemented, namely educational spaces. For this, the campus of the School of Engineering at JU will be used to perform observations. The observations will focus on the types of spaces that are present for students in the campus and the different natural elements that are already present. The second part of the observations will focus on commercial establishments that use natural elements in their shop spaces. These observations will focus on how different elements are used in stores to bring a sense of nature to customers and motivations for doing so (if any).

3.6 Moodboard

Moodboards are collections of pictures of images that are used commonly by designers. The moodboard is used to represent the theme that is pursued while designing a product. They can be used for multiple aspects of the design, such as color schemes, materials, design language etc.

3.7 Function Analysis

Function analysis plays an important role in the design process, enabling designers to comprehend the purpose and requirements of a product or system. It involves identifying the functions that the product or system must perform and prioritizing them based on their significance. This helps designers create a design that satisfies the needs of the users while taking into account technical and economic constraints. For a master thesis, where product or system design is the main focus, function analysis is an essential tool. According to Ulrich and Eppinger (Ulrich K. T., 2017), function analysis is critical for product design, as it aids designers in understanding customer needs and market requirements, allowing them to create an efficient and effective design.
3.8 **Brainstorming**

Brainstorming is a type of internal search method used during the concept generation. The search conducted during brainstorming is internal since it relies on the knowledge possessed by the team to generate ideas. It is regarded as the most open-ended and creative task during product development. This process can be thought of as retrieving relevant information from one's memory and adapting it to the current problem. It can be executed individually or collaboratively by a group of people. (Ulrich K. T., 2017)

3.9 **Sketching**

Designers frequently use sketching as an essential research and development tool to assess their concepts on paper, preserving them for future evaluation, modification, and iterative improvement. Sketching helps to solidify a design idea and enables designers to explore various design possibilities, endeavoring to shape and express the concept's form and significance.

Designers typically begin their creative process by using traditional tools such as pen or pencil and paper to generate and sketch out their ideas. During the sketching process, designers also annotate their work, providing helpful reminders and cues to themselves, while also highlighting essential elements that need to be communicated to other members of the design team and stakeholders (Milton, 2013).

3.10 **CAD Modelling**

Computer Aided Design deals with using computer software to create 3D models of the selected concept. These models help the designer to understand the scale and size of the concept, its components, and how it can be assembled. It also allows the designer to create good surfaces as desired, and to further be used for digital prototypes.

In this project, the software that will be used for CAD are Autodesk Alias and Autodesk Fusion. Alias is a surface modelling software that allows the designer to create surfaces according to specifications, or free form too. Fusion on the other hand is a solid modelling software, and it helps the designer create models that are solid and have a definite geometry and structure to them.
3.11 Rendering

Rendering is a method of producing photorealistic product images for product visualization. Using renders, the designer can present their product to the viewer to help illustrate the features of the product, how it will look in real life, and how the materials will appear. Renders and animations are used for digital prototyping.

One of the most popular software used for product rendering is Blender, which will be used in this project. It provides numerous tools to the designer in order to facilitate very real looking renders. It is also flexible, and can support a variety of objects, lighting environments and camera angles, and can also be used to create animations, while providing real world physics simulation support.

3.12 Physical Prototyping and Mock-ups

Mock-ups are physical models that are made from materials readily available, such as foam, cardboard, paper, wood etc. They are used to quickly evaluate the proportions, dimensions and interactions of concepts and design ideas.

Rapid Prototyping can also be used in the place of mock-ups sometimes, to get better ideas about surface finishes and interactions with users, if those are the factors to be evaluated. The most common method of rapid prototyping is 3D printing, which is a type of additive manufacturing method using a nozzle that extrudes molten filament, usually PLA, and builds a model layer by layer from bottom to top.

Physical prototypes are refined versions of mock-ups, usually created during the final design phase. They are generally made from the same material as the final product, or other materials to imitate the actual product. Prototypes can also be used to evaluate design parameters and ergonomics, and other forms of testing.

3.13 Product Testing

Product Testing is done to validate and verify the theories and concepts that have been developed in the design process. They can be done in various ways, including using physical prototypes to get user responses, creating the product to perform physical tests such as stress, strain etc. and creating digital versions of the product for simulations and virtual testing. In this project, the final concept will be tested virtually using VR technology. This involves creating a scene or environment that the user can access using VR headsets, where the product is displayed in contextual environments and the user can observe and interact
with the product. The feedback from the user can then be recorded and analyzed for validation.
4 Approach, Implementation and Results

4.1 Plan

The Gantt chart detailing the project plan is affixed in Appendix A – Gantt Chart. The plan had to be refined multiple times to accommodate changes due to deadlines and other factors.

4.2 Discover

This section deals with the implementation of the Discover phase of the project.

4.2.1 Literature Search

The Literature search was conducted with the purpose of finding as much about the problem area as possible. The search was conducted on multiple sources such as Google Scholar, Primo and Scopus.

The first step in the literature search was to define keywords, that could be used to search for relevant literature. Synonyms and supporting terms were used to refine and narrow the search. The keywords and synonyms can be found in the table below.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Synonyms</th>
<th>Supporting Terms</th>
<th>Related terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biophilia</td>
<td>Biophilic Design</td>
<td>Natural elements</td>
<td>Nature connectedness</td>
</tr>
<tr>
<td>Educational spaces</td>
<td>Colleges, Universities</td>
<td>Environments</td>
<td></td>
</tr>
<tr>
<td>Workspace</td>
<td>Offices, workplace</td>
<td></td>
<td>Commercial</td>
</tr>
<tr>
<td>Well-being</td>
<td>Happiness, Mental wellness</td>
<td>Perception</td>
<td>Productivity, creativity</td>
</tr>
</tbody>
</table>

*Table 1 Keywords*

With these keywords, search phrases were created using the Boolean terms AND and OR. These search phrases were then used in databases such as Primo, Google Scholar and Scopus, to find relevant literature. Literature that were deemed pertinent to the topic was then selected based on the title and abstract, and then reviewed.
4.2.2 Results of Literature Review

The literature search resulted in 12 relevant literatures being selected for review. The literature spanned the different topics that were considered, such as Biophilic Design Theories, Biophilic Design in workspaces, Educational environments and the perception of natural elements.

4.2.2.1 Biophilic Design in workplaces and educational environments

With the advent of urbanization, there has been an increased interest in understanding the factors surrounding productivity and happiness in workplaces and educational environments. (Blanusa, 2021) found that introducing plants into office workspaces and break-out spaces generated a considerable increase in the productivity, creativity and attention of participants. There was also no significant decrease in the same parameters when the plants were removed from the spaces as compared to when they were not present initially. The participants also observed that they had increased physical and visual interaction with these plants after their introduction into the spaces.

The heart rate and blood pressure of participants were shown to decrease when biophilic elements were added to their immediate surroundings, and this decrease was found to be even more considerable when the participants were in an open space as compared to a closed one. Including biophilic elements also resulted in an improved creativity score among participants, while also leading to better reaction times. As with (Blanusa, 2021), participants were also observed to spend more time interacting with biophilic elements, especially green plants and biomorphic shapes (Yin, 2019).

Furthermore, (DeLauer, et al., 2022) looks into the effects of nature and natural elements in educational settings. The authors report that there is a large potential for the built environment of residential campuses to incorporate biophilic design elements to provide a supportive and nurturing space all year round. The study also found that the time spent outdoors varied with weather conditions and other factors. Natural spaces also contributed to improved social interactions among students, and indoor spaces that included biophilic elements created a sense of refuge and comfort among students, which contributed to improved bonding and studying. The inclusion of natural light is another aspect that provided better concentration, attentiveness and learning in classrooms (DeLauer, et al., 2022). Multiple researchers (Almusaed, Alasadi, & Almssad, 2022) and (Mustafa & Yaseen, 2019) who looked into the implementation of biophilic design in the architectural design of schools in hot climates, reported that 13 of 14 biophilic patterns were found to be present in the investigated school (Mustafa & Yaseen, 2019), while green spaces, open areas and water bodies were crucial in providing desirable, recreational and active outdoor spaces for students (Almusaed, Alasadi, & Almssad, 2022).

The patterns were formulated by Browning in a previous study (Browning W. R., 2014) and were categorized under three main topics:
- Nature in the Space
  - Visual connection with nature
  - Non-visual connection with nature
  - Non-rhythmic sensory stimuli
  - Thermal and airflow variability
  - Presence of water
  - Dynamic and diffuse light
  - Connection with natural systems
- Natural analogues
  - Biomorphic forms and patterns
  - Material connections with nature
  - Complexity and order
- Nature of the space
  - Prospect
  - Refuge
  - Mystery
  - Risk/peril

Thus, there appears to be a significant amount of biophilic principles and ideas being implemented in school and office architecture and interiors, otherwise termed the “built” environment.

4.2.2.2 Perception of Biophilic Design

By analyzing a variety of different products designed over the years, research into biophilic design (Ahmad Sayuti, Bonollo, & Montana-Hoyos, 2021) and (Sayuti, 2015) has looked deeply into the perception of different biophilic elements, and recorded those elements that seemed to be more favored by respondents. By considering over 160 furniture design concepts that used biophilic elements, a detailed and concise typology of furniture design concepts using living organisms was formed. This helped understand the main factors motivating designers to incorporate biophilic elements and intended results for such implementations. It also helped to classify the products into 4 main categories and 24 purposes, which are:

- Function and practicality
  - To learn
  - Farming or food
  - Purify air and water
  - Generate energy
  - Encourage hobbies
  - Other reasons
• Aesthetic and Semantics
  o Aesthetic value or decoration
  o Collection and display
  o Communication or to convey a message
  o Artistic reasons
  o Contemplation
  o Other reasons

• Experience
  o To experience or interact with nature
  o Environmental consciousness
  o To heal, calm or lower stress
  o Entertainment
  o To stimulate senses
  o Other reasons

• Experimental
  o Conceptual design
  o Part of a research project
  o Exploration of new materials
  o Exploration of new technologies
  o To break the rules or be different
  o Other reasons

Nurul (Ahmad Sayuti, Bonollo, & Montana-Hoyos, 2021) further found that some elements were in fact perceived to be more popular than others. These included green leafy plants, which were the most popular type of biophilic element to be implemented in furniture. Moss and cactus, on the other hand, were not very popular, and mushrooms were considered unpopular due to their association with mold. At the same time, living animals were far less popular among respondents as compared to plants, with fish being the most preferred animal while still being below the average acceptance of plants. While it may seem like plants are clearly preferable, (Ahmad Sayuti, Bonollo, & Montana-Hoyos, 2021) also found that the visual design and aesthetics of the furniture still influenced the popularity among participants.

4.2.3 Market Research

The market analysis was focused on discovering products that used biophilic design philosophies. The points in focus were:

• The type of product (mass-produced or exhibitory)
• The ways in which biophilia was implemented into the design.

12 concepts were discovered and studied in the analysis. These products used different methods to include natural elements, either through direct use of natural elements or
through encouraging interaction with natural elements. A table of the concepts, showing the products and their characteristics, is given below.

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Natural elements used</th>
<th>Stage of development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrarium desk</td>
<td>Table</td>
<td>Green plants</td>
<td>Concept</td>
</tr>
<tr>
<td>Grass table</td>
<td>Coffee table</td>
<td>Grass</td>
<td>Concept</td>
</tr>
<tr>
<td>Cat couch</td>
<td>Sofa</td>
<td>Animals(Cats)</td>
<td>Concept</td>
</tr>
<tr>
<td>Shoe rack</td>
<td>Shoe storage and seat</td>
<td>Grass</td>
<td>Concept</td>
</tr>
<tr>
<td>Pet sofa</td>
<td>Sofa</td>
<td>Animals(pets)</td>
<td>Concept</td>
</tr>
<tr>
<td>Pet seat</td>
<td>Seat</td>
<td>Animals(pets)</td>
<td>Concept</td>
</tr>
<tr>
<td>Modular work table</td>
<td>Work desk</td>
<td>Green plants, wood</td>
<td>Product</td>
</tr>
<tr>
<td>Curious cat table</td>
<td>Table</td>
<td>Animals(cats)</td>
<td>Concept</td>
</tr>
<tr>
<td>Breathing partition</td>
<td>Wall/space divider</td>
<td>Green plants</td>
<td>Product</td>
</tr>
<tr>
<td>Animal pots</td>
<td>Pots</td>
<td>Green plants, animals and birds</td>
<td>Product</td>
</tr>
<tr>
<td>Outdoor grass chair</td>
<td>Chair</td>
<td>Grass</td>
<td>Concept</td>
</tr>
</tbody>
</table>

*Table 2 Market analysis*

The market analysis can be found in Appendix B – Market Analysis.

The findings from the market analysis showed that there were a lot of concepts that were developed for exhibitory purposes, to show the different products in which biophilic philosophies can be implemented, and to demonstrate the approaches used for such implementations. However, there were very few products that were actually released into the market, with most of the concepts being left in the concept stage. Another prominent finding was that most concepts emphasized on a direct, literal approach to biophilic design, usually implementing such features as using green plants or other living organisms and the color green. While this is definitely an approach to biophilic design, it also brought out a potential gap in the problem area in that indirect or metaphorical approaches to biophilic implementation were largely missing or uncommon.

### 4.2.4 Observations and Interviews/Discussions

As part of observations, multiple unstructured observations were conducted in different environments, to understand the application areas, and also to understand the different factors that can be taken into consideration when using elements like plants, smells etc. in products.

The first area or space that was observed was the university itself, and the various spaces that are present in the School of Engineering. Some pictures can be found below on these. The School of Engineering has multiple spaces outside of classrooms, where students can sit and interact, socialize and study or work. These can be just tables and chairs, or sofa booths, or dedicated study rooms that can be booked on the JU mobile app. There are also a lot of biophilic elements that are present in these spaces, such as both real and fake plants and trees and the inclusion of natural light in most spaces, either through large windows,
glass panels, or glass roofing. The observations involved no participation in these environments and found that there was a lot of interaction between students in these spaces. The seating is comfortable for both studying and socialising, and there was an abundance of natural light in all spaces. The closed walls of the study rooms and the high sofas in the study booths both give a feeling of privacy and personal space for the people within.

![Study Room in JTH](image1.png)

![Open study booth in JTH](image2.png)

The second set of observations and interviews/discussions were focused on the implementation of biophilic elements in commercial establishments. Showrooms of two brands were selected, since they were either directly involved in nature-related products (Naturkompaniet) or they involved products or concepts that were deemed interesting to study for the project (Rituals). At both these shops, the focus of the observation was on the smells and scents that were present in the shops and how they were utilized to provide different effects to customers.
It was observed that using natural elements like rocks and wood logs added to the perception of nature in Naturkompaniet, while Rituals bunched up scents of the same range in a location to give customers an idea of how the scent feels as they stand next to the
products. Both these methods resulted in a warm, welcoming and comfortable atmosphere that was present throughout the shops.

The third set of interviews/discussions dealt specifically with plants, and involved talking to employees at plant shops/nurseries, to understand what kind of plants can be used for products (if they were to be used), what factors needed to be taken into consideration for such plants and the care and maintenance required for plants. The interviews were not recorded as audio, at the request of the employees, however, the main points that were discussed were noted and compiled. These points were:

- Plants like Hedera and Spathiphyllum species are very popular in indoor use because they require little maintenance and care, and can grow in very little sunlight too. These plants also have a nice small aesthetic and so are popular as potted plants.
- Using plants indoors helps in improving the humidity of the room, which has positive effects on students and their behavior.
- Mushrooms and fungi can be used to imitate a damp forest floor, however, they can also cause problems with wooden furniture and additionally allergies among students.
- The most common forest scents that are found around the city of Jönköping are Pine, Moss and Damp Leaves.
- Ferns are another excellent plant type that can be used indoors. Since they grow naturally on the forest floor where there is very little sunlight, they can grow efficiently in rooms with little to no sunlight, and need to be watered very sparingly. They also bring a wild, forest-like look to the interior of a room.
- If common plants are to be avoided, then herbs and aromatic plants can be used indoors. The catch is that sometimes these plants may cause too much fragrance in the rooms, which can be deemed unpleasant by some people. The same applies to flowering plants with strong fragrances, such as jasmine, lavender and hyacinths.

4.3 Define

This section deals with the Define phase of the project, where the problem area, problem statement, application area and specifications and requirements are narrowed down and defined.

4.3.1 Problem Statement and Problem Area

From the analysis of the literature, and from the findings through the market analysis, it became clear that there were several gaps in the implementation of biophilic design principles in product design. Especially where workspaces and living spaces were concerned, a majority of implementation involved the use of direct, literal elements of biophilic theory such as green plants, other living organisms like mushrooms, fish and
reptiles, natural materials and the color green. This prompted an interest into the metaphorical and indirect approaches that can be taken when it comes to bringing natural elements into workspaces.

The main points in consideration were the use of aspects such as smells and sounds, the inclusion of senses other than just visual, and metaphorical representations of nature or natural elements.

The application area was also narrowed down to the work areas where students interacted, socialized and studied. This was chosen after understanding the effects that natural elements had on such spaces, as a direct result of the literature review.

The chosen market was for education institutions, such as JU. The customers, thus, would be the institutions themselves, while the end users would be students and other people who use the work areas in JU. Other stakeholders include medical staff, maintenance and repair staff, material suppliers and manufacturers of the product.

It is also worth noting that, while all other aspects of the project were defined clearly, the actual type of product was deliberately left undefined, so as to not hinder the concept generation process. Although this is not a conventional approach to design thinking, it was felt that this was a necessary step, given the slightly more abstract nature of the project to begin with. As such, the range of products and possibilities for realizing the problem statement was large, with products that could be anything from chairs and tables to lights or wall partitions, blinds and even artistic features, to name a few. However, it was decided to not focus on designing the workspace or interiors, or to design an architectural feature or built environment, since that would require a different set of skills and expertise. The final product definition started to take shape once the initial brainstorming was completed and the results were analyzed.

4.3.2 Function Analysis

An initial function analysis was conducted to identify main functions that could be used for brainstorming. This was preliminary, since the final product type had not been defined yet. However, the function analysis was revisited again in the ideation stage, to define a final set of functions for the product. The function analysis can be found below.

<table>
<thead>
<tr>
<th>Verb</th>
<th>Noun</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implement</td>
<td>Biophilia</td>
<td></td>
</tr>
<tr>
<td>Relax</td>
<td>Users</td>
<td></td>
</tr>
<tr>
<td>Connect</td>
<td>Users</td>
<td>Nature</td>
</tr>
<tr>
<td>Appear</td>
<td>Discreet</td>
<td></td>
</tr>
<tr>
<td>Mimic</td>
<td>Patterns</td>
<td>Nature</td>
</tr>
</tbody>
</table>

*Table 3 Function Analysis*
4.3.3 Requirements and Specifications

Similar to the function analysis, the requirements and specifications were initially made in a more general sense, and then refined during the ideation stage, to be relevant to the product selected. The following requirements were defined based on the problem statement, the observations and literature research:

- The product must fit into educational workspaces.
- The product should express natural elements in non-literal ways.
- Applies at least one of the five basic Biophilic Principles – engagement, adaptation, attachment, interaction and interconnection.
- Takes into account health conditions and allergic responses.
- Must have a simple aesthetic.
- Uses sustainable materials.
- Easy to clean and maintain.

These requirements were defined based on the different gaps that were identified, such as using non-literal methods and implementing in educational spaces. Additionally, other requirements were defined based on different factors that must be taken into account for such products, such as health factors, maintenance and sustainability.

4.3.4 Moodboards/Imageboards

Multiple imageboards and moodboards were made to express the different aspects of nature that could be considered for inspiration. These included visuals, smells, elements of nature, type of environment, and emotions and feelings associated with nature. A lot of the images were captured in the immediate surroundings of Jönköping locality, while other images were sourced from the internet. The moodboards/imageboards can be found in the Appendix C – Moodboards/Imageboards.

4.4 Develop

This section deals with the Develop phase, where concept generation and ideation activities are conducted.

4.4.1 Brainstorming

The brainstorming was done in multiple iterations. Due to the abstract nature of the project initially, brainstorming was necessary as a quick way to generate several different concepts, such that various types of products were considered. Once this initial brainstorming was completed, the results were quickly analyzed and the product types with most potential were selected. Feature maps for these selected products were made in the next iteration, to
generate different and diverse product features. A second brainstorming session was performed after this, to generate more specific ideas and concepts.

4.4.1.1 First Iteration

The first iteration of brainstorming dealt with the initial generation of concepts and product types. It was performed as two sessions, with each session lasting 50 minutes. Each session was further divided into sections of 10 minutes. In each 10 minute section, one type of product was ideated. At the end of the brainstorming session, the concepts were analyzed for 10 minutes, and the features with the most potential were identified. This was then repeated for the second session, such that at the end of the two sessions, various types of products were looked at. These included chairs, tables, wall panels, blinds and curtains, solitary sculptures and decorative elements, and lamps. The results of the first iteration can be found in Appendix D – First Brainstorming Iteration.

An additional feature that was considered highly relevant was the inclusion of smell as a diffused element, to create a more immersive experience of being in nature. Smell and scents were considered important based on the idea that the sense of smell, similar to the sense of sound, are both more subconscious senses compared to the sense of sight and touch. This allows the product to not be as distracting to users, while at the same time involving senses that are more often associated with memory and emotional bonds [insert reference].

4.4.1.2 Feature maps

Once the first iteration of brainstorming was completed, six product categories were selected to move forward with. These were:

- Windchimes and related products featuring wind.
- Wall panels and wall dividers
- Chairs
- Lamps
- Blinds and curtains
- Carpets and flooring

These categories were chosen because they had the most potential for non-literal representations of natural elements and objects.

The second brainstorming iteration was then performed, with two sessions of 60 minutes each, in a manner similar to the first iteration. The differing aspect from the first brainstorming iteration was that, instead of concept sketches being made, feature maps for each product category was formed. These maps involved looking at features that could be included in the product, and the different variations and factors to be considered for each feature. At the end of the second iteration, six feature maps for six product categories were made, and analyzed. The feature maps can be found in Appendix E – Feature Maps.
4.4.1.3 Third Iteration

After analyzing the ideas, concepts and features from the first and second brainstorming iterations, a third brainstorming iteration was performed. The focus of this iteration was on developing more specific concepts based on the features and product categories discussed earlier. The third iteration was shorter than the previous two iterations, and involved one session of 60 minutes, in a format similar to the previous two.

4.4.2 Selected Concepts

Three concepts were selected from the third brainstorming iteration for further work. These concepts were selected because they showed good potential for further development, and had unique or distinctive features that were relevant to the problem area. The three concepts are discussed below.
4.4.2.1 Concept 1

The first concept was an idea for a chair that expressed natural colour and light patterns of the aurora or northern lights through its form. The chair has multiple rods/shafts that are supported by a metal base. The rods are made of materials like bamboo and wood, have different sections painted in green and magenta, and are allowed to slide up and down on the base, with springs fixed to the bottom of each shaft. The top of each shaft has a cushioned fabric attached to it, to provide comfort to users. When a person sits on the chair, the rods are pushed down in irregular ways according to the person’s weight, their posture, their activity etc. and so they form unique patterns on the chair. This is similar to the abstractness found in the auroral patterns.

Figure 6 First concept
4.4.2.2  **Concept 2**

The second concept was a roof mounted kinetic sculpture, inspired from windchimes and luminaires, and followed a similar concept as the first one, mimicking natural light and colour patterns. The concept was inspired by the way in which wind movements affect objects such as leaves and windchimes, and looked at mimicking the same movements without the presence of wind, under the motivation that such movements would cause the perception of wind or a breeze metaphorically.

![Diagram of Concept 2](image)

*Figure 7 Second concept*

4.4.2.3  **Concept 3**

The third concept was a set of wall panels that could also be converted to space dividers or blinds. The panels were made of thin fabric, and had a similar appearance to seaweed and kelp, found in oceans and seaside areas. The motivation behind this concept was the way in which sunlight filtered to the ocean depths, because of the nature of water. In a similar way, when used as blinds, the panels would filter out some light, while also providing a cool ocean-like effect in the area. Additionally, the panels also featured a built-in scent diffuser, which diffused ocean and sea smells, increasing the immersive experience of the space.
Approach, Implementation

The three concepts were discussed and their features were analysed with the project supervisor, and it was decided that some features from each concept were very interesting. The first two concepts involved mimicking natural patterns and motion, and this was considered as a good way to represent natural elements in a non-literal manner. The second concept also showed the alluring quality of a kinetic sculpture, as it is something that is unique and at the same time a welcome addition to any space. The feature of depicting wind movements without the presence of wind was also selected to proceed with, as it further added to the idea of a deeper, metaphorical representation of biophilia. The idea of utilising fabric was chosen from the third concept, as fabric is a material which is considered lightweight and commonly associated with wind, and it is also a natural material (depending on the type of fabric), while offering a range of possibilities for a kinetic sculpture.

Taking these features into consideration, new concepts were created, with the purpose of creating kinetic or moving installations that depicted natural motion, wind or natural patterns.

4.4.3 Refine

With the ideas from the previous step, additional concepts were generated. These looked at the specific idea of depicting the feeling of wind through moving objects. One concept
stood out in particular, and was thus selected to be developed into the final concept. This design is illustrated in the figures below.

Initially, the concept was conceived as a wall-mounted sculpture with a stretched piece of fabric, with a mechanism that will push on the fabric such that it takes the shape of a wave. This would be a visual representation of wind and breeze movements. Additionally, the sculpture would also feature a built-in scent diffuser that would diffuse breezy scents, which would provide a sense of space and openness, which would compliment the motion of the fabric. Different configurations of the sculpture were looked at, such as mounted on the wall, mounted at an angle etc.

Figure 9 Wall mounted sculpture with details about mechanisms
One such configuration was a roof-mounted sculpture, similar to the windchimes from the brainstorming phase. It was this configuration that was finally chosen, as it would be less distracting and more discreet. The wind movements were also changed to the ripple patterns formed by rain falling down, as this was considered more relevant to being mounted on the roof.

Figure 10 Angular configuration for sculpture

Figure 11 Visualization of rain patterns on fabric
4.4.4 Mock-ups

With the final concept now fully defined, several small-scale mock-ups were created to investigate different mechanisms that could be used to generate patterns on the fabric. The mock-ups were made with simple materials and components, with some specialised parts being created by 3D printing. All the mechanisms involved rotational motion being converted into translational motion, and so different mechanisms for this were also investigated. Different types of fabric were analysed for their relevance to this concept.

Figure 12 Mock-up to test different mechanisms on fabric
Figure 13 Small scale mock-up of the shaft and plate mechanism

Figure 14 Effect of metal spheres on elastic fabric
4.4.5 Computer Aided Design

Once the final concept was defined, it was further detailed using 3D modelling software. For this design, the majority of 3D modelling was performed in Autodesk Fusion 360, with fabric being constructed in Blender. This was done because of the advanced physics and fabric simulation tools that Blender offers, alongside rendering and animation tools. More detailed work about how the different parts would be attached together was done during the CAD modelling.

4.5 Deliver

4.5.1 Prototyping

The final concept was further developed and prototyped, both physically and digitally. Several digital renders were made for the concept to show the patterns and movement on the fabric. These were done in Blender. The physical prototype was made from materials that were different from the final concept. The main housing and the plates were made from MDF boards, while the shafts were printed from x-PLA material. The prototype used two stepper motors to drive the mechanism, which were controlled by an Arduino Nano board and two DRV 2285 motor driver ICs. The fabric was then suspended from the housing using wooden rods. Additionally, a VR ecosystem was also created, with a backdrop of an office space, to place the concept and show it in a contextual setting. This VR space was showcased in the final Thesis Fair. In the VR system, an animation of the sculpture working with its patterns was made, and looped so it would keep playing over and over again. Due to the size of the physical prototype, its weight, and the potential that a VR model showed for testing and getting feedback, the virtual prototype was showcased at the thesis fair.

4.5.2 Testing and Feedback

In order to understand the reactions that the concept evokes in users, the virtual prototype was showcased at the thesis fair xJobbsmässan at the Campus Arena in JU, and a questionnaire was created to let the audience experience the concept and give their feedback. The questionnaire was created in such a way that it would be short, but at the same time capture some important information regarding the concept, the emotions and reactions it evokes, and how it can affect the perception of the space. Random visitors to
the stall were offered a VR headset to put on their heads and look into the space with the concept overhead. Finally, they were introduced to the questions and their responses were recorded. The first question was to identify the type of mindset that people had toward including natural elements into their workspaces, while the following questions were about the concept, how it was interpreted, and what kind of feeling it evoked in participants. The last question was about how likely they would be to use the concept in their workspaces, which would be an indication of how the concept is received. The questions and responses can be found in Appendix F – Questionnaire Responses.
5 Final Concept

5.1 Final Concept

The final concept is a ceiling mounted kinetic sculpture that mimics the patterns formed by rainwater falling down, on a piece of stretched fabric. Given the unpredictable nature of weather conditions in Sweden, and the calming effect that rain usually has when one is looking at it, rain was an ideal element to represent in the product. The sculpture is designed to be mounted in the ceilings of work areas, such as the ones that were used for observations. The housing contains the main mechanisms and different parts, while the fabric is suspended from this. The housing is also the part that attaches to the roof or ceiling. The shape of the housing for the mechanisms is such that it is hidden from view when looked at from below, so that the emphasis stays on the fabric and the patterns displayed on it. The sculpture is also capable of being made in different sizes, so as to fit different spaces. This feature can be seen in the renders below. By developing a product that mounts into the ceiling, it offers a discreet and subtle way of integrating natural elements into these spaces, while the sculpture and its patterns ensure that this integration of natural elements is metaphorical. This way, even though the desired effect is that of raindrops, the actual interpretation is left open to each individual who can perceive it in their own way.

The concept was a culmination of testing various mechanisms, and selecting the one that provided fabric patterns closest to nature. The chosen fabric was a mixture of 95% Cotton and 5% Elastane, which ensured high durability and an ideal amount of elasticity. Combined with the refined mechanism, it produced the most natural effects.
The mechanism involved using metal balls of different sizes, which were held above the fabric by strings. The strings were in turn attached to plates that would move up and down. As the plates moved down, the metal balls would push onto the fabric, creating ripple-like effects on it. The fabric would be suspended from the main body of the sculpture, which would house all the electronic and mechanical equipment, and it would be in a constantly stretched state. The body of the sculpture would be mounted to the roof or ceiling and would also be connected to an electrical outlet for power. Internally, two motors were used to move the plates up and down.

It was decided that the motors would run at different speeds, so that the two plates would not be in sync, consequently reducing the regularity of the patterns that would be formed on the fabric. The plates were connected to the motor by means of an internal shaft assembly, similar to those found on motorcycle throttles. This is a convenient and clean way to convert rotational motion into translational motion, and involves two shafts, one inside the other. The outer shaft has a groove cut onto its surface, and is connected to the motor and will rotate. Since the plate is connected to the internal shaft, the latter cannot rotate with the outer shaft, and the groove ensures that it can only move up and down.

The product will be used in open work areas, above desks and tables. The size of the product can be varied according to the requirements, as the underlying working principle remains the same, with only some components requiring to be resized. This allows the product to be fitted into any space, irrelevant of shape or size, while preserving its main functionalities. Since most of these spaces had false ceilings, it becomes easier to attach the sculpture on the ceiling. At the same time, since the mechanism involves strings and balls, it can also be adapted to different heights as required.
5.2 Computer Aided Design model

The CAD model for the final concept can be seen below.
In the Figure 19, the internal components can be seen.
Figure 20 shows the patterns forming on the fabric as seen in simulations, with the patterns resembling the ripples caused by raindrops falling on water. Figure 21 shows the sequence in which the ripples are formed and dissipate on the fabric. The Figure 22 and Figure 23 show a contextual render with the sculpture mounted above a coffee table in an open break area in a university, and inside a room with rain outside.
Figure 22 Contextual render in university break area

Figure 23 Contextual render of concept with rain in background
5.3 Prototyping

As mentioned before, the prototyping was done in both physical and virtual forms. The physical prototype involved making a housing out of MDF boards, with the planes being laser cut from the same material, and using stepper motors for driving the shafts. Stepper motors were used since they are more readily available, can be easily controlled using a small microcontroller, and they consume less power and are small in size. The physical prototype was done in a 1:3 scale, so that the dimensions will not be too large. Below, the different parts of the prototype and its appearance once assembled are displayed. The detailed prototype drawings can be found in Appendix G – Prototype Drawings.
The virtual prototype involved both photorealistic renders and animations of the concept (as seen above), and a Virtual Reality (VR) setup to experience and demonstrate the concept in an office workspace. The setting was chosen as an office workspace since it was in a better quality and had a more realistic effect. Figure 28 and 29 show the setup of the VR space in Blender, while Figure 30 shows the presentation booth at the thesis fair, where the concept was showcased, and participants were asked to test the concept and answer a questionnaire.
Final Concept

Figure 28 Scene setup in Blender

Figure 29 The office workplace HDRI that was used
Figure 30 Presentation booth at the thesis fair
6 Conclusions and Discussions

6.1 Discussion of the Research questions

6.1.1 What are the factors and motivations surrounding the integration of natural elements with traditional workspace products?

With the advent of urbanization, there has been a renewed push for research into the different ways in which nature and natural elements can be included in our living and working spaces. Numerous scientific studies show that there are positive effects of such an inclusion, including physiological effects such as improved heart rates and blood pressure or psychological effects such as improved creativity, emotional well-being and attentiveness, and reduced stress and anxiety. The inspiration behind biophilic design is also the inherent and genetic connection that humans have with nature, and the different ways in which to restore it. While all these provide a strong motive for incorporating nature in workspaces, there are several other factors to consider. Through review of literature, interviews with professionals and observations, a variety of different factors were identified in this project.

The first and most important factor would be the context and scale of the implementation. This can vary from the entire built environment to a small chair or desk, and from a small school to a large college. Consequently, the resulting product can differ vastly. Another important factor to consider is what natural elements are to be incorporated. In some cases, green plants are used, while in others, sunlight and water are featured. This is closely related to the context and size. The third important factor to consider is the medical aspect, that is, the product should not hinder or affect the users in any way. This can include allergies, negative psychological effects, and physical safety.

When it comes to including green plants in workspaces, there are more factors to consider. These include the amount of sunlight that is available in the space, how easily it can be maintained or taken care of and the ambient temperature. Taking all these aspects into consideration also narrows down the variety of plants that can be used, leading to some plant species being extremely popular in such applications. For example, spathiphyllum plants are very popular in indoor workspaces, as they are easy to maintain, require very little watering, can grow with minimal sunlight and also have the added bonus that their roots help purify air. This results in them being one of the most common plants that are used for biophilic applications.

In this project, different factors were considered while developing the concept. While green plants offer a variety of advantages, they were perceived as too literal an implementation, while the project was focused on a more metaphorical approach. The resulting concept involved several features such as motors and fabric, so additional factors had to be considered too. These included the aspect of sound, specifically noise caused by the different moving parts. This was resolved by using twin motors placed on perpendicular
edges of the housing, with the motors themselves being silent and having minimal vibrations. Another factor to be considered was the material of the fabric, which had to be sustainable and from natural sources, as this was a requirement. Thus, cotton was chosen as the fabric of choice.

Furthermore, the work areas and areas of application also had to be considered. These came with their own set of factors, such as size and shape of the areas, and also the height of the ceilings, the size of panels for false ceilings, lighting and what devices were used for lighting, whether there were artificial light sources or predominantly natural light. Since the product had to be mounted from ceilings, it could not impede the distribution of light to these work areas, while the sizes of panels in false ceilings provided size guides while also encouraging the idea of having multiple sculptures that were each the size of a panel.

### 6.1.2 How can workspace products integrating natural elements be designed in an educational setting?

There are many different ways and methods that can be used for the design of products that involve biophilic aspects, and these can be both literal and metaphorical. In this project, the metaphorical side was chosen, and this resulted in a kinetic roof sculpture that depicts the pattern of raindrops on a piece of fabric. The natural elements used here, rain and raindrops, are not elements that are commonly used in biophilic design, and were certainly not present in the market analysis done for the project. However, through sculptures that can be installed in any location, and that can be of different sizes, natural elements can be easily brought into educational spaces like those found in JU. At the same time, other natural elements are also needed, such as green plants and natural light. These elements are important for their own reasons, including health and psychology, as was discussed in the literature review. This applies to all educational spaces, both JU and otherwise. As mentioned in the observations, there are already many different natural elements present in JU, and the product would add to these. The same can be said for other educational institutions which may have other different methods of applying biophilic design in their built environment. As a whole, by having natural elements on the ground and walls (plants), an abundance of natural light, and elements such as the designed product on the ceilings, a complete natural space can be established, which expresses and incorporates multiple aspects of nature to give an immersive and comfortable environment for students.

The product itself was a result of multiple ideation cycles. The motive behind using fabric to express raindrops was to encourage the users to interpret the sculpture in their own way, while at the same time, being subtle yet easily identifiable to users. This would allow them to connect their personal memories and feelings about rain to the sculpture, which would further enhance their affinity toward nature. Metaphorical approaches were used because there was a lack of research and implementation in these, which was considered a gap that could be explored. The project started based on literature reviews about the positive effects of nature on humans, and this allowed the questions asked in the project to be more product oriented.
**6.1.3 What methods can be used to show the improved perception of workspaces with the introduction of the concept design?**

In order to get an understanding of the effects that the concept has on users, and to validate the concept as a way to incorporate natural elements into workspaces, it has to be tested among users and their responses and feedback have to be compiled and analyzed. Perception is an important factor in work areas, since it allows the spaces to be more comfortable for users. There are several methods that can be used for testing perception, including surveys, questionnaires and implementing the prototype in a contextual setting and observing reactions. These methods were widely used in the literature reviewed (Blanusa, 2021) (Sayuti, 2015), and focused on getting feedback from users using questionnaires or interviews. Where specific details were required, questionnaires and interviews were used, while observations were also used to obtain more generic information and to understand the context of the problems and studies. For this project, questionnaires were used to get feedback from users, after they experienced the concept in a virtual reality setting at the thesis fair. Virtual reality showed a lot of potential since it would be a more immersive experience, and it would also isolate the user from the noise and distraction that are present in the fair. In some studies (Yin, 2019), pictures and virtual reality was used to test user perception and get feedback, and this provided a basis for this project. The thesis fair was also an ideal setting since it attracted people from different fields and professionals from the industry and students alike, and the participants would be random and unbiased. By getting feedback from professionals, an understanding of how the product will be perceived in workspaces can be obtained, while students provide a more contextual feedback about perception in educational spaces. Thus, the perception of target users can be obtained this way.

The questionnaire was designed based on other similar questionnaires used in literature reviewed. The questionnaire contained five questions related to the concept, and had 9 respondents, including students, lecturers who were not associated with the project, and industry professionals. The questions involved understanding the perceptions of users toward using natural elements in their workspaces, finding out how they interpreted the concept, and how likely they would be to use the product in their workspace. The options given were a 0-5 rating for most questions, while the question on what kind of natural element was seen in the concept had an open answer and the question on the emotional reaction to the concept had a range of pictorial options representing different emotions, which were derived from the PrEmo method. The PrEmo method is a popular way to measure distinct emotions in a non-verbal manner and can be used both qualitatively and quantitatively. It involves 14 hand drawn characters, each expressing a different emotion, that include Desire, Surprise, Inspiration, Amusement, admiration, Satisfaction, Fascination (positive emotions) and Indignation, Contempt, Disgust, Boredom, Disappointment, Dissatisfaction and Unpleasant surprise (negative emotions). The emotions used in this questionnaire were based on the PrEmo method, and were Peaceful, Surprised, Happy, Relaxed, Skeptical, Bored, Confused, Loving and Safe. And these include both positive as well as negative emotions, to give the respondents an equal range to choose from.
The results from the questionnaire show a positive reaction toward the concept. All of the respondents responded that they liked to include natural elements in their workspace (score of 4+ on a scale of 0-5), and 89% of respondents answered that they felt the concept expressed a natural element(s), with all of them answering that the patterns of the concept expressed rain or water. 44% of respondents showed “Peaceful” as a response to observing the concept in VR, with 22% choosing “Surprised”, and 78% answered that they would like to use the concept in their own workspaces (score of 4+ on a scale of 0-5). Although this was a test done on a small scale, it still holds credibility and validates the concept among target users and people who spend a significant amount of time in workspaces, and shows the potential that biophilic design has in the context of workspace perception.

At the beginning of the project, it was mentioned that most biophilic implementations were purely exhibitory in nature, and did not look into making a manufacturable product. While the concept developed in the project also seems to be exhibitory in nature, the various details that have been thought out, such as the mechanisms involved, the type of fabric and the way in which it can be customized to different sizes together provide a strong foundation for realizing the product on a larger scale, and marketing it to potential users.

Through the development of a product in this project, the primary aim of the project has been accomplished. At the same time, there have also been advancements in the understanding of how biophilic principles can be used to create artistic and marketable products, which would be of value to further research in this field.

### 6.2 Reflections and Further work

This project was quite challenging from the start, given its nature and the goals that were set. Being an individual thesis also meant that most decision making and planning activities were undertaken individually, with some inputs from the supervisor. While this provided a large amount of freedom to pursue different ideas and solutions, there were several points in the project where having concrete decisions set aside by a third party would have been welcome. However, given the progress over the course of a few months, the project as a whole has been a thoroughly satisfying experience, with a lot of new knowledge being gained that could prove useful in future endeavors. The project started with an idea to create a concept, but the design process was such that in the end, it resulted in a sculpture being created instead, which brings together the aesthetic and artistic aspects of design with the functional, practical and mechanical aspects in order to make it work.

With regard to further development, there are different areas that can be refined or developed in the future. These include identifying niche markets where the product can be marketed, other universities and educational institutions and also commercial
establishments where the product can be used, the manufacturing and production details such as bill of materials, specific manufacturing processes, and packaging and logistics. There can also be further work done on the mechanism behind the concept, such that it can express other natural patterns such as ocean waves or wind. A more comprehensive user testing with a full sized physical prototype would also be extremely beneficial in understanding the user perception and reactions in a deeper way. It would also be interesting to see if the product can be customized to suit different geographies, and the patterns extended to include the same.
7 References


8 Appendices

8.1 Appendix A – Gantt Chart
8.2 Appendix B – Market Analysis
8.3 Appendix C – Moodboards/Imageboards
Appendix D – First Brainstorming Iteration
8.5 Appendix E – Feature Maps
8.6 Appendix F – Questionnaire Responses

Relaxation Product Survey
9 responses

How likely are you to include / appreciate natural elements in your workspace?
9 out of 9 answered

4.4 Average rating

[Graph showing average ratings]

What is your reaction / feeling to seeing the concept?
9 out of 9 answered

Peaceful
4 resp. 44.4%
Do the patterns represent natural elements or shapes?
9 out of 9 answered

Yes 8 resp. 88.9%
If yes, what kind of element do they represent?
7 out of 9 answered

Almost like raindrops that make the fabric heavy when dropping onto the fabric

Water

Water

Water ripples, Rain drops

Water and wind

raindrops

Rain

How appealing or attractive will you find a workspace with this concept?
9 out of 9 answered

3.8 Average rating

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8.7 Appendix G – Prototype Drawings
Prototype cad