Bacterial colouring: Using multi-disciplinary methods for eco-friendly textile design

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Bacterial colouring is a study on, how bacterial pigments can be used in a textile design context as a more climate and environmentally friendly alternative to the synthetic dyes used in the industry. The project is positioned within the field of natural science and design research using methods from the two disciplines, hence carrying out multi-disciplinary research. It is a part of the design research field 'growing design' where designers often collaborate with natural scientist to carry out biofabrication, thus providing new knowledge to the biodesign field. The natural science methods used are from biotechnology and are used to isolate, identify bacteria and produce bacterial pigments. The design methods are comprised of several prototyping studies from material research to application as a textile design proposal. For the design prototyping we applied projections divided into three steps: scenario 1, 2 and 3, where it was envisioned, how the colour range could broaden, if all colours were replaced with bacterial pigments.

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Introduction

From the minute we are born textiles become an essential part of life. We wear textiles on our body, and it surrounds us in our homes, where they provide comfort and protection. Textiles are appealing to our senses. The way they are haptically perceived and how they are characterised by the visual language and especially use of colour. We all have our individual taste, as to what we consider aesthetically appealing, sometimes based on cultural background and the surroundings we are a part of in our everyday life, and thus we are attracted to different textile expressions: colour, material, pattern and texture. At the same time textiles are contributing to great climate and environmental challenges within the whole textile life cycle, due to its use of unsustainable energy, production methods, exploitation of materials and waste contribution.

Environmental issues

Textiles are a substantial contributor to the global pollution of the planet with the consumption of 4% of global freshwater annually, 10% global industrial CO2 production, 20% global wastewater emission and 16% global pesticide use [1]. This is in accordance with the statistics in the publication Pulse of the Fashion Industry from 2017 from Global Fashion Agenda [2]. In United Nations Sustainable Development Goals (SDG) Report from 2020, they report an increase in global material footprint from 2010 to 2017. Even though the SDG Report describes that progress in sustainable production and consumption is being made, we have far from succeeded in doing so [3].

These figures are connected to the production of textiles in which the raw materials are harvested or produced. They are then further processed through different processes: spun, woven, knitted, tufted, printed, dyed and getting after-treatment [4].

The pollution problems connected to the dyeing process are water use, energy consumption, use of toxic chemicals and wastewater emission [5]. In the dyeing process there are 72 toxic chemicals of which 40% are impossible to remove from the wastewater [5]. This creates a need to act to ensure a more sustainable future of textile colouring.

Sustainability has in the last decade revolved around reuse, reduce, recycle and upcycle still fitting within the model of mass production [6]. We are now at a point, where we need to look at other paths to lead eco-friendly manufacturing.

Historical perspectives of colours

Textiles and colour are deeply connected, since the visual appeal of a textile is often connected to colour. Historically it is also interesting to look at colour. Natural dyes from our surrounding including plants, fruits and insects were being extracted and applied to textiles as early as 3500 BC [5]. The major problem connected to natural pigments is the durability of the colour when washed and exposed to light. To enhance the durability a mordant is needed to fix the dye to the textile. The mordants can be toxic and impact the quality of the wastewater. Besides natural dyes require large amounts of water in the dyeing process [5].

The industrialisation changed the origin of the colours from being extracted naturally to being chemically produced from fossil-oil in a laboratory environment [7]. In 1856 William H. Perkin was successful in producing the world's first synthetic pigment called *anilin purple*. This marked the shift in textile dyeing and led to the replacement of most natural pigments for synthetic pigments instead [8]. The synthetic pigments are durable and cheap to produce, hence creating a low incentive to search for a more climate-friendly alternative.

The synthetic dyes have contributed to the climate catastrophe we are facing now and as the industrialisation changed the textile industry, we now have the chance to change how we produce dye and invent new solutions.

Industrial applied bacterial colours

The biotechnological development has made it possible to produce a new type of natural pigment in this paper referred to as bacterial pigment. This have been extensively studied in the natural science research field, where it has been studied which types of bacteria produce pigments and the structure behind these molecules and hence the colour [9-10], also suggesting that it could be applied within the textile area [11].

Bacterial pigments have several advantages compared to the natural and synthetic pigments, according to Vienna Textile Lab a start-up working on producing bacterial pigments [12]. Their bacterial pigments use 90% less CO_2 in dye production process, 95% less water in the textile dyeing process and produces 99% less toxic waste [13].

Besides Vienna Textile Lab there are two other start-ups in Europe called Pili and Colourifix also working on creating bacterial pigments for industrial scale textile colouring [14,-15]. Colorifix started a pilot project in a dyehouse in Portugal in July 2020. They have created strong partnerships within the textile industry and are backed by H&M, which show that commercial interests are also starting to see bacterial dye as a potential solution. Colorifix describes their process: "Compared to conventional dyeing step for cotton, the Colorifix technology reduces water consumption by at least 49%, electricity by 35% and CO_2 emmisions by 31%" [15].

Established designers are also starting to see possibilities in working with bacteria for textile colouring. The London based agency Faber Futures founded by Natsai Chieza have worked on several projects creating textiles dyed with bacteria in collaboration with scientists from Gingko Bioworks [16]. Also, the Dutch based design studio Kukka founded by Laura Luchtman has created bacterial coloured sportswear in collaboration with PUMA [17]. Until now designers have worked with bacterial pigments, mainly researching what is possible at this given point in time, and created beautiful textiles often with an organic pattern. In this study we want to study the bacterial pigments as surface colours and use future design scenarios to try and visualise how the design potential of bacterial pigments could be approached.

The biodesign research field

The biotechnological development and the accessibility of science have influenced the design practice. In the last decade the field of biodesign have emerged enabling designers to work within the intersection of biology and design using biofabrication in their design process [18]. Biofabrication is incorporation of living material or living matter. It presents an eco-friendly way of developing material and material technologies, since it uses renewable resources that feed living organisms and thus replaces the fossil-based material technology [19].

The research presented in this paper is part of growing design meaning: "*fabrication of materials and products from living organisms*" [20]. A corresponding terminology to growing design is nature as a co-worker as a part of the hierarchy of working with living organisms: *Nature as a model, nature as a co-worker, reprogrammed nature, hybridised nature and conceptualised nature* [21]. In the field of growing design several researchers are experimenting with living materials and organisms either in collaboration with natural scientists or in a 'Do-It-Yourself" approach, where the designer has full control of the material development [19].

The collaboration between natural science and design disciplines, often present in growing design projects, have been studied various researchers [22-25]. In this project the collaboration has a multi-disciplinary foundation between natural science and design, where disciplines utilise knowledge from each other [22]. In this project a biochemical engineer and a textile designer have worked together to explore the design potential of bacterial pigments.

The design research part builds on research through design [26], prototyping various material experiments and design artefacts as our main knowledge contribution. Prototyping is a way for designers to make manifestations of design ideas which concretises and externalises conceptual ideas [27-28]. The prototyping studies made it possible to make tangible experiments with the colours, hence creating knowledge about design potential of bacterial colouring but also in regards of a design-science collaboration, which the growing design builds upon. We applied this knowledge in the further design process, developing prototypes for colour compositions and textile patterns.

Future perspectives of bacterial colours

In our research project *Bacterial Colouring* we wanted to address the problems connected with the use of synthetic dyes. Our study presents a climate and environmentally friendly way to dye with locally occurring soil bacteria, as an alternative to the conventional dyeing of polyester textile with synthetic pigments. This was tested in a design context by designing a woven textile design coloured with bacterial pigments.

It was important for us to study if the bacterial pigments could create uniform-coloured surfaces and expanding the aesthetic possibilities and thus not only create organic patterned surfaces, but research for an industrial application potential.

In this paper we will present the applied methods both within natural science and design. Then we will present how these methods have contributed with new knowledge to create design experiments. A discussion of the applied methods and paths for further studies will follow and finally a short conclusion.

Methods

The applied methods are a combination of natural science methods from biotechnology and design research methods focusing on prototyping studies. The project starts by applying the natural science methods and the outcome of those are then used in the design research methods emphasising their co-dependency, the outline of the research is shown in Figure 1.

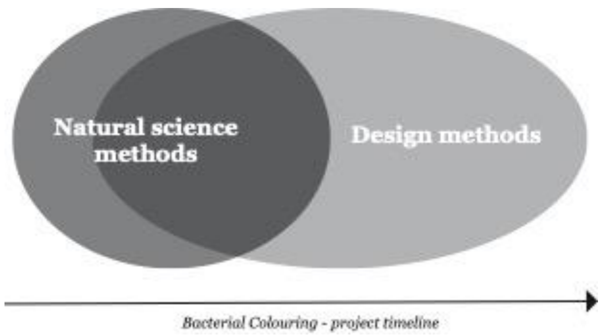

Figure 1: Colour preference among college students.

The natural science methods are comprised of fieldwork, bacteria isolation, DNA purification, Polymerase Chain Reaction (PCR), gel electrophoresis, DNA sequencing and finally our pigment production. The design research methods are comprised of different prototyping studies from material research to colour composition analysis and textile application. We wanted to bring the results from the laboratory into a design context, where a textile design is created from several prototyping studies.

Natural science methods

Collecting bacteria samples locally outside

The bacteria we worked with, were all soil bacteria, which can be found in our local surroundings, which according to the Köppen Climate Classification is a part of the Marine West Coast Climate (Cfb)

[1]. Figure 2 (left side) shows different locations, where we collected the samples. We collected 21 samples from different surfaces by taking a sterile inoculation loop and picking up a small sample. The sample was transferred to a sterile petri dish prepared with Luria Broth (LB) agar. LB agar provides the nutrients for the bacteria to grow and is comprised of a gelatinous agar containing peptones, yeast extract and sodium chloride [29].

Figure 2: Surfaces for collecting bacteria samples.

The LB agar plates with the bacteria samples grew at either room temperature, 25 degrees Celsius or 37 degrees Celsius. This was chosen to have different conditions, since the optimal growth temperature of bacteria can vary. We did not know, which bacteria we had collected, so to get as much variety of bacteria as possible, we tried different growth temperatures, hence enhancing growth for some bacterial strains. In figure 2 (right side) the bacterial samples are displayed and show their growth on the agar plates after a period of 2-3 days. At this point the bacterial colonies can be seen on top of the LB agar in the petri dish as small dense material clusters, some of which were coloured, but most of them were white or opaque and not of interest to us in this study.

Isolate and identifying bacteria

The samples were not bursting with colour, but when we looked closely, we could spot small pigmented colonies. Figure 3 shows one of the plates, where a pigmented colony is visible, which was then isolated on a new sterile LB agar plate and grown under the rights conditions and hence the pigmented bacteria become clearly visible.

The name of the isolated bacterium was still unknown, so the DNA sequence was mapped to find the name of the bacterium and hence whether it was safe for us to continue working with. In figure 4 the different steps in the process are shown. First, we needed to extract the DNA from the bacterium. A sample was collected from the isolated bacterium and the DNA was extracted with a DNA extraction kit. The extracted DNA were run through a copying machine in a process called Polymerase Chain Reaction (PCR). In the PCR process two small synthetic DNA fragments (primers) which complement the extracted DNA are used to perform the copying process. To check if the PCR was successful a gel electrophoresis was performed. Gel electrophoresis consists of a polysaccharide gel called agarose gel with small wells, where the sample of interest can be loaded in one of the wells and a control sample in another well. A current run through the gel and since DNA is negatively charged it migrates through the gel according to its size. The DNA sample is made visible with a DNA-binding dye and seen as a band on the gel. The DNA band is then cut out, purified and sent for DNA sequencing.

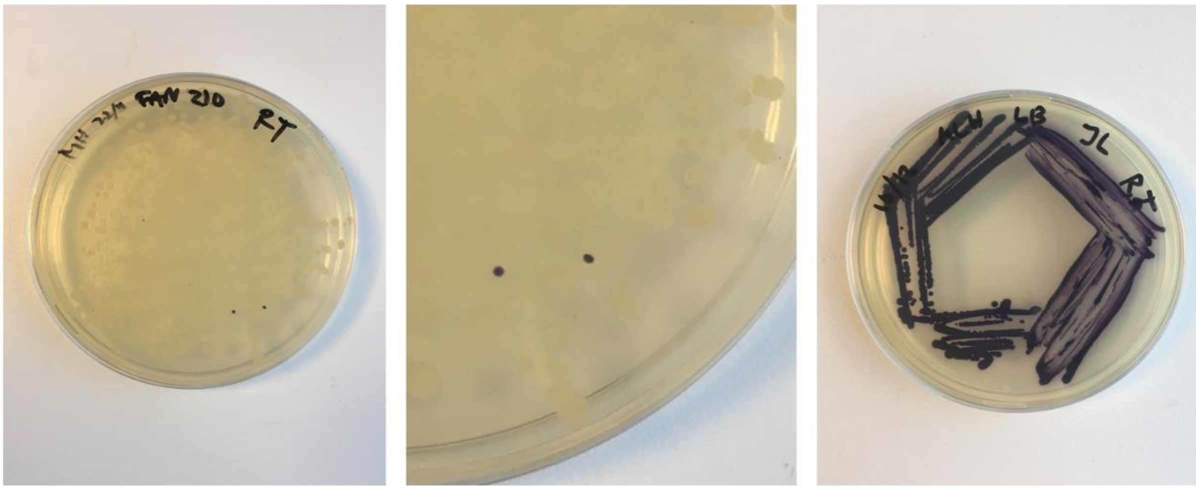

Figure 3: Sample with bacteria containing a pigmented colony is isolated.

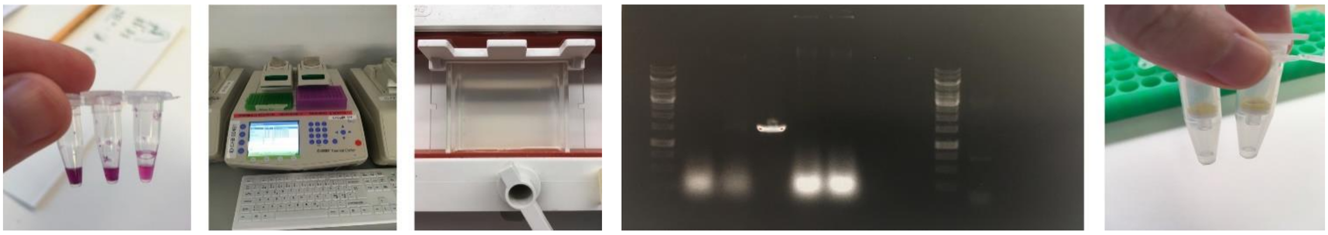

Figure 4: DNA is copied in the copying machine, run on a gel to check for DNA and finally sent for sequencing.

A company called Eurofins specialised in DNA sequencing performs this step. With the DNA sequence known a program called Basic Local Alignment Search Tool (BLAST) can tell the name of the bacterium. BLAST is an online search tool and here the DNA sequence of interest is uploaded, and the program provided us with a name for our isolated bacterium with a probability of approximately 98-99%.

Pigment production

Three different soil bacteria were used in the project: Janthinobacterium lividum (purple pigment), Serratia marcescens (red pigment), Micrococcus luteus (yellow pigment). The three soil bacteria are biosafety level 1 and thus safe for us to work with, when we take precautions and thus wear gloves and a lab coat. The bacteria all have an optimal growth temperature between 25-37 degrees, so we could grow them together in the same incubator, which is a storage box keeping a constant temperature in our case at 28 degrees Celsius.

The bacteria were grown in sterile petri dishes prepared with sterile liquid LB, which is made the same way as LB just without the agar called *LB broth*, in an incubator at 28 degrees for 3-5 days. Over time the bacteria produced a pigment, which can be used to colour textiles, shown in Figure 5.

Figure 5: Pigment production of the three pigments: purple, red and yellow.

Design methods

Material research: dyeing textile samples

The pigments produced by the bacteria are to some extent similar to the synthetic pigments used to dye polyester fibers. This can be seen from their chemical structure, since they have chemical groups which reminds of the chemical groups present in disperse dyes [30]. The bacterial pigments are insoluble in water, which also is the case with disperse dyes. This knowledge provided the foundation for choosing our dyeing method, since polyester was chosen as the textile to be coloured.

The dyeing process were performed in a pressure cooker through a heating process. Polyester textile is normally dyed in a heating process at 130 degrees. It was not possible to reach this temperature with the available equipment, so the pressure cooker was a compromise, since it can reach temperatures above 100 degrees. Polyester fibers get soft and starts to vibrate, when heat is applied. The pigment can then adhere to the fiber and colour the textile. The textile samples were prepared as 9cm × 18cm samples and put in a glass jar, which was placed in the pressure cooker and dyed for 2 hours. This process is no different from the dyeing process normally used to colour polyester textile, even though bacterial pigments were used.

Prototyping: material experiments

The material experiments were created in a three-step scenario projecting how bacterial dye could evolve. We used a scenario to try and predict what the next five years could look like, if bacterial pigment were developed and implemented instead of the conventional synthetic dyes. The three-step scenario is shown in Figure 6.

Scenario 1 is based on the bacterial pigments available now and is textile samples dyed using only bacterial pigments. Scenario 2 is a prediction of what could be possible within 1-2 years and the textile samples for this scenario are created from scenario 1 and mixing bacterial pigments with conventional synthetic dyes for polyester. Scenario 3 is a prediction of what could be achieved in 5 years and the textile samples are made from scenario 1, 2 and using synthetic dyes. The reason we have divided the replacement into steps, is due to fact, that creating and implementing the bacterial pigments is a time-consuming process.

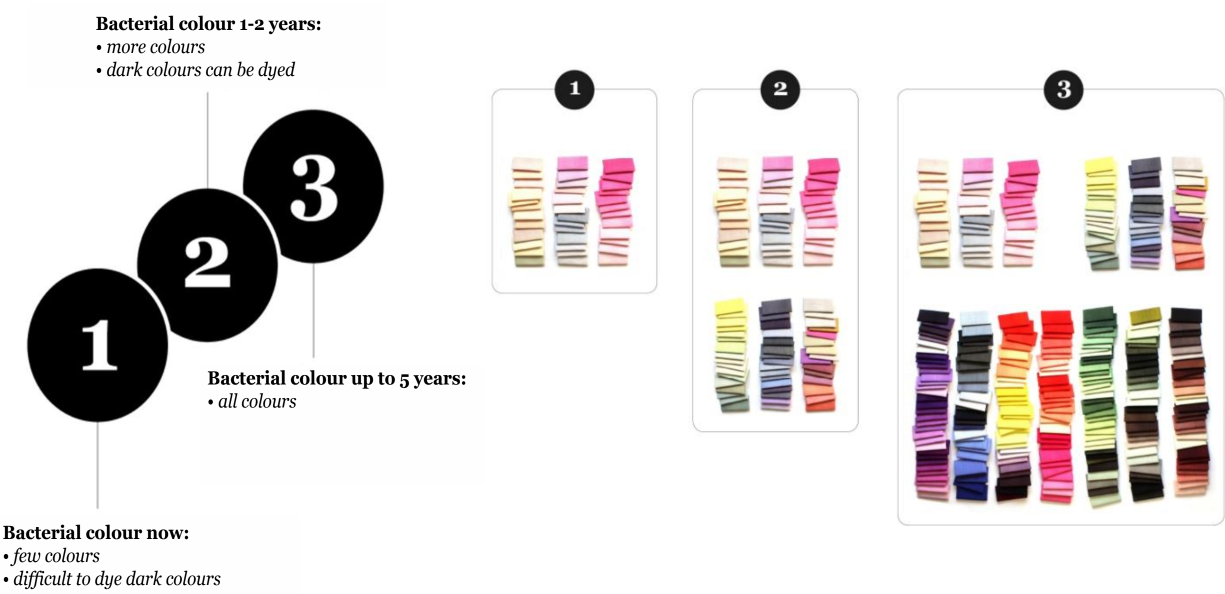

Figure 6: Three-step scenarios.

Prototyping: design case

The coloured textile samples from each scenario were used to create a wide range of colour composition, in an iterative process, contributing with knowledge of how the colours look, when they are placed next to each other, hence providing knowledge to the further development of the textile design. Afterwards the different versions were used in a comparative analysis, a selection of colour compositions from scenario 1 are shown in Figure 7.

Figure 7: Development of colour compositions.

Textile design practice builds on knowledge, teaching methods and design theory of which some dates back to the designers from the Bauhaus movement: Walter Gropius and Johannes Itten [31]. One of the first colour theorist you meet as a textile designer is Johannes Itten, who published *The Art of Colour* in 1961. We chose to use Ittens colour theory principles and his twelve-step colour circle as an inspiration to create different themes for the different colour compositions e.g., contrast colours or neighboring colours. The colour composition development was done separately for each of the three scenarios. The colour compositions provided a way to study, if the colours where possible to produce in a range, that would be visually appealing to apply in a textile design context.

Figure 8: Textile samples and the chosen colour compositions from each of the three-step scenarios 1, 2 and 3.

Design experimentation

In the textile development process our previous studies could be applied. We wanted to create a woven textile design and to do this we needed to study, how the colour and colour compositions would behave in yarn instead of a textile surface.

First, we attempted to translate the chosen colours from the textile surface samples to yar n samples, displayed in Figure 9. It was important to experiment with the colours and colour compositions in the yarn to see if the colours were still appliable.

Figure 9: Yarn and colour compositions yarn samples from scenarios 1.

Second, we attempted to create a binding pattern for the woven textile design. The binding pattern describes how the textile is woven, hence its structure. It was created from the simplest woven structure called plain weave. We chose to use a plain weave, due to its strong structure and we wanted to emphasise the colour as the major design element. The development process is shown in Figure 10, where the colour changes how the binding pattern looks, even though it is the same pattern.

Figure 10: Different colour expression in plain weave structure.

In Figure 11 samples from the woven structure development are shown. We printed out paper samples with our textile design structure to get an overview of the different colour compositions and also to get an idea of how the textile design would look in the right scale. From the paper samples we chose the colour compositions for the final textile design and created 15cm × 15cm handwoven samples to get an idea of how the textile could look, if it was woven on an industrial weave.

Figure 11: Paper samples of the textile pattern and handwoven textile samples.

Findings

Design prototypes

The studies show, that it was possible to use bacteria as an alternative to synthetic pigments and apply in a design context and have led to results in different stages, which could be applied in the following design process.

The first result is the material samples we created from the three-step scenario. They are displayed in Figure 6. It was not possible for us to work with more than three different bacterial pigments, but we were still able to produce a range of colour from those pigments creating a varied colour expression from pink, violet and yellow to orange, green and brown of which some were very vibrant. In the coming years more pigments will become wide available for designers to use, which we tried to depict with scenario 2 and scenario 3. Scenario 2 is a mix of synthetic and bacterial pigments, thus indicating that until all pigments become available from bacteria, we can substitute them along the way and decrease the need for synthetic pigments.

The material samples from each scenario were used to create the colour compositions for the final textile design. Figure 8 shows the chosen colours and colour compositions for each of the three scenarios. Here we can see an increase in the colour range and colour intensity through the three scenarios. The final result is a woven textile design 36 colour compositions in total, 12 in each scenario.

Collaborative approach

The collaborative nature of the project made it possible to carry out experiments not normally possible in either of the two disciplines on their own. Without the natural scientist, it would not have been possible for the designer to go out in the nature, find and isolate the bacteria and produce pigment from them, hence the collaboration made it possible for the designer to experience all of the steps from cultivating bacteria to designing a textile, where in a 'normal' design process, the designer would have to imagine, what the natural science process would be. On the other hand, the natural scientist would not have tested the bacterial pigments in a context, they would have stopped their process after they had seen the bacteria were capable of producing pigment and possibly worked on optimising the pigment yield and cultivation method.

The collaborative approach made it possible for the designer to apply knowledge from the natural science field and use the knowledge to explore a design potential. Thus, the collaboration gave new ideas and reflections for both disciplines.

Future work

The research described in this paper could be developed further in several directions. We will present 7 paths A-G, where we see future studies could be carried out from the challenges, we met in the present research project.

A) A study on the full effect of the bacterial pigments: We had six weeks to produce our bacterial pigments. This affected scenario 1, where all the material samples were dyed with bacterial pigments, narrowing the colour range we could create, not only the number of different colours but also their intensity. We would have liked to study, how intense the colours could get using our dyeing method, but we chose to study the colour range instead, since it was important for the further study and our hypothesis, that bacterial pigment in the future can replace synthetic dyes.

B) A study of several different bacterial pigments: This could determine if the colour range could be expanded and if it truly can replace synthetic dyes as we envisioned in scenario 2 and 3.

C) A study of the bacterial pigment's lightfastness: It is crucial for the industry to create textiles, which are lightfast, making it relevant to study if our dyeing method creates lightfast bacterial colours, not only for polyester but also dyeing other materials e.g., wool, cotton and silk.

D) A study in the materials, which can be coloured with bacterial pigments: In the present study we chose to work only with a polyester textile, since we from the chemical structure of the pigments knew, that it would bind the pigments. It would be relevant to apply other textiles produced from different fibers: synthetic fibers, natural fibers and recycled fibers. D) would be relevant to study in combination with A), B) and C).

E) Several studies in user involvement: In our research project we did not involve possible users. Colouring with bacteria is a radical change for both the industry and the consumer, so their feedback would have been valuable to our further study, since colours are perceived differently by every human being and affected by the surroundings, they are presented in. If the bacterial pigments should be brought closer to end-market, consumer insights should be studied. The consumers are essential, since they are the ones using designs created with bacterial pigments. First, what are they thinking about wearing or using designs created with bacteria? Second, what do they think of the colours produced by the bacteria?

F) A study of bacterial pigments as a dynamic entity: Until now our thoughts have been directed to using the bacterial pigments as an alternative to synthetic pigments. Another approach could be to change the way, we think about colour as a static material and instead look at the colour's dynamic possibilities in combination with the bacteria. Bacteria are living organisms, so we could study, if it is possible to grow the colours directly in the textile, hence creating dynamic textiles using biofabrication and questioning our relationship with other species. F) could also be studies together with E) e.g., how does it feel to wear living bacteria on your body?

G) A study of the bacterial pigment's future possibilities using synthetic biology: Bacterial dye has the ability to evolve within the design field. According to Collets hierarchy from nature as-coworker to re-programming nature, as is the case with the company Colorifix. Their methods use synthetic biology to create their pigments genetically modifying a bacterium's DNA in line with class I genetically modified organisms (GMO) [15]. This implies a whole new design field to investigate, where the bacterial pigments can lead the way for future research. Designers here get the possibility to push the sustainable agenda forward and create interesting and sound design products, where new material technology such as biofabrication and synthetic biology can be applied in a design context.

Conclusions

Our project *Bacterial Colouring* studied if synthetic pigments could be replaced with bacterial pigments as a climate and environmentally friendly alternative and applied in a textile design. We used biotechnological methods to produce our bacterial pigments and applied them in design research through prototyping doing material research and investigating colour compositions suitable for the final textile design proposal. At this point in time, it is not possible to produce all colours from bacterial pigments, so in the scenario projections we envisioned a world, where all colours were made with bacterial pigments. Our study finds, that it is possible to apply bacterial pigments in a textile design context and develop a design and natural science collaboration to explore and eco-friendly design potential of colouring.

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