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Properties of Bacterial Nanocellulose for Scenic Arts

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***Abstract*—**Kombucha (a symbiotic culture of bacteria and yeast) produces material capable of acquiring multiple shapes and textures that change significantly under different environment or temperature variations (e.g., when it is exposed to wet conditions), properties that may be explored in the scenic industry. This paper presents an analysis of its specific characteristics, exploring them as a non-conventional material for arts and performance. Costume Design uses surfaces as a powerful way of expression to represent concepts and stories; it may apply the unique features of nano bacterial cellulose (NBC) as assets in this artistic context. A mix of qualitative and quantitative (interventionist) methodology approaches were used such as review of relevant literature to deepen knowledge on the research topic (crossing bibliography from different fields of studies: biology, art, costume design, etc.); as well as descriptive methods: laboratorial experiments, document quantities, observation to identify material properties and possibilities used to express a multiple narrative ideas, concepts and feelings. The results confirmed that NBC is an interactive and versatile material viable to be used in an alternative scenic context; its unique aesthetic and performative qualities, which change in contact to moisture, are resources that can be used to show a visual and poetic impact on stage.

***Keywords*—**Biotechnological materials, contemporary dance, costume design, nano bacterial cellulose, performing arts.

I. Introduction

THE production of textiles with synthetic fibers causes a huge human, social and environmental cost to our planet [1]. The use of living organisms is an alternative inception of resources capable of offering ecological materials and processes, and with the potential to replace conventional textile fiber production systems [2].

In 2003, Suzanne Lee during research for her book *Fashioning the Future: Tomorrow's Wardrobe* explores the use of live microorganisms as a new source of fabrics for fashion industry; inspiring since then numerous designers to experiment with Kombucha Bacterial Cellulose [3]. This source of cellulose, on the contrary of cellulose obtained from plants, reduces the number of steps and costs to be processed [4], and it does not contribute to the environmental problem of deforestation [5].

Kombucha is a symbiotic culture of bacteria and yeast that ferments when sugar and tea are added, creating a fully compostable viscous material (NBC) that can be shaped into three-dimensional forms, and conventionally cut and sewn like a fabric to become a garment [6]. Also, when NBC is wet, it presents self-sealing properties so a seamless volumetric piece can be achieved [7]. According to the harvest, temperature and other variables, different ranges of thickness of the mat of cellulose can be obtained [8]; this will affect not only the translucency and transparency of the material, but also the nuances of the color applied [9].

NBC exhibits many properties such as biocompatibility, biodegradability [4], high crystallinity, high tensile strength, and a large water holding capacity [10]. This particularity of NBC to significantly change its shape, dimensions and its tensile strength under wet conditions, affects its short durability [11]; the material loses its properties and becomes fragile, limiting its use as a conventional garment [12]. In response to this fact, several studies have been carried out proving that it is possible to significantly improve the water resistance of NBC by applying chemical finishing [13], through material polymerization processes [11], or by physical enclosure of certain proteins [10].

This paper aims to recognize how the hydrophilic properties, generally seen as disadvantages, may still hold applicability (even added-value), being applied in different contexts (e.g., performance arts). This hydrophilic feature could be interesting to a more artistic context, such as the performance field of costume design, where the evaluation, exploration and investigation of resources, for effects and possibilities, is not only desirable but highly demanded.

The study on materials that expresses concepts and stories is an essential part of a costume designer's practices. Many costume designers agree on the difficulty of finding materials with textures, volumes, colors and effects that strengthen the concept the director or artist is trying to convey to the audience in order to create a conceptual impact on stage [14], [15].

The use of the unique properties of the NBC as a tool to express feelings and concepts is increasingly growing [16]-[18]. In fact, NBC has already been explored as a feasible material for costume design due to its great visual and performative properties [18]. The performative qualities of some biomaterials were explored during the international conference of costumes: *Critical Costume Exhibition 2015*, encouraging alternative methods of representation, art methodologies, the role of the costume and performance symbology [19].

Dancers, through a sequence of ephemeral actions/ movements, seek to communicate a sensation to the viewer which remains in their memory as emotions or perceptions [20]. The message that a costume can convey is conditioned by the emotional responses that the artist develops with it [21]. Beyond the concept or style for which the costume has been designed, its materiality (material, weight and texture)

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decisively affects the senses of the dancer, causing specific sensations and movements, and therefore a specific dance aesthetic [22], showing that there is a perceptive response that affects the dancer induced by the materiality of the garment.

The aim of this study is to identify the capacity of NBC material to express concepts and emotions through its own visual appearance and through the interaction with the dancer, influencing its dance performance. A costume design was planned and executed in NBC for the materialization of a specific narrative for a dance scene, alluding to concepts such as metamorphosis, transience of life and impermanence (Figs. 1-4); transformations that the hydrophilic properties of NBC could represent.

II. Materials

A. Ingredients for the Fermentation

For the production of nanocellulose, it was followed the recipe of Suzanne Lee *Grow Fabric in Your kitchen*, obtained from *Popular Science* [23], where it is given the instructions to a craft homemade fermentation process using the following ingredients: Water, green tea, organic cider vinegar, sugar and a live kombucha culture. The utilized kombucha culture was obtained from *Kombuchaorganic*.

B. Recipients and Materials Used during the Fermentation

Polypropylene plastic containers were used as recipients for the harvests, which were covered with a 100% cotton muslin cloth, and finally each container was fixed with a hemp rope around.

C. Dyeing Materials

Water and soluble cochineal natural food colorant 82% were acquired from *Manuel Riesgo drugstore.*

D. Sewing Materials

To make the patterns of the dress the following materials were used: a 100% cotton muslin, a 100% cotton red thread spool, a metal nickel zipper and a pair of scissors.

III. Methods

A. Fermentation

The fermentations were carried out following a spontaneous *Do-it-yourself* method, which is an interventionist methodology. A series of cellulosic films were grown in different incubation processes and temperatures. Starting from the amount of ingredients that Suzanne Lee indicates in her recipe [23] to obtain a 17.78 cm x 15.24 cm piece of microbial cellulose leather: 2 l of water, 2 green tea bags, 200 ml of organic cider vinegar, 200 g of granulated sugar and 1 live kombucha culture. Adjustments were made to these quantities (as suggested by Suzanne Lee in her recipe [23]) to obtain NBC pieces of different sizes (larger in this case), according to the measurements of the interior surface of the container (36 cm x 68 cm). Therefore, the ingredients were: 18 l of water, 18 green tea bags, 1.8 l of organic cider vinegar, 1.8 kg of granulated sugar and 1 live XL size kombucha culture.

Following the recipe, in each fermentation, the water was boiled first; the tea bags were added and left to soak for 15 minutes and then mixed with sugar until it was completely dissolved. Later, once the solutions reached a temperature of around 20 ºC, it was poured into its corresponding container, and after that, the vinegar and the Kombucha culture were added. Eventually, each container was covered with a muslin cloth, with a cord around the container to fix it to avoid contact with external elements.

The harvests took place under room temperature conditions (18 ºC-22 ºC), in a static cultivation form and in a well-ventilated area, protected from direct sunlight. After the cellulose films formed on the surface had reached the convenient thickness (1 cm - 1,4 cm), which took six weeks each to harvest; the cellulose films were removed and rinsed with water several times to take away the components that were impregnated during the fermentation.

B. Dyeing and Drying Procedures

To dye the cellulosic films obtained from the different incubations the same process was made: 6 l of water was boiled in a large stainless-steel pot, then was added 8 g of cochineal dye extract in order to obtain a highly concentrated bath and a deep red color on the cellulose films. Once the colorant was completely dissolved, the solution was removed from the heat and left aside until it reached a temperature around 35 ºC. Subsequently, the bath was poured into a plastic container and placed on it the cellulose film completely stretched to ensure that the color penetrated uniformly, and was left for around 2 hours. Next, it was removed and washed with plenty of water to reduce its dye content, then it was squeezed, and placed on a towel for 24 hours so that it would adsorb a large part of the liquid, and finally it was placed on a flat glass surface and left at room temperature until it was completely dry. During the drying process the color was getting darker and darker and acquiring a leather texture.

C. Cut and Sewn Procedures

Once we had enough samples to make the garment (4 samples of 36 cm x 68 cm), the patterns were made in muslin fabric and adjusted on the BC films to be cut and finally sewn. A wardrobe fitting with the dancer was necessary in order to adjust the garment to her body perfectly.

IV. Results and Discussions

Results show the aesthetics and plasticity capability of NBC. When the costume is dry, it displays a variety of textures, stiffness and opacities (Figs. 1 and 2); the range of colours depends on the different thickness of the materials resulted from the harvests. Its translucency and transparency gave exclusive nuances and opacities. Additionally, the NBC presented some areas which were getting dry, exhibiting unique wrinkles and rough appearance.

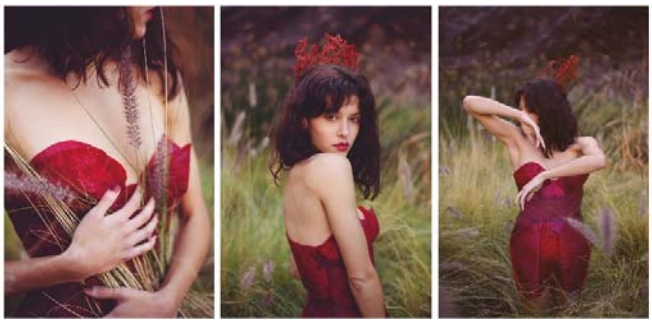

Fig. 1 Performer with the bacterial cellulose costume

The interaction between the garment, its materiality and the performer, evoked an emotional response to the dancer and its performance. The dancer emphasized:

> "The type of movement I was creating at the time was influenced by the delicacy of the garment and learning all the handmade work behind it, made me be more aware of what I was wearing and of my own movements" (D. Arzarello, personal communication, May10, 2021).

This notion of subtlety is perceived through the set of images made from the dancer's own sensory experience with the garment, from her spontaneous movements (Fig. 2); the materiality of the costume affected the artist expression with a slower and smoother movements, creating a unique aesthetic induced by the somatic experience of the costume, in accordance with the opinions of two authors already mentioned [21], [22].

Fig. 2 Performer dancing with the bacterial cellulose dry costume

Once this material was exposed to water (Figs. 3 and 4) it lost its rigidity, the texture changed (creating interesting wrinkles that resembled wet paper), it lost its opacities, gained brightness, started to lose its red color, and gained thickness. It transformed, gained flexibility, adhered tightly to the body, showing ranges of transparency; it was like the skin, enabling a greater freedom of movement and comfort to the performer. The dancer stated: "When the dress got wet it sticked to my body as if it were a second skin, and I felt even more comfortable to make my movements" (D. Arzarello, personal communication, May10, 2021).

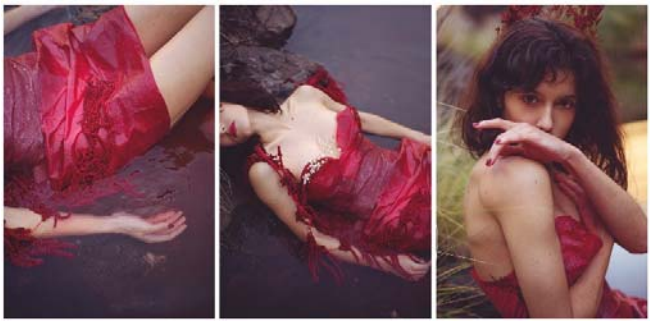

Fig. 3 Performer with the bacterial cellulose wet costume

This study shows, that NBC has great deformation properties and gain elasticity in wet conditions. Similar to our research and results, the costume designer and scenographer, Ingvill Fossheim [18] concluded during her investigation about the use of NBC as an alternative material for contemporary dance costume, that the material after being in contact with the performer skin (heat and sweat), gained flexibility, adherence to the body, density and changed its texture and natural pigmentation (it was not dyed).

The performative properties of NBC improved after being exposed to moisture, it sticks to the body (Figs. 3 and 4), it becomes more flexible and stronger. The humidity may be a playful element for the performer/concept, evoking a transformation of shape, textures and colors, rendering a desirable and necessary visual impact and poetry for a scenic arts context.

Fig. 4 Performer dancing with the bacterial cellulose wet costume

Although the overall success in attaining the objectives proposed in regards to the performance, there were some challenges worth mentioning: first of all, one aspect conditioning the process in terms of the quantity of NBC material bio fabricated was related to the physical space available to locate all the containers (since the more space the more harvests can be carried out at the same time, instead of waiting for the previous fermentations to have the desired size to start the new ones). This fact alone did indeed limit the size of the NBC garment. Another aspect to take into account when growing NBC is the variable temperature, as the ideal fermentation temperature for a quicker process of growth is

between 25 ºC to 30 ºC, growing obviously slower in minor temperatures, which is confirmed by observation and reviewed literature [24]. The project presented in this study was developed through a fermentation process taking place during the colder months of the year. Therefore, the related process timeframe (growth and harvest) was higher, also crucial, to obtain the desired thicknesses.

Another difficulty faced during this study was that some harvests presented mold contamination, which meant having to start the whole process all over again. The presence of unwanted microorganisms on the NBC growth and harvest process is more likely to occur in a home-growing procedure. This could happen due to the use of recipients that were not clean enough, ingredients that could be contaminated, a low temperature for fermentation, among other reasons [25].

Another relevant event was that some films of nanocellulose made during the fermentation had irregular thicknesses, which meant that, once dried, these would get different strengths, stiffness and translucencies. As these authors affirmed [8], there are many variables that affect the thickness of the mat resulted, among which are the ingredients, duration and temperature of the fermentation. Nevertheless, this event was used to favor the project, since different thickness allows a variety of translucency and nuances of colors in the same piece of nanocellulose films [9]. Likewise, it was taken into account that the pieces could not be replaced, so special attention had to be paid when constructing the garment to avoid weakening the material with cracks, holes, etc. However, as this event occurred once, it is of significance to mention that this issue was solved thanks to the self-sealing property of the NBC; a wet strip of the material was placed on the crack, and once dried, it did seal the crack completely.

Prior to the beginning of this research in NBC material for scenic arts, some samples were made in order to understand the fermentation process of Kombucha, by changing its variables: adding natural flowers (Figs. 5 (a) and (b)) to create a natural eco print (which were incredibly well preserved for long time), playing with textures (wrinkles) and adding natural dyeing colors such as indigo and beetroot dye (Figs. 5 (c) and (d)). These previous studies helped the designers/authors get acquainted to the materials and varied process as well as understand in a greater depth the different surfaces and properties that this material can acquire.

(a) (b) (c) (d)

Fig. 5 Experiences with Kombucha Bacterial Cellulose

V. Conclusions and Future Recommendations

The use of NBC material as a raw material for a stage costume implies the creation of an ephemeral and unrepeatable event, where the sensory experience of the performer towards the costume can be modified by the shape, texture, thickness, colors, etc., in the same biodegradable material. These properties and characteristics can be created through a process of co-creation, the one where, symbiotically, a living organism and the direct intervention of the designers during and after its fermentation (e.g., changing the ingredients, the growing time in order to obtain into a stiffer or more malleable material, among other variables) can be decisive for the projects and originate different aesthetical elements. On the other hand, this is revealing in terms of grasping the potential of NBC to be part of unique performative events and even to investigate the influence of costumes' Design on the stage work.

Although other materials may mimic skin or similar textures, NBC also has the particularity to change its appearance and properties (some can be even improved, such as the performative ones) in presence of moisture during the performance act, which is important for some of the performative arts. The expression of a certain feeling or trait may be materialized in the form of a color or texture, and be affected by the humidity and the NBC changing capacities, evoking concepts inherent to the material itself such as ephemerality, transmutation and the transience of life.

The need to use patience, to be attentive, to take care of the culture, observant of all the process and adapt to the spontaneous and unpredictability of the process and of the production; to learn from it in order to improve it, for instance, is something that the designer has to take into account when working with a biomaterial, such as the NBC. Through this study it is expected to inspire/influence designers/researchers about the diverse forms of expression that a homemade material (NBC) can achieve in the scenic context and the possibilities it may offer.

Further experimentations with NBC material, including the use of different recipes of fermentations, the applications of others dying colors, the play with its self-sealing qualities and a 3-dimensional form capacity are necessary to have a full comprehension of the application of this material in a scenic context.

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