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Virtual try-on and analysis of haenyeo suits using digital technology

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Abstract: This study aims to digitize information about Korean haenyeo suits and reveal their characteristics and current status to preserve the culture of Jeju haenyeo in South Korea. We created an avatar of a woman in her 60s—the typical wearer of haenyeo suits—measured the physical properties of the haenyeo suit fabric, generated patterns reflecting these properties, and conducted virtual try-on simulations. After analyzing haenyeo suits according to the morphological criteria of shape, dimensions, and clothing pressure, this study identified the following regarding their characteristics and current status. A haenyeo suit has activeness to facilitate the movements of a haenyeo during work and protectiveness to prevent seawater from entering. At a time when the number of haenyeo suit manufacturers is continuously decreasing, the pattern dimensions of the suits must be standardized. Moreover, a haenyeo suit has patterns that closely fit the wearer's body. Hopefully, this study will inspire further research on the haenyeo culture.

Keywords: *Clothing construction, Digital technology, Diving suit, Haenyeo suit, Sportswear.*

1. Introduction

The haenyeo culture in Jeju, South Korea, has contributed to improving the status of women within communities around the world [1]. Accordingly, the Culture of Jeju Haenyeo was inscribed on the Representative List of the Intangible Cultural Heritage of Humanity of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) (November 30, 2016), and *haenyeo* was designated a National Intangible Cultural Property No. 132 in South Korea (May 1, 2017). In South Korea, haenyeo is taught in elementary schools as an occupation among skilled workers in agriculture, forestry, and fishery [2]. The Jeju Special Self-Governing Province, which works to promote the culture of Jeju haenyeo worldwide, opened the Jeju Haenyeo Museum in 2006 [3]. Studies on haenyeo have been conducted by folklorists, sociologists, and anthropologists, and medical studies have been conducted on the physical reactions of haenyeo related to their work environment [4].

The haenyeos employ the technique of breath-hold diving, which is different from scuba diving—a popular leisure sport [5]—to collect seafood [6]. A haenyeo suit, worn for breath-hold diving, represents a clothing culture adapted to the climate and geography of Jeju [7]. Korean Haenyeo suits have been diversified since the early 1970s, and haenyeos choose their suit according to their personal preferences. Consequently, rubber haenyeo suits acquired widespread popularity [8]. A rubber haenyeo suit, which is made of rubber on the outside and neoprene on the inside, is now a must-have suit for the haenyeos [9]. Haenyeo suits symbolize the haenyeo culture; nonetheless, studies on haenyeo suits remain scarce, likely because of a lack of relevant data.

The Jeju Haenyeo Museum comprehensively exhibits the traditional culture in Jeju under the theme of haenyeo [10]. It published a research report on haenyeo suits in Jeju in 2012, revealing a total of six haenyeo suit manufacturers in Jeju; however, this number is debatable. Another study Cho [11] reported that, although the number of new haenyeos has been increasing among young and middle-aged women, the number of haenyeo suit manufacturers has been continuously decreasing. As the number of haenyeo suit manufacturers may decrease in the future, research data on haenyeo suits must be collected to preserve the culture and convey it to future generations.

Recently, numerous studies have employed digital technology to ascertain the characteristics of clothing—this enables preserving and passing down traditional clothing [12]. One significant advantage of this approach is

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the ability to measure the garment pressure between the body and the fabric. However, it is crucial that virtual garments are simulated as realistically as possible, as the physical properties of the actual fabric must be accurately reflected in the virtual model. Clothing pressure refers to the pressure generated by the contact between clothing and the human body [13] which is used as a tool to evaluate the fit of clothing [14]. Hence, this study added clothing pressure a morphological criterion. This study performs a nuanced analysis of the pattern shape, dimensions, and clothing pressure of haenyeo suits based on digital technology and thereafter discusses the characteristics and current status of haenyeo suits.

2. Methods

There are five haenyeo suit manufacturers in Jeju, and this author purchased medium-sized haenyeo suits from four of them, which have sizes of small, medium, and large. Consequently, a total of four haenyeo suits were studied; AH, BH, CH, and DH. All seams of the haenyeo suits were cut with scissors and broken down. The patterns of the haenyeo suits were digitized with the digitizer. Next, this study used a CLO software (CLO Virtual Fashion Inc., South Korea) to analyze the pattern shape through the outline shape of the haenyeo suits and examine their dimensions. Avatar data were required to analyze the clothing pressure of the suits. As most of the haenyeos are over 60 years old [4] this study used an avatar of a female in her 60s provided by Size Korea (https://sizekorea.kr/; Site that provides body measurements of Koreans) (Table 1). Based on the digitized patterns of the haenyeo suits, this study created a 3D (three-dimensional) virtual haenyeo suit and put it on the avatar. The CLO fabric kit (CLO Virtual Fashion Inc.) was used to measure the physical properties of the fabrics of the haenyeo suits, which were applied to the virtual haenyeo suit. It was used to simulate the appearance of a person wearing a haenyeo suit. After completing the virtual simulation of putting the suit on the avatar, this study measured clothing pressure. The CLO software reveals clothing pressure as a color distribution. Blue indicates greater extra space in the suit and red indicates less extra space. After confirming clothing pressure with the color as above, this study measured clothing pressure by the site of the body in five replicates to calculate the mean and standard deviation (SPSS Statistics 29.0; IBM, USA). Figure 1 illustrates the clothing pressure measurement sites (Upper suit: Front collar, Back collar, Front neck point, Cervicale, Bust, Back shoulder, Abdominal, Posterior waist point, Upper arm, Elbow, Forearm, Wrist / Lower suit: Crotch, Hip, Front thigh, Back thigh, Knee, Popliteal fossa, Leg, Calf, Front ankle, Back ankle). By doing so, this study examined the level of clothing pressure when the suit was worn.

Table 1.
Dimensions of a female avatar in her 60s (unit: cm).

Item	Measurement item
Stature	154.5
Neck circumference	33.9
Bust circumference	84.4
Waist circumference	122.0
Abdominal circumference	108.0
Upper arm circumference	23.7
Hip circumference	117.4
Thigh circumference	67.2
Knee circumference	33.6
Calf circumference	33.3
Minimum leg circumference	21.1

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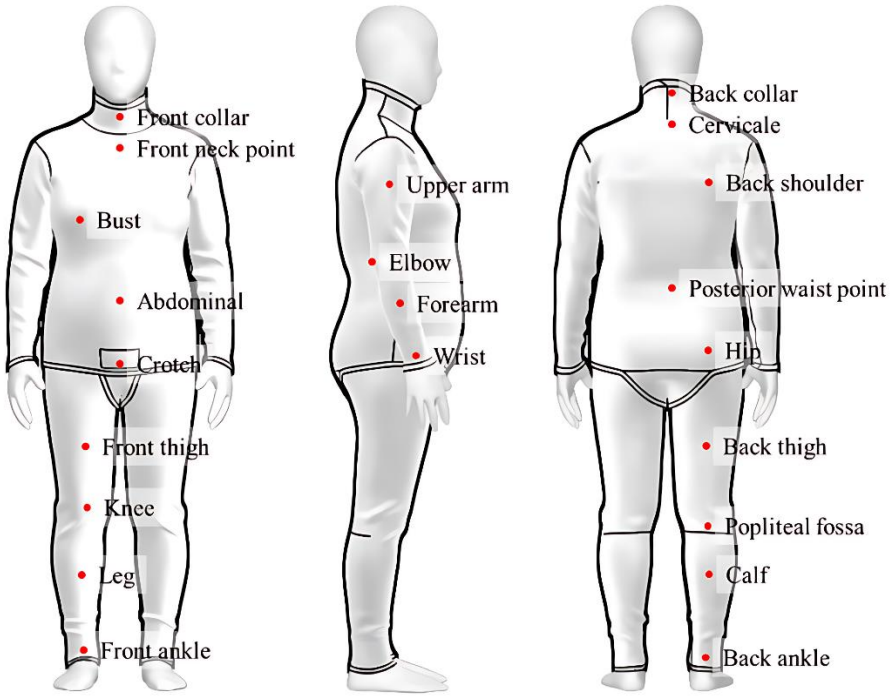

Figure 1.
Clothing pressure measurement sites of a haenyeo suit.

3. Results

3.1. Pattern Shape of Haenyeo Suit

The following patterns of the haenyeo suit were identified: The upper suit was designed with a dart behind the neck, and a low cap height was designed for sleeves. The lower suit was designed with darts behind the knees and gusset patterns around the crotch area—these patterns facilitate a comfortable dive underwater (Muljil) for the haenyeos. The cuff patterns were included in the collar in the upper suit, in the cuff opening in the sleeves, and in the hem in the lower suit. The lower suit consisted of high-rise pants with the rise that was so long that it could reach the chest area. To keep these pants in place, the hem of the back of the upper suit included the crotch patterns that held the upper and lower suits together. These patterns were designed to prevent seawater from entering the haenyeo suit. Figure 2 depicts the patterns of a haenyeo suit.

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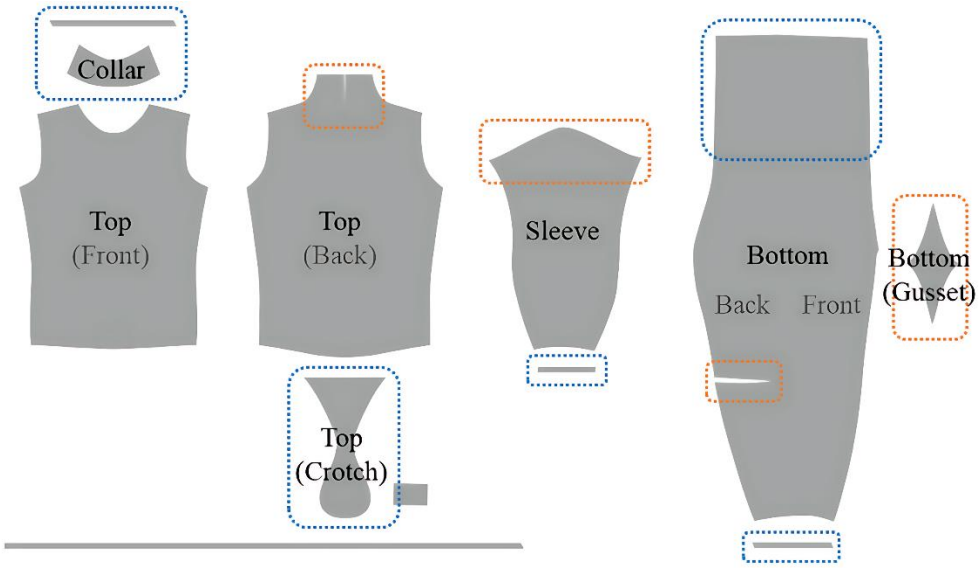

Figure 2.
Patterns and characteristics of a haenyeo suit (Orange line: designed to facilitate diving underwater, blue line: designed to prevent seawater from entering).

3.2. Pattern Dimensions of Haenyeo Suit

Figure 3 illustrates the pattern dimension measurement sites of a haenyeo suit; Tables 2 and 3 present the measurements. When the pattern dimensions between clothes of the same size differ by more than 1.0 cm, they are considered to be different [15]. Based on this 1.0 cm threshold, it was observed that a few measurement sites had similar pattern dimensions between the haenyeo suits from different manufacturers, while many dimensions differed by more than 1.0 cm between them. These included front neck depth, center front length, front hem breadth, back neck dart length, center back length, crotch patch length, and crotch patch width in the upper suit; sleeve cap height, sleeve breadth, and sleeve band cuffs breadth in the sleeves; and pants length, crotch height, knee dart length, pants band cuffs height, gusset length, and gusset breadth in the lower suit. With the decline in the number of haenyeo suit manufacturers, these findings demonstrate that the patterns of haenyeo suits must be standardized.

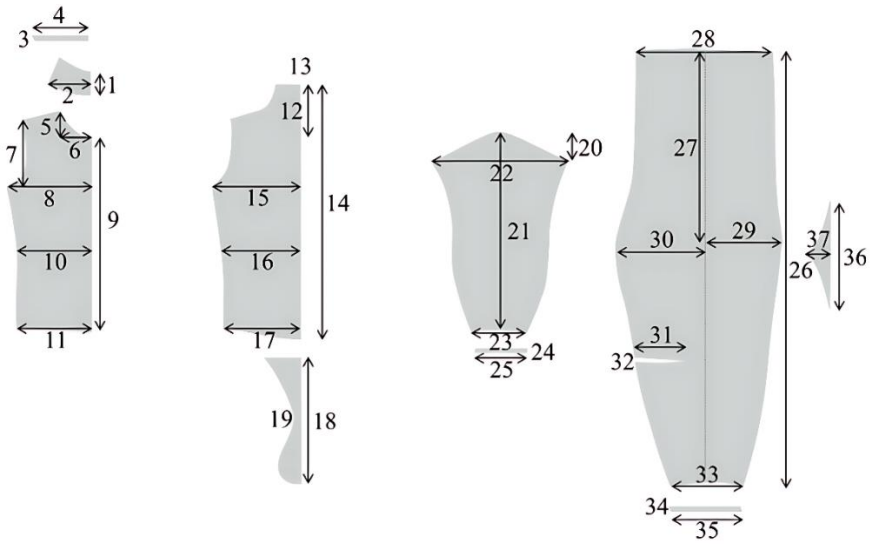

Figure 3.
Measurement items of a haenyeo suit.

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Table 2.
Pattern dimensions for the upper suit (unit: cm).

Item		AH	BH	CH	DH	Mean	Standard deviation
1	Collar length	5.7	5.3	5.8	6.1	5.7	0.3
2	Collar breadth	10.6	10.6	11.6	11.0	10.9	0.5
3	Collar band cuff height	1.6	1.0	3.0	1.3	1.7	0.9
4	Collar band cuff breadth	15.7	16.1	15.5	14.6	15.5	0.6
5	Front neck depth	5.5	7.3	8.7	6.7	7.1	1.3
6	Front neck breadth	8.3	7.1	6.9	8.4	7.7	0.8
7	Shoulder height	17.5	19.1	17.7	17.2	17.9	0.8
8	Chest breadth	22.4	22.2	22.1	22.3	22.2	0.1
9	Center front length	54.5	52.2	52.4	50.8	52.5	1.5
10	Front waist breadth	19.4	19.8	19.0	19.4	19.4	0.3
11	Front hem breadth	21.4	21.3	19.9	19.5	20.5	1.0
12	Back neck dart length	8.8	9.2	12.5	10.9	10.3	1.7
13	Back neck dart	0.6	0.2	0.1	0.2	0.3	0.2
14	Center back length	68.4	64.2	64.9	66.5	66.0	1.9
15	Back breadth	21.9	22.0	22.0	23.2	22.3	0.6
16	Back waist breadth	19.8	19.8	18.8	20.1	19.6	0.5
17	Back hem breadth	21.2	20.1	20.0	20.2	20.4	0.5
18	Crotch patch length	34.3	35.3	38.0	33.0	35.1	2.1
19	Crotch patch width	1.7	8.8	2.7	3.6	4.2	3.2
20	Sleeve cap height	7.0	6.7	5.4	7.8	6.7	1.0
21	Sleeve length	51.4	50.2	50.2	51.6	50.9	0.8
22	Sleeve breadth	38.1	35.8	37.4	35.9	36.8	1.1
23	Sleeve hem breadth	15.1	16.0	14.7	14.2	15.0	0.7
24	Sleeve band cuffs height	1.4	1.2	1.5	1.1	1.3	0.2
25	Sleeve band cuffs breadth	15.7	14.5	13.5	13.5	14.3	1.0

Note: Numbers refer to those in Figure 3.

Table 3.
Pattern dimensions for the lower suit (unit: cm).

Item		AH	BH	CH	DH	Mean	Standard deviation
26	Pants length	117.4	110.8	111.9	113.1	113.3	2.9
27	Crotch height	53.0	44.8	48.0	50.1	48.9	3.5
28	Pants waist breadth	37.5	36.5	35.6	35.9	36.4	0.9
29	Front crotch breadth	19.2	20.6	20.6	20.2	20.1	0.7
30	Front crotch breadth	24.1	23.8	22.9	23.6	23.6	0.5
31	Knee dart length	14.6	13.1	15.5	14.1	14.3	1.0
32	Knee dart	1.5	2.1	1.3	1.3	1.5	0.4
33	Pants hem breadth	18.4	18.0	18.8	18.7	18.5	0.3
34	Pants band cuffs height	1.0	1.3	1.5	1.2	1.3	0.2
35	Pants band cuffs breadth	19.5	16.5	16.5	18.5	17.7	1.5
36	Gusset length	31.2	32.3	39.5	28.2	32.8	4.8
37	Gusset breadth	15.1	17.2	11.3	13.8	14.3	2.5

Note: Numbers refer to those in Figure 3.

3.3. Clothing Pressure of Haenyeo Suit

The physical properties of neoprene—a synthetic rubber material commonly used in haenyeo suits—were assessed using the CLO Fabric Kit to measure the garment pressure between the body and the fabric. The assessments were input into the CLO software; Table 4 presents the results. The CLO software does not assign units to the physical properties defining fabrics; therefore, only numerical values are presented. The results for the Virtual Try-On were as shown in Figure 4. This is the result of putting virtual clothing that reflects the material properties of a haenyeo suit on a female avatar in her 60s.

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Table 4.
Physical properties of haenyeo suit fabric in CLO software.

Mechanical properties of fabric	Value
Weft stretch	40.0
Warp stretch	39.0
Weft bending	66.0
Warp bending	66.0
Bending-Bias (right, left)	66.0
Internal damping	1.0
Density	88.0
Friction	3.0
Thickness	3.6

Table 5.
Clothing pressure measurement of a haenyeo suit (unit: kPa).

Item		AH	BH	CH	DH	Mean	Standard deviation
Upper suit	Front collar	46.7	24.9	37.0	48.6	39.3	10.8
	Back collar	51.7	37.5	22.4	55.6	41.8	15.1
	Front neck point	30.2	41.1	58.0	37.5	41.7	11.8
	Cervicale	33.6	28.2	50.4	32.8	36.2	9.7
	Bust	43.2	46.7	52.8	39.9	45.6	5.5
	Back shoulder	41.5	35.5	45.2	39.3	40.4	4.0
	Abdominal	43.3	39.4	53.9	46.5	45.7	6.2
	Posterior waist point	21.2	18.5	30.3	21.5	22.9	5.1
	Upper arm	18.1	29.8	23.9	25.9	24.4	4.8
	Elbow	13.2	6.9	15.2	9.2	11.1	3.7
	Forearm	5.1	4.5	7.0	5.8	5.6	1.1
	Wrist	50.6	63.4	76.7	64.2	63.7	10.6
Lower suit	Crotch	17.5	24.3	21.5	41.2	26.1	10.4
	Hip	43.3	48.3	52.7	49.6	48.5	3.9
	Front thigh	18.4	21.0	28.3	14.7	20.6	5.7
	Back thigh	17.7	14.9	23.1	11.3	16.7	5.0
	Knee	13.5	15.5	30.8	10.6	17.6	9.0
	Popliteal fossa	7.6	11.7	22.9	6.3	12.1	7.5
	Leg	30.7	35.1	39.9	19.8	31.4	8.6
	Calf	32.0	40.0	43.5	23.3	34.7	9.0
	Front ankle	85.9	95.2	71.8	85.1	84.5	9.6
	Back ankle	86.5	82.6	70.1	66.5	76.4	9.6

Figure 5 illustrates the simulated clothing pressure of the haenyeo suit (representative haenyeo suit: AH), while Table 5 lists the clothing pressure values. Regarding the average clothing pressure by site, it was found that clothing pressure ranged from 39.3 to 41.8 kPa in the collar, from 22.9 to 45.7 kPa in the upper suit, from 5.6 to 63.7 kPa in the sleeves, and from 12.1 to 84.5 kPa in the lower suit. Regarding the collars, the front collar had higher clothing pressure than the back collar except for CH. Only the front collar of a haenyeo had separate patterns, while a dart was designed in the back collar extending from the panel to the high neckline. With this configuration of the patterns, the collar of the haenyeo suit closely fitted the back neck of the wearer, which resulted in higher clothing pressure in the front collar than in the back collar. In the upper suit, the posterior waist point, which is the most concave part of the upper body, had lower clothing pressure, and the bust and the abdominal, which were the convex parts, had higher clothing pressure. It is in part because the panel of the haenyeo upper suit was designed with flat patterns with no dart, which resulted in different clothing pressure across the shape of the human body. For the lower suit, the hip is the convex part of the lower body, and the clothing pressure is similar to that of the bust and the abdominal in the upper suit.

The thigh and the leg part between the hip and the ankle showed lower clothing pressure. Meanwhile, the front and back ankles showed higher clothing pressure. Regarding the patterns of the haenyeo lower suit, it is almost vertical from the waistline of the pants and closely fits the ankle part. Consequently, there is some margin between the hip and the ankle, which would have resulted in lower clothing pressure. A reason that higher

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clothing pressure was observed in the ankle was that the patterns were designed to closely fit the wearer to prevent the entry of seawater. Upon reviewing the pattern dimensions and clothing pressure of the haenyeo suits, this study found that a haenyeo suit is crafted in a pattern design that closely fits the wearer.

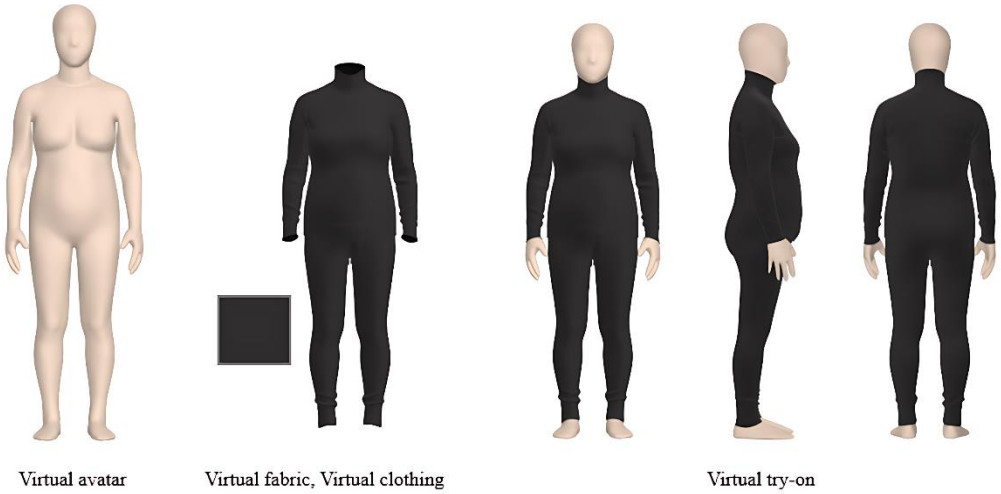

Figure 4.
Virtual try-on of a haenyeo suit.

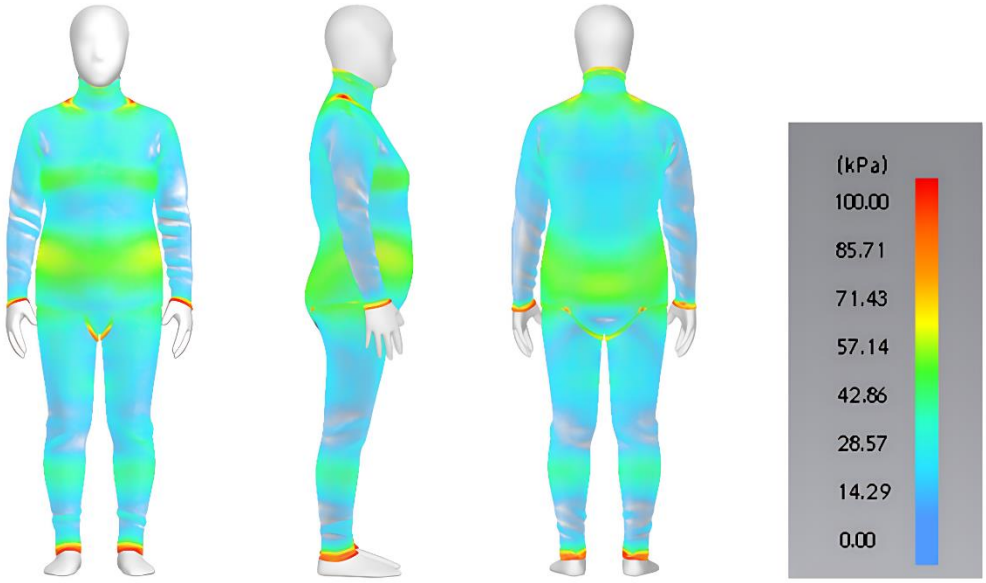

Figure 5.
Clothing pressure simulation of a haenyeo suit.

4. Conclusion

A haenyeo suit symbolizes the culture of Jeju haenyeo in South Korea. However, studies on Korean haenyeo suits are scarce, and the number of haenyeo suit manufacturers continues to decline. There are five manufacturers in Jeju that can produce haenyeo suits. This study digitizes information about haenyeo suits and reveals their characteristics and current status to preserve this culture. This research is a topic that has not been conducted in the field of clothing studies before.

The results of the analyzed pattern shape, dimensions, and clothing pressure of the haenyeo suits are as follows: A haenyeo suit included a collar that wrapped around the neck in the upper suit with a dart at the back of

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the neck. The lower suit included darts behind the knees and gusset patterns around the crotch area—patterns intended to render diving underwater (Muljil) more comfortable. Further, the collar, sleeve hem, and pants hem included cuffs; the waistline of the lower suit was located at the bustline; and there were crotch patterns that held the upper and lower suits together—these patterns prevent the entry of seawater into the haenyeo suit when working underwater. As the pattern dimensions of haenyeo suits vary depending on the company, they must be standardized (Upper suit: front neck depth, center front length, front hem breadth, back neck dart length, center back length, crotch patch length, and crotch patch width / Sleeves: sleeve cap height, sleeve breadth, and sleeve band cuffs breadth / Lower suit: pants length, crotch height, knee dart length, pants band cuffs height, gusset length, and gusset breadth). Higher clothing pressure was observed in the back collar, bust, and abdomen in the upper suit and in the ankle in the lower suit. Clothing pressure was higher in the protruding sites of the body and the sites where seawater is likely to enter. In other words, one of the characteristics of a haenyeo suit is the patterns closely fitting the wearer. This study serves as a reference to convey to future generations the symbolism of the Jeju haenyeo—one of the most notable national cultures in South Korea. This study regarding the haenyeo suit—a symbol of the Jeju haenyeo culture—also contributes to advancing the clothing sector. If standardized dimensions for haenyeo suits are established, even if the number of haenyeo suit manufacturers decreases and production becomes difficult, another sportswear manufacturing company will be able to produce them. The research holds significance as it uses digital technology to analyze the details of a haenyeo suit and ascertain its characteristics. It is particularly meaningful as it provides pattern data, material data, and garment pressure data, which are essential for the digitalization of haenyeo suits. Hopefully, this study will inspire further research on the Jeju haenyeo culture.

Transparency:

The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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