sustainability

Article

Is It Worth Buying a Second-Hand Shell Jacket? An Evaluation of Shell Jackets' Functionality and Price over Time

Louisa Nilsson [1,*], Anna Björklund [2], Judith H. Waller [1] and Mikael Bäckström [1]

1 Sports Tech Research Centre, Department of Engineering Mathematics and Science Education, Mid Sweden University, 831 25 Östersund, Sweden; judith.waller@miun.se (J.H.W.); mikael.backstrom@miun.se (M.B.)
2 Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, 114 28 Stockholm, Sweden; anna.bjorklund@abe.kth.se
* Correspondence: louisa.nilsson@miun.se

Abstract: Global textile production and consumption has increased steadily over the past 15 years, which has caused significant impacts on the climate and the environment. In 2022, the EU launched a strategy for sustainable and circular textiles, stating that extending the life of textile products is the most efficient way to reduce their impact on the climate and the environment. Shell jackets for outdoor use are textile products that are frequently discarded by their first users and re-sold on the second-hand market. This study evaluates the performance of 16 second-hand shell jackets from three second-hand stores in Sweden via material testing of four key functional aspects. Comparing the results with the jackets' original performance, this study describes the change in functionality over time. The results indicate that air permeability does not change significantly, whereas water repellency, water penetration resistance, and breathability decrease over time, although they do so at different rates. With the aim of promoting circularity and encouraging longer product use, this study also compares the price evolution of jackets with their functionality over time. The results reveal that the resale price of the jackets is lower than could be expected based on the level of remaining functionality in the jackets.

Keywords: textile ageing; membrane laminates; DWR; water repellency; water penetration resistance; breathability; circular economy; product lifespan

check for updates

Citation: Nilsson, L.; Björklund, A.; Waller, J.H.; Bäckström, M. Is It Worth Buying a Second-Hand Shell Jacket? An Evaluation of Shell Jackets' Functionality and Price over Time. *Sustainability* **2024**, *16*, 3451. https://doi.org/10.3390/su16083451

Academic Editor: Andrius Plepys

Received: 27 February 2024
Revised: 12 April 2024
Accepted: 17 April 2024
Published: 20 April 2024

1. Introduction

Textiles are fundamental to our society and have an important role in human life. They are not only used in clothing, footwear, and household textiles, but also in medical and protective equipment, buildings, and vehicle furnishings. Despite a rising awareness of the environmental impact of the textile sector, the global production and consumption of clothing and footwear is constantly increasing. Between 2000 and 2015, the global production of clothing and footwear almost doubled [1] and the consumption is expected to increase by 63% from 2019 to 2030, rising from 62 million tonnes to 102 million tonnes in 2030 [2].

In Europe, the total consumption of textile products, including clothing, footwear, and household textiles, was 6.6 million tonnes in 2020. Clothing corresponded to 50% of the consumed textile products, while footwear and household textiles corresponded to 20% and 30%, respectively. However, textile production and consumption cause significant impacts on the climate and the environment by using resources, land, water, and chemicals, and releasing pollutants into both the air and water [1,3]. In 2020, textile consumption was the fifth highest contributing sector to both primary raw material use and climate change. In terms of water consumption and land use, the consumption of textile products was the third highest contributor [4].

The EU has reacted to the problem of the increasing production and consumption of textile products. In March 2020, a new circular economy action plan was launched, in which the textile sector was identified as a sector with high potential for circularity. In line with this, the action plan proposed that a comprehensive EU strategy for textiles should be developed [5]. In March 2022, the EU Strategy for Sustainable and Circular Textiles was finally launched. The key actions of the strategy included setting eco-design requirements for textiles and introducing clearer product information, including a Digital Product Passport. Additional actions included stopping overproduction and overconsumption, and harmonizing EU Extended Producer Responsibility rules for textiles. Measures to address the unintentional release of microplastics and to address the challenges from the export of textile waste were also included in the strategy [6]. At a global level, the EU Strategy for Sustainable and Circular Textiles has the potential to contribute positively to several of the UN Sustainable Development Goals, including Goal 6: Clean water and Sanitation; Goal 7: Affordable and Clean Energy; Goal 12: Responsible Consumption and Production; and Goal 13: Climate Action [7].

The EU Strategy for Sustainable and Circular Textiles states that "extending the life of textile products is the most effective way of significantly reducing their impact on the climate and the environment" [6] (p. 3). One business model which meets the requirements of this strategy to extend the life of products is the resale of second-hand products. For the success of such a business model, understanding consumer attitudes in terms of motivations and barriers is crucial. In previous research, the main motivations for buying second-hand clothing and other second-hand products were found to be related to economic, environmental, ethical, and hedonic reasons [8,9]. The barriers against buying second-hand clothing were mainly related to hygiene [8,9], the shopping experience [9], and social aspects [10]. Another barrier against buying second-hand clothing and other second-hand products that is highlighted in the literature is related to product performance, as the consumer lacks information about the condition of second-hand products and is normally not offered any insurance or guarantees for the products [8,11]. This barrier related to product performance is of particular concern for technical textile products, and has been confirmed to be relevant to second-hand shell jackets [12].

The resale of second-hand products mainly takes place in physical stores and on digital platforms. In physical stores, the consumer can evaluate the product themselves, but on digital second-hand platforms, the consumer relies on the information provided by the seller. Usually, the seller provides the consumer with images of the product, together with a product description containing product information such as model, size, age, and condition. Some digital platforms also require the seller to estimate the condition of the product under loosely defined categories such as excellent, great, and good condition. In both physical stores and on digital platforms, the evaluation of product condition only includes a visual inspection, which relies on the experience of the person carrying out the examination [13,14]. Visual inspection is a subjective evaluation, which is good enough for some types of products; however, visual inspection does not fully tell the truth about the condition and functionality of technical products, such as outdoor clothing and specifically shell jackets.

Outdoor clothing is a category of textile products that has recently grown on the second-hand market. In Sweden, the resale of second-hand outdoor products has increased in both physical stores and on digital platforms. In 2017 and 2020, two new second-hand stores for outdoor products opened in Sweden [15,16], and during the same time period the Swedish second-hand digital platforms Tradera and Blocket increased their sale of second-hand outdoor products [17]. In 2022, the outdoor brand Fjällräven was the most popular clothing brand on Tradera [18] and, according to an investigation initiated by Blocket in 2022, 80% of the people questioned had purchased second-hand outdoor equipment [19]. On the second-hand digital platform Facebook Marketplace, a large amount of second-hand clothing and equipment is sold through outdoor buy and sell groups. There are Swedish Facebook groups for the resale of outdoor clothing and equipment in general, but also for equipment for specific outdoor activities such as biking, ski mountaineering, kayaking, and climbing. The largest Swedish Facebook group for the resale of outdoor clothing and equipment has about 40,000 members and the number of members is increasing continuously [20].

One textile outdoor product that is frequently sold in physical second-hand stores and on digital second-hand platforms in Sweden is the shell jacket. Shell jackets are windproof, water repellent, water penetration resistant, and breathable jackets comprising a technical textile called membrane laminate. The laminates consist of a face fabric, a membrane, and a backer for a 3-layer laminate (see Figure 1), and a face fabric and a membrane for 2- and 2.5-layer laminates. The technologies and materials used to produce the membrane laminates vary between manufacturers, but common to all shell jackets is the water repellent finish, called durable water repellent (DWR), which is applied to the face fabric. Manufacturers encourage users to wash and reapply DWR to their shell jackets regularly to optimize the performance of the membrane laminate and prolong the life of the jackets. DWR can either be sprayed onto the jacket after washing or be washed in during a second wash cycle [21,22].

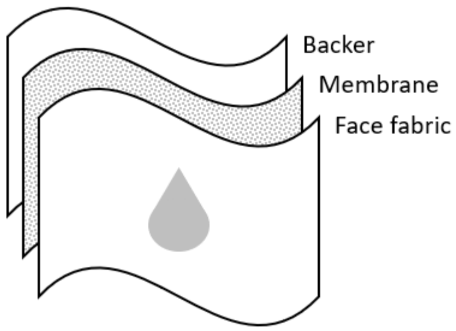

Figure 1. Membrane laminate composition.

Shell jackets and membrane laminates are exposed to several ageing factors during use, including environmental and mechanical impacts, as well as effects from contamination and maintenance. In the research field of the textile ageing of consumer products, shell jacket membrane laminates have until now only been aged and evaluated for their resistance to temperature and washing [23–25]. One focus has instead been on determining the ageing effects on the DWRs. DWRs have been aged and evaluated for their resistance to UV, temperature, humidity, abrasion, washing, and drying [26–30]. These ageing factors have been evaluated separately but also together in various combinations. In the majority of studies on both membrane laminates and DWRs, the ageing of the material has been performed in a controlled laboratory environment. Only one study of DWRs, was found where the material was aged in an uncontrolled outdoor environment [28]. To the best of our knowledge, no study, either for membrane laminates or DWRs, has evaluated used material that has potentially been exposed to multiple types of ageing factors.

The aim of this study is to evaluate the functionality of real used products over time and to evaluate whether setting prices based on visual inspection made by the second-hand stores reflects the actual condition of the jackets. This will in turn confirm whether the barrier against buying second-hand shell jackets related to product performance is justified. The result of this study not only has the potential to increase the lifespan of new textile products, but also to extend the lifespan of second-hand textile products, in particular shell jackets.

To fulfil the aim of this study, 16 second-hand jackets from three Swedish second-hand stores for outdoor products were evaluated via objective material testing. The material test results were compared with the original performance of the jackets and used to identify how functionality and price changed over time for shell jackets and membrane laminates.

2. Materials and Methods

To identify how functionality changed over time for shell jackets and membrane laminates, the jackets' specification and original and second-hand performances were identified and compared. The functionalities of interest in this study were air permeability, water repellency, water penetration resistance, and breathability. These are the four main functionalities of shell jackets that contribute to the jackets' overall performance. Air permeability describes how windproof a jacket is, which is the amount of air that can pass through a jacket under a defined period of time, while water repellency describes to which extent a jacket repels water from its outer surface. Water penetration resistance describes how much water pressure a jacket can withstand before water begins to penetrate through the membrane, and the measurement of how much perspiration a jacket allows to escape to the outside is described as the breathability of a jacket.

2.1. Test Methods

The material test methods used in this study were based on standards taken from the International Organization for Standardization (ISO), except for air permeability (see Table 1) [31–33]. The Akustron air permeability tester that was used to measure air permeability was only able to record air permeability greater than 3 mm/s [34]. The water penetration resistance test was performed in a laboratory that was conditioned according to the specifications of ISO 139 Textiles—Standard atmospheres for condition and testing [35], with parameters of 20.0 ± 2.0 °C and 65.0 ± 4.0% relative humidity. The air permeability, water repellency, and breathability tests were, on the other hand, performed in an unconditioned laboratory, which had a constant temperature of 23 °C and relative humidity of 28% during testing.

Table 1. ISO standard and equipment used for each functionality.

Functionality	ISO Number	ISO Name	Equipment
Air permeability	-	-	Akustron air permeability tester
Water repellency	ISO 4920:2012 [31]	Textile fabrics—Determination of resistance to surface wetting (spray test)	SDL Atlas M232 Spray Rating Tester
Water penetration resistance	ISO 811:2018 [32]	Textiles—Determination of resistance to water penetration—Hydrostatic pressure test	SDL Atlas M018 Hydrostatic Head Tester
Breathability	ISO 15496:2018 [33]	Textiles—Measurement of water vapor permeability of textiles for the purpose of quality control	Versaperm VPW-ISO15496 Grant GD100 water bath circulator

2.2. Second-Hand Jackets

For this study, 16 second-hand shell jackets were evaluated. The jackets were bought from three second-hand stores in Sweden which have a focus on outdoor clothing and equipment. The selection of jackets was intended to be representative of the market, with a variety of ages, prices, technologies, and materials. However, the choice was limited by the availability of jackets. The age of the jackets selected for this study varied between 1 and 19 years and the price varied between SEK 800 and SEK 2500. Overall, 13 jackets had a 3-layer membrane laminate construction, 2 jackets had a 2.5-layer membrane laminate construction, and 1 jacket was a 2-layer membrane laminate jacket. The technologies used in production and the materials of the membrane laminates varied, see Table 2.

Table 2. Jacket selection specification.

Jacket	Age (Year)	Original Price (SEK)	Second-Hand Price (SEK)	Technology	Layers	Face Fabric Material	Membrane Material	Backer Material
1	12	5800	850	Gore-Tex Pro	3	Nylon	ePTFE	Nylon
2	6	6500	2500	Gore-Tex Pro	3	Nylon	ePTFE	Nylon
3	6	5000	2250	Gore-Tex Pro	3	Nylon	ePTFE	Nylon
4	8	4736 *	1550	STORMsystem™	3	Polyester	Polyester	Polyester
5	5	3500	2000	Surpass 2.5 L Hardshell™	2.5	Polyester	Polyester	Polyester
6	13	6500	2500	Gore-Tex Pro	3	Polyamide	ePTFE	Polyamide
7	6	5000	1800	Apex 3 L Hardshell™	3	Polyester	Polyester	Polyester
8	19	4300	1800	Gore-Tex Pro	3	Polyamide	ePTFE	Polyamide
9	1	5000	2500	Gore-Tex Infinium	3	Polyester	ePTFE	Polyester
10	8	4000	1900	Gore-Tex	3	Nylon	ePTFE	Polyester
11	8.4 *	2000	800	Dry.Q™ Active	2.5	Nylon	Nylon	Nylon
12	10	3700	800	durAtec Supreme	3	Nylon/elastane	Nylon/elastane	Nylon/elastane
13	6	6800	2500	3 L Cutan	3	Polyamide	Polyamide	Polyamide
14	8	4500	900	Dermizax®NX	3	Polyamide	Polyamide	Polyester
15	8.4 *	4736 *	750	HiPe Core	2	Polyester	Polyester	-
16	10	3700	1200	durAtec Supreme	3	Nylon/elastane	Nylon/elastane	Nylon/elastane

* Assumption.

2.3. Jacket Specification and Original Performance

The jackets' specification (age, original sale price, technology, and material) and original performance (water penetration resistance and breathability) were identified through product specifications on the jackets' product tags and from the sales pages of the jackets. The manufacturers of the jackets were also contacted and provided with the part numbers of the jackets in order to obtain information. The part numbers were found on the jackets' product tags. In the cases where information could not be found, assumptions were made as follows: for jackets of unknown age and/or original price, a value was allocated based on the averages of the available information found for the other jackets. For jackets of unknown original water penetration resistance, a resistance to 20,000 mmH_2O was assumed, which represented the maximum measured value in the testing conducted in this study. For jackets of unknown original breathability, new jackets were assumed to have a breathability of 17,857 $g/m^2/24$ h based on the average of available information for the other jackets. In addition, the jackets' original performance for air permeability and water repellency were 'fully windproof' (0 mm/s) and 'fully water-repellent' (ISO 5 [31]), respectively.

2.4. Jacket Second-Hand Performance

The second-hand performance of the jackets was identified using material testing. Six test samples of 200 $\times$ 200 mm were cut from each jacket. Two test samples were cut from the hood (left and right), two from the shoulder (left and right), and two from the back (upper and lower), as shown in Figure 2. Air permeability and water repellency were tested for all six test samples. Water penetration resistance and breathability were tested for two test samples each, with water penetration resistance examined on the left shoulder and lower back and breathability investigated on the right shoulder and upper back. Water penetration resistance and breathability were not tested on the test samples taken from the hood due to the presence of seams on some of the hood test samples, which affected the test results.

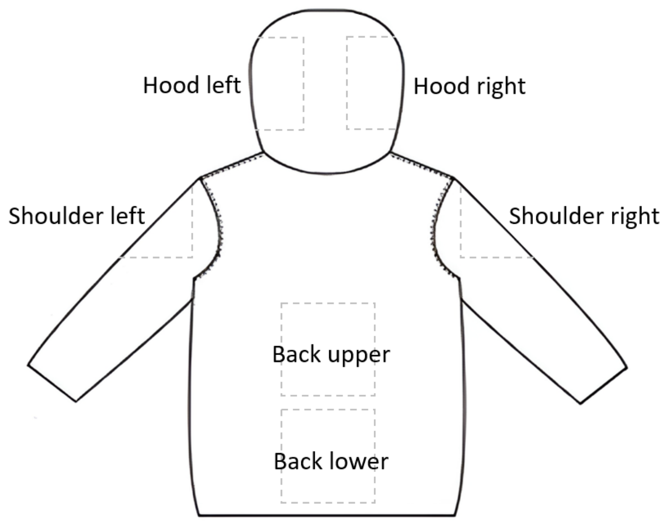

Figure 2. Jacket test sample positions.

2.5. Calculation and Visualization of the Result

The performance of the second-hand jackets was calculated and compared with the original performance. This information was then used to visualize the evolution of functionality and price over time. The second-hand performance was calculated for air permeability, water repellency, water penetration resistance, and breathability by calculating the average of the test results for each functionality. In addition, the total second-hand performance was calculated as an average based on the test results for all four functionalities combined. When calculating total functionality, the four functionalities were weighted equally. The breathability test results for jackets 2, 3, and 13 were excluded due to unreasonably high results, resulting from, e.g., damaged or broken membrane laminates. Similarly, the water penetration resistance result for jacket 12 was removed due to test failure. The second-hand and original performance were then compared to identify how much of the original functionality was left for each jacket. To visualize the evolution of functionality and price over time, data on functionality and price were combined with data on age. The plot included the averaged values of the second-hand performance and the values of the original performance (=1). The plot also included the second-hand price, normalized to the original price, and the original price (=1).

3. Results

Here, the original and second-hand performance of each shell jacket are presented together with linear representations and data points for functionality and price over time for all shell jackets.

3.1. Original and Second-Hand Performance

Table 3 presents the original and second-hand performance of each jacket for each of the four functionalities: air permeability, water repellency, water penetration resistance, and breathability. No difference is observed between the original and second-hand air permeability performance, whereas original and second-hand water repellency, water penetration resistance, and breathability performance all differ to varying extents. Less variation is seen for water repellency than for the other two functionalities.

Table 3. Original and second-hand performance.

Jacket	Air Permeability			Water Repellency			Water Penetration Resistance			Breathability		
	Original (mm/s)	Second-Hand (mm/s)	Decrease (%)	Original (ISO 5-0)	Second-Hand (ISO 5-0)	Decrease (%)	Original (mmH2O)	Second-Hand (mmH2O)	Decrease (%)	Original (g/m²/24 h)	Second-Hand (g/m²/24 h)	Decrease (%)
1	0	0	0	5	3.0	40	28,000	10,380	63	17,857 *	4943.0	72
2	0	0	0	5	2.0	60	28,000	1430	95	17,857 *	-	-
3	0	0	0	5	2.5	50	20,000	9610	52	15,000	-	-
4	0	0	0	5	2.0	60	20,000 *	8440	58	17,857 *	4422.7	75
5	0	0	0	5	4.0	20	20,000	5900	70	15,000	10,666.6	29
6	0	0	0	5	5.0	0	28,000	20,000+	-	17,857 *	12,227.5	32
7	0	0	0	5	3.0	40	20,000	20,000+	0	15,000	5983.7	60
8	0	3	0	5	1.5	70	45,000	735	98	17,857 *	10,146.2	43
9	0	0	0	5	4.5	10	28,000	12,260	56	17,857 *	8325.1	53
10	0	0	0	5	1.5	70	28,000	13,000	54	17,857 *	9105.6	49
11	0	0	0	5	5.0	0	20,000 *	3120	98	17,857 *	10,666.6	40
12	0	0	0	5	3.0	40	20,000	-	-	15,000	4682.9	69
13	0	0	0	5	2.5	50	20,000	12,000	40	20,000	-	-
14	0	0	0	5	4.0	20	20,000	15,000	25	30,000	6504.0	78
15	0	0	0	5	4.0	20	20,000 *	3940	80	17,857 *	9625.9	46
16	0	0	0	5	3.0	40	20,000	12,220	39	15,000	3902.4	74

* Assumption.

3.2. Functionality over Time

Figure 3 presents the change in functionality as a function of time (0–19 years) for each of the functionalities investigated. Air permeability remains stable over time, whereas water repellency decreases at a rate of around 2% per year. In contrast, breathability and water penetration resistance decrease more rapidly over time (about 5% per year). In total, functionality, if measured as the total aggregated value of the four measured functionalities, decreases at a rate of about 3% per year.

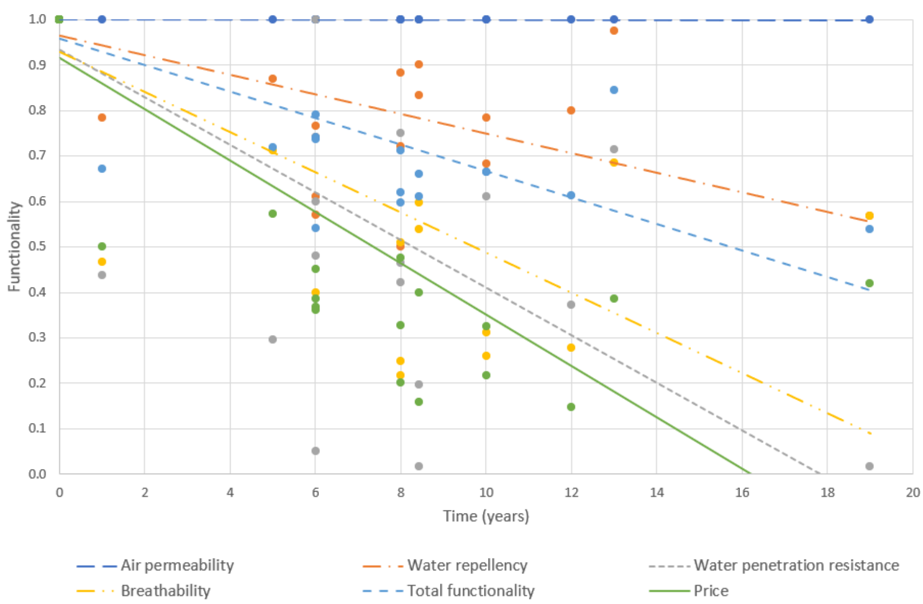

Figure 3. Functionality and price over time.

When compared to the individual tested functionalities and total combined functionality, it can be seen that the resale price drops more rapidly over time (about 6% per year). Water penetration resistance is the functionality that most closely matches the evolution in price.

4. Discussion

In this study, the total functionality of shell jackets was assumed to be a combination of four main functionalities, which were assessed for shell jackets: air permeability, water repellency, water penetration resistance, and breathability. Due to the limited sample size of jackets in this study and some missing data related to age, original price, and original performance, the results are only indicative. A linear representation was chosen to help visualize the overall trends and facilitate the comparison of the results. To assess the impact of the missing data and the use of averages, further analyses were conducted. In these, firstly, all averages were excluded and, secondly, the average for original price was removed and the average for original breathability was replaced with 15,000 $g/m^2/24$ h, which was the lowest value taken from the information found for the other jackets. The results from these additional analyses, in both cases, showed that the breathability, price, and total functionality decreased slightly more rapidly over time, but that the overall pattern remained unchanged. The overall consistency of the results, which showed that air permeability remained relatively constant and water resistance, breathability, and water penetration resistance all decreased over time, and that price decreased more rapidly over time than total functionality, was therefore seen as reliable. We predict that using a more diverse and larger sample size of jackets and more information about the jackets would strengthen the overall pattern observed, and would enable the trends regarding decreases in functionality to be defined more accurately.

The four shell jacket functionalities of this study are weighted equally in terms of total functionality. It could be argued that water penetration resistance is more important to the overall functionality than, for example, breathability, and should therefore have a higher weighting. Since water penetration resistance decreases most rapidly of the four functionalities over time, such a weighting would imply a more rapid deterioration of total functionality. It is difficult to determine how the functionalities should be weighed correctly without separate research into this. As such, in this study, equal weighting was assumed.

Air permeability remained constant over time in this study. Since the evolution of air permeability over time has not been evaluated in any previous studies of membrane laminates or DWRs, there are no existing results in the literature that could confirm this outcome. Industry measurements indicate that new shell jackets have an air permeability of about 0.02–2.5 mm/s [36]. The equipment used to measure air permeability within this study was only able to measure air permeability greater than 3 mm/s. It is therefore possible that the testing was not sensitive enough to detect any changes from the original values. Further testing with a higher precision instrument would be required to assess changes in air permeability over time in order to identify whether a larger resolution change over time is interesting from a material point of view. However, it is generally accepted that air permeability below 5 mm/s is perceived as being fully windproof [37,38] and all of the jackets fulfil this criterium.

Water repellency, water penetration resistance, and breathability were all observed to decrease over time in this study, although they did so at different rates. The decrease in water repellency was related to the decline of DWR functionality, whereas the decrease in water penetration resistance and breathability were mainly related to the performance of the membrane. DWR treatment is considered to be non-permanent and is supposed to be reapplied regularly by users during the life of the jackets. According to De Montfort University [39], 91% of shell jacket users wash their jackets one or more times per year and 55% of users apply a new DWR after every wash. This indicates that one in two users reapply DWR at least once a year. Without knowing the precise history of the jackets tested, it is impossible to know how often re-impregnation has been carried out on the jackets within the sample set of this study. It is therefore possible that the presence of re-impregnated jackets could explain why water repellency decreases less rapidly over time compared to the other two functionalities. Water penetration resistance and breathability are related to the performance of the membrane, and could, in the case of the decline in water penetration resistance, be explained by the membrane becoming more fragile as it ages, and thereby not withstanding high water pressure in the same way as a new membrane does. In the case of breathability, the decline could be explained by dirt and other contaminants clogging the small holes of the membrane that the water vapor is supposed to pass through. More in-depth analyses of the material are needed to enable us to identify the exact reasons behind the decline of the functionalities; however, this is beyond the scope of this study.

Previous studies confirmed the decline of water repellency, water penetration resistance, and breathability over time for shell jackets, but did not confirm the difference in decline between the functionalities. This is due to the fact that water repellency, water penetration resistance, and breathability have not been evaluated in a single study before. The three functionalities have been evaluated for aged membrane laminates in two previous separate studies [24,25], and aged DWRs have been evaluated for water repellency in one previous study [26]. Evaluating several functionalities in the same study, as has been performed here, provides valuable information about the difference in terms if decline between the functionalities, as well as information about the overall functionality of membrane laminates and DWRs.

No previous studies were found that evaluated actual used shell jacket membrane laminates and DWRs. The membrane laminates and DWRs that were evaluated in previous studies had only been aged in controlled laboratory environments [23–28,30], except for one study in which DWRs were partly aged in a controlled laboratory environment and partly in an uncontrolled outdoor environment [28]. In the study by Schellenberger et al. [28], DWRs were exposed to weather in combination with laboratory abrasion and washing, which does not fully correspond to the expected exposure from real use due to several reasons. The real use of jackets also includes impacts from contamination and exposure to several ageing factors simultaneously, not separately and consecutively, as occurred in the study of Schellenberger et al. Additionally, ageing in a controlled laboratory environment is accelerated and may not correspond to the ageing over time that jackets are subjected to under real-use conditions.

On the other hand, there are challenges with assessing used shell jacket membrane laminates and DWRs. The main challenge is to know which ageing factors have influenced the material during use. Even if there are some general statistics about shell jacket use [34], the exact use of the jackets in this study is unknown. It is not known how the jackets have been maintained and cared for, which ageing factors the jackets have been exposed to, or the amount or combination of exposure. To better understand which ageing factors have contributed to the results of this study, more detailed histories of the jackets, including maintenance, repair, and estimated usage, would have been of interest. The users who handed in the jackets in the second-hand stores could have been given a survey or been interviewed to collect such information. Another more demanding strategy for collecting such information would be to evaluate jackets from a user study instead of jackets from second-hand stores. In such a user study, users would be provided with new jackets and asked to log their use of them. After a certain period, the jackets would be collected and evaluated. The test results would thereafter be compared to the use information of the jackets. However, this kind of study is both resource-intensive and demanding of time, and would only be representative of the specific type of jackets selected for use in this study.

In a controlled lab environment, the ageing factors and amount of exposure are always known; however, ageing in controlled environments is limited by existing test standards and the difficulty of estimating a realistic amount of exposure [40]. The number of existing ageing standards are few and standards do not exist for all types of ageing impacts. In addition, there are only a few standards that combine different ageing impacts, and these tend to focus on only one or two potential factors. For example, ISO 6330:2012, which focuses on the impact of maintenance, only includes domestic washing and drying [41]. To make ageing in a controlled environment more realistic, new standards that combine different ageing impacts need to be developed and more user information needs to be gathered to estimate realistic amounts of exposure.

While this study focuses on physical functionality coupled with textile parameters, it is important not to underestimate the impact of other shell jacket components such as zippers (front, ventilation, outer and inner pockets), arm end hook and loop tapes, bottom and hood cords, hanger loops, and sealed seams. A broken front zipper can arguably reduce the overall functionality of a shell jacket dramatically, even if the membrane laminate still has a lot of functionality left. Test standards exist, for example, to measure the operability and strength of zippers, and hook and loop tapes [42–44]. However, more equipment and time would have been needed to perform these tests within this study, and the visual inspection of the jackets is deemed sufficient to enable a basic assessment as to whether these components are functional or not.

The result that price declines more rapidly over time compared to functionality can be explained by the fact that the price of second-hand jackets is based only on visual inspection of the jackets, which is reliant only on the aesthetic condition of the garment. Physical functionalities, which are evaluated in this study, may not be fully apparent from visual inspections, and require complex material testing in order to be assessed. This is problematic since existing standardized material test methods often require expensive and specialised equipment and are not developed to be performed outside a laboratory environment such as, for example, in a second-hand store. In addition, some of the test methods are destructive and therefore cannot be applied to jackets that are intended to be sold after being tested. More simplistic and non-destructive test methods, often used during product development and for evaluating claims, do exist within the textile industry [45–49]. However, these test methods are not standardized and often use homemade test equipment and are therefore difficult to implement on a larger scale.

There are advantages of using visual inspection for price setting. It enables, for example, the assessment of jacket components and trims such as zippers, hook and loop tapes, cords, etc. Visual inspection also includes the assessment of overall appearance, taking account of dirt and stains, and aspects such as design and colour. As price setting in second-hand stores is mainly based on visual inspection, it can be questionable to compare the physical functionality of only the jackets' membrane laminate with price, as is performed in this study. On the other hand, the difference in the decline indicates that the general appearance of second-hand shell jackets plays a large role when estimating how attractive it will be to a future consumer.

In the future, in order to better understand the relation between functionality and price of the second-hand jackets, it will be important to understand how the inspections of the jackets are conducted in the second-hand stores. There is currently no standard for comprehensive visual inspection of jackets. André and Nilsson [50] have previously tried to develop a visual inspection protocol that can compare different types of functionalities with the price of second-hand shell jackets. To further develop and refine their protocol would enable a better comparison between measured functionality, assessed functionality, and price. Then, standardizing such a protocol should lead to improved consumer confidence in second-hand product quality.

Finally, to increase the lifespan of jackets by encouraging second-hand sales, some of the barriers to consumer acceptance need to be removed, and most importantly, the gap between price and functionality needs to be closed. Several strategies could be applied to enable second-hand stores to set a price on second-hand jackets that accurately reflects the jackets' condition, and which consumers can understand and accept. One strategy could be to base the price setting on objective test results and communicate the functionality of the jackets to the consumers. However, this would require new standardized non-destructive test methods that can be used on-site in the second-hand stores and a solution for communicating functionality to the consumers, for example a performance label. Another strategy could be to reduce the influence of appearance on the price setting and the consumer attitude and behaviour by applying timeless aesthetic design and refurbishment. Timeless aesthetic design is a design approach that aims to create products that resist becoming outdated over time [51]. The design approach needs to be adopted by manufacturers at an early stage, and already be incorporated in the design phase of the jackets. Applying timeless aesthetic design removes the influence of appearance related to design, colour, etc., which increases product lifespan by reducing product obsolescence due to looking outdated. Refurbishment, on the other hand, can be carried out by second-hand stores to improve the appearance of jackets, for example by removing dirt and stains from the fabric, and to restore physical functionality, by conducting repairs and reproofing. All these strategies initially add time and costs for producers and second-hand stores, but could in the long run be feasible and profitable to circular business models if a higher price for the second-hand jackets could be charged.

5. Conclusions

This is the first study to evaluate the change in functionality over time of used shell jacket membrane laminates and DWRs, as indicated by air permeability, water repellency, water penetration resistance, and breathability. Despite some limitations in this study, mainly connected to the small sample size, the overall trends in performance can be considered reliable. The results indicate that air permeability remains relatively constant over time, while water repellency, water penetration resistance, and breathability decrease over time. Notably, water penetration resistance and breathability decrease more rapidly over time compared to water repellency. The difference in deterioration rate is thought to be explained by water repellency being related to the functionality of the DWR, which deteriorates over time but can be reapplied to restore functionality. The water penetration resistance and breathability, however, are related to the deterioration of the membrane's performance over time, which cannot be restored. Interestingly, the price of shell jackets in second-hand stores decreases more rapidly over time compared to total functionality. An interpretation of this is that the consumers of second-hand shell jackets in the second-hand stores receive more functionality than they pay for.

Author Contributions: Conceptualization, L.N., A.B., J.H.W. and M.B.; methodology, L.N.; validation, L.N. and J.H.W.; formal analysis, L.N.; investigation, L.N.; resources, L.N.; data curation, L.N.; writing—original draft preparation, L.N.; writing—review and editing, L.N., A.B., J.H.W. and M.B.; visualization, L.N.; supervision, A.B., J.H.W. and M.B.; project administration, L.N.; funding acquisition, M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Swedish Foundation for Environmental Strategic Research (Mistra).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: This research is supported by the Mistra Sport and Outdoors research and collaboration program. We are grateful to colleagues within Mistra Sport and Outdoors for valuable discussions related to the study and to the second-hand outdoor stores for their support.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Ellen McArthur Foundation. A New Textiles Economy: Redesigning Fashion's Future. 2017. Available online: https://ellenmacarthurfoundation.org/a-new-textiles-economy (accessed on 2 June 2023).
2. European Environment Agency. Textiles and the Environment in a Circular Economy, Eionet (2019/6). 2019. Available online: https://ecodesign-centres.org/wp-content/uploads/2020/03/ETC_report_textiles-and-the-enviroment-in-a-circular-economy.pdf (accessed on 13 June 2023).

3. European Commission Joint Research Centre. Environmental Improvement Potential of Textiles (IMPRO Textiles), Publications Office of the European Union JRC85895. 2014. Available online: https://publications.jrc.ec.europa.eu/repository/handle/JRC85895 (accessed on 2 June 2023).
4. European Environment Agency. Textiles and the Environment: The Role of Design in Europe's Circular Economy, European Environment Agency (01/2022). 2022. Available online: https://www.eea.europa.eu/publications/textiles-and-the-environment-the (accessed on 2 June 2023).
5. European Commission. A New Circular Economy Action Plan, European Commission (COM(2020) 98 Final). 2020. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN (accessed on 2 June 2023).
6. European Commission. EU Strategy for Sustainable and Circular Textiles, European Commission (COM(2022) 141 Final). 2022. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0141 (accessed on 2 June 2023).
7. United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development, United Nations (A/RES/70/1). 2015. Available online: https://sdgs.un.org/2030agenda (accessed on 18 February 2024).
8. Gullstrand Edbring, E.; Lehner, M.; Mont, O. Exploring consumer attitudes to alternative models of consumption: Motivations and barriers. *J. Clean. Prod.* **2016**, *123*, 5–15. [CrossRef]
9. Laitala, K.; Klepp, I.G. Motivations for and against second-hand clothing acquisition. *Cloth. Cult.* **2018**, *5*, 247–262. [CrossRef] [PubMed]
10. Ekström, K.M.; Gustafsson, E.; Hjelmgren, D.; Salomonson, N. *Mot en mer Hållbar Konsumtion: En Studie om Konsumenters Anskaffning och Avyttring av Kläder*; University of Borås: Borås, Sweden, 2012; Volume 20.
11. Guiot, D.; Roux, D. A second-hand shoppers' motivation scale: Antecedents, consequences, and implications for retailers. *J. Retail.* **2010**, *86*, 383–399. [CrossRef]
12. André, H.; Björklund, A. A framework to open the black box of the use phase in circular economy life cycle assessments: The case of shell jacket reuse. *J. Ind. Ecol.* **2023**, *27*, 1137–1150. [CrossRef]
13. Olivensjö, K.; (Re-adventure, Stockholm, Sweden). Personal communication, 19 April 2023.
14. Oxling, J.; (Tracks, Gothenburg, Sweden). Personal communication, 4 April 2023.
15. Hansson, P. Ska ge Friluftskläder en Andra Chans. Dagens Handel. 2020. Available online: https://www.dagenshandel.se/article/view/765837/ska_ge_friluftsklader_en_andra_chans (accessed on 28 June 2023).
16. Tracks Recycle. Tracks Recycle. 2023. Available online: https://www.tracksrecycle.se/ (accessed on 13 June 2023).
17. Wande, H. Het marknad–allt fler Köper Begagnat. Tidningen Näringslivet. 2021. Available online: https://www.tn.se/ekonomi/6544/het-marknad-allt-fler-koper-begagnat/ (accessed on 28 June 2023).
18. Hagelin, S. Ny rapport: Outdoormärkena Som Svenskarna Helst Shoppar Second Hand. Mynewsdesk. 2022. Available online: https://www.mynewsdesk.com/se/tradera/pressreleases/ny-rapport-outdoormaerkena-som-svenskarna-helst-shoppar-second-hand-3178221 (accessed on 28 June 2023).
19. Rosenkrantz, E. Sportlovet Kan Göra Hål i Plånboken Hos Föräldrar. Mynewdesk. 2022. Available online: https://www.mynewsdesk.com/se/blocket/pressreleases/sportlovet-kan-goera-haal-i-plaanboken-hos-foeraeldrar-3158358 (accessed on 28 June 2023).
20. Köp & Sälj Friluftsprylar. Facebook. 2023. Available online: https://www.facebook.com/groups/323126067790023 (accessed on 13 June 2023).
21. Norrøa. Product Care. 2024. Available online: https://www.norrona.com/en-GB/warranty-and-repair/product-care/ (accessed on 11 April 2024).
22. Rab. How to Wash a Waterproof Jacket. 2024. Available online: https://support-uk.rab.equipment/hc/en-us/articles/360013402518-How-to-wash-a-waterproof-jacket (accessed on 11 April 2024).
23. Gibson, P.W. Effect of temperature on water vapor transport through polymer membrane laminates. *Polym. Test.* **2000**, *19*, 673–691. [CrossRef]
24. Kowalski, M.; Salerno-Kochan, R.; Kamińska, I.; Cieślak, M. Quality and quantity assessment of the water repellent properties of functional clothing materials after washing. *Materials* **2022**, *15*, 3825. [CrossRef] [PubMed]
25. Sumin, L.; Kimura, D.; Lee, K.H.; Park, J.C.; Kim, I.S. The effect of laundering on the thermal and water transfer properties of mass-produced laminated nanofiber web for use in wear. *Text. Res. J.* **2010**, *80*, 99–105. [CrossRef]
26. Kowalski, M.; Salerno-Kochan, R. An effect of washing on durability of hydrophobic finishes of membrane laminates. *Autex Res. J.* **2018**, *18*, 137–142. [CrossRef]
27. Schellenberger, S.; Gillgard, P.; Stare, A.; Hanning, A.; Levenstam, O.; Roos, S.; Cousins, I.T. Facing the rain after the phase out: Performance evaluation of alternative fluorinated and non-fluorinated durable water repellents for outdoor fabrics. *Chemosphere* **2018**, *193*, 675–684. [CrossRef] [PubMed]
28. Schellenberger, S.; Liagkouridis, I.; Awad, R.; Khan, S.; Plassmann, M.; Peters, G.; Benskin, J.P.; Cousins, I.T. An outdoor aging study to investigate the release of per- and polyfluoroalkyl substances (PFAS) from functional textiles. *Environ. Sci. Technol.* **2022**, *56*, 3471–3479. [CrossRef] [PubMed]
29. Van der Veen, I.; Hanning, A.-C.; Stare, A.; Leonards, P.E.G.; De Boer, J.; Weiss, J.M. The effect of weathering on per- and polyfluoroalkyl substances (PFASs) from durable water repellent (DWR) clothing. *Chemosphere* **2020**, *249*, 126100. [CrossRef] [PubMed]

30. Van der Veen, I.; Schellenberger, S.; Hanning, A.-C.; Stare, A.; De Boer, J.; Weiss, J.M.; Leonards, P.E.G. Fate of per- and polyfluoroalkyl substances from durable water-repellent clothing during use. *Environ. Sci. Technol.* **2022**, *56*, 5886–5897. [CrossRef] [PubMed]
31. *ISO 4920*; Textile Fabrics—Determination of Resistance to Surface Wetting (Spray Test). ISO (International Organization for Standardization): Geneva, Switzerland, 2012.
32. *ISO 811*; Textiles—Determination of Resistance to Water Penetration—Hydrostatic Pressure Test. ISO (International Organization for Standardization): Geneva, Switzerland, 2018.
33. *ISO 15496*; Textiles—Measurement of Water Vapour Permeability of Textiles for the Purpose of Quality Control. ISO (International Organization for Standardization): Geneva, Switzerland, 2018.
34. Rycobel. Air Permeability Tester. 2023. Available online: https://www.ryco%20bel.com/products/air-permeability-tester-akustron (accessed on 21 May 2023).
35. *ISO 139*; Textiles—Standard Atmospheres for Conditioning and Testing. ISO (International Organization for Standardization): Geneva, Switzerland, 2005.
36. McAdams, B.J.; (Elkton, DE, USA). Personal communication, 1 March 2022.
37. Gore-Tex. Windstopper. 2024. Available online: https://www.goretexprofessional.com/technologies/windstopper/windproof-uniform (accessed on 11 April 2024).
38. Adventure Bagging. The Importance of Waterproof & Breathability Ratings. 2024. Available online: https://adventurebagging.co.uk/technical-clothing-metrics-ratings/ (accessed on 11 April 2024).
39. De Montfort University. Outdoor Jackets with Durable Water Repellent Finish: A Consumer & Brand Perspective on Product Features, Usability & Product Aftercare. 2015. Available online: https://global-uploads.webflow.com/5ed628f951e6c112227290bb/5f3817d134eb9e7e163788ac_DWR%20FINAL%20REPORT.pdf (accessed on 16 August 2023).
40. Fulton, M.; Rezazadeh, D.; Torvi, D. Tests for evaluating textile aging. In *Advanced Characterization and Testing of Textiles*; Dolez, P., Vermeersch, O., Izquierdo, V., Eds.; Woodhead Publishing: Sawston, UK, 2018.
41. *ISO 6330*; Textiles—Domestic Washing and Drying Procedures for Textile Testing. ISO (International Organization for Standardization): Geneva, Switzerland, 2021.
42. *ASTM D2062-03*; Standard Test Methods for Operability of Zippers. ASTM International: West Conshohocken, PA, USA, 2021.
43. *ASTM D5170-98*; Standard Test Methods for Peel Strength ("T" Method) of Hook and Loop Touch Fasteners. ASTM International: West Conshohocken, PA, USA, 2021.
44. *ASTM D5169-98*; Standard Test Methods for Shear Strength (Dynamic Method) of Hook and Loop Touch Fasteners. ASTM International: West Conshohocken, PA, USA, 2021.
45. Cech, P.; (Elevenate, Åre, Sweden). Personal communication, 6 April 2023.
46. Gunnarsdotter, J.; (Rock Group Sweden, Luleå, Sweden). Personal communication, 5 April 2023.
47. Lidbom, Å.; (Haglöfs, Stockholm, Sweden). Personal communication, 27 April 2023.
48. McPherson, N.; (Klättermusen, Åre, Sweden). Personal communication, 4 April 2023.
49. Tiffin, L.; (Brav Norway AS, Lørenskog, Norway). Personal communication, 28 April 2023.
50. André, H.; Nilsson, L. Are secondhand shell jackets better than users think? A comparison between perceived, assessed and measured functionality throughout lifespan. *Resour. Conserv. Recycl.* **2024**, *204*, 107470. [CrossRef]
51. Lobos, A. Timelessness in sustainable product design. In *The Colors of Care, Proceedings of the 9th International Conference of Design & Emotion, Bogota, Colombia, 6–10 October 2014*; Universidad de los Andes: Bogota, Colombia, 2014.