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Consumers' Perceptions and Attitudes toward Products Preventing Microfiber Pollution in Aquatic Environments as a Result of the Domestic Washing of Synthetic Clothes

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Abstract: Microfibers released by synthetic clothes have a significant negative effect on the environment. Several solutions have been proposed and evaluated for their effectiveness, but studies have failed to address the human-centered aspects of these products. In this research, the possibilities and needs from a consumer perspective for a new filtering system for domestic washing machines were examined. First, a quantitative (questionnaire) and a qualitative (interviews and observations) exploration were done to understand the desired requirements from a user perspective. Next, the acceptance of various existing solutions for microfiber catching was investigated. To verify these requirements, a new concept was designed and evaluated with a questionnaire. The results were analyzed using descriptive statistics. It can be concluded that the problem of microfibers is not well known, and the impact of people's washing behavior is underestimated. Since microfibers are almost invisible, the effectiveness needed to be proven. Effectiveness is seen as the most important characteristic of a product that captures microfibers, followed by durability. Both factors ensure long-term usage. However, changing washing habits is not evident, and usage should be straightforward and user-friendly to save time, especially considering the new cleaning actions, which should be clear and unambiguous.

Keywords: microfibers; plastic pollution; laundry and maintenance; awareness; microfiber filter; consumer perception

1. Introduction

Plastics are the primary source of litter found in oceans and inland waters [1]. Besides large plastic items that mostly float on the surface, microscopic plastic particles (<5 mm in their largest dimension) cause considerable environmental problems to the oceans [2]. One specific type of microplastics are microfibers released from the washing of synthetic fabrics [3], which are nonrenewable and nonbiodegradable and take up more than 60% of global fiber consumption [4,5]. In this paper, "microfibers" are fibers from a synthetic source. Currently, most wastewater treatment plants are not equipped with tertiary treatment and filter out only around 50% of microfibers [6]. Even the most advanced wastewater treatment plants are not able to capture all the microfibers [7,8]. Consequently, significant amounts of microfibers end up in the oceans [2]. In this research, the possibilities and

needs for a filtering device for domestic washing machines aiming to prevent microfibers released by synthetic clothes from reaching the environment are examined.

1.1. Microfibers

The most common synthetic microfiber materials are polyamide 6, polyethylene terephthalate (polyester), and polypropylene [4,9]. Polyester is the dominant microfiber pollutant, with an annual production of 70 million tons in 2018 [4]. The main sources of microfiber pollution are domestic laundry, the textile industry, landfills, domestic drainages, and dumping of synthetic clothes in rivers or oceans [4]. This research is focused on household laundry. It is known that polyester, polyamide, and acrylic garments release the most microfibers. [10] In a typical washing load, the number of released fibers can vary greatly, depending on the content of the load [8,11]. Fleece fabrics (also polyester) release up to two million fibers [8]. Although synthetic–natural blends might release fewer fibers than pure polyester [12], due to their combined properties [11], mixing materials is not desirable for future recycling possibilities [13]. The known textile parameters influencing microfiber shedding are fiber type (diameter, length, tensile strength), yarn type (spinning type, yarn structure), fabric type (composition, structure, weight) and the chemical or mechanical finishing [5,8]. The construction quality of the garments is an additional important factor, having fewer fibers released when the quality is higher [5,14,15]. Although natural materials (such as cotton) and artificial materials from a natural source (e.g., viscose) degrade in natural water and are not as harmful as synthetics, they can contain toxic additives and dyes that may be harmful to the environment [5,14,16]. Since cotton and other non-synthetic fibers often release even more fibers than synthetics during a typical washing cycle [10,16], it is interesting to also consider capturing other types of fibers.

1.2. Tackling Microfiber Pollution

Removing the fibers from contaminated sources is a very expensive and difficult task [4], thus tackling this problem at the source is desirable. Microfiber pollution can be stopped at multiple levels: the production of textiles, the fabrication, usage, and washing of synthetic garments, and wastewater treatment plants among others [4]. The most advanced wastewater treatment plants (WWTPs) stop more or less 90% of the microplastics [7,8,11], although none of the WWTPs that exist now are specifically designed to capture microplastics [16]. On top of that, most WWTPs are not equipped with a tertiary treatment, which means they stop only around 50% of all passing microfibers [6]. At the moment, the WWTP in Flanders, which is taken as our field of investigation, is not adjusted to the removal of microplastics from wastewater [17]. In developing countries, with less infrastructure, it is common that wastewater is not collected and treated [18]. Even if the WWTP were completely effective in removing all microfibers from the wastewater, the extracted microplastics often still enter the environment through the sludge being employed as soil fertilizer [5,11,19,20]. Concentrations of microplastics in the seabed where sewage sludge was dumped until 1998 in the UK were three times higher than at other reference sites [3]. In conclusion, this means that WWTPs, as well as untreated sewage, septic tanks, or greywater, can be side-pathways into the environment for microfibers [7,21]. On the European scale, the influence of industrial laundry is smaller than the sum of laundry done in all households [8]. Thus, we made the choice to focus on intervening at the level of domestic washing. Furthermore, this solution can increase the microplastic issue awareness among consumers, in contrast with solutions focusing on industrial laundry or wastewater treatment plants.

1.3. Influence of Household Laundry

Washing machine conditions have a considerable influence on the number of fibers released. Synthetic fabrics become soiled faster, and are therefore washed more frequently [22]. The mass of recovered fibers is significantly greater for top-loader than front-loader machines. While top-loader machines are most common in North America, the front loader machine is dominant in Europe [21], where 87% of European citizens own a washing machine and 3% go to a laundromat. In developing

countries, such as Brazil, China, and India, over 30% of residents use hand washing. However, a growth of washing machine usage is predicted in the near future [23].

During domestic washing, both mechanical and chemical factors can influence fiber shedding: mechanical influential factors are temperature, cycle, axis direction, rotations per minute, the quantity of water, and capacity of the machine. Chemical influencers are the type and quantity of detergent, the use of fabric softener, and the presence of other products [5,8,24]. Most fibers are released during the first washing of the garment. After that, the fiber shedding decreases and stabilizes [8,11,14,25]. When the piece starts to wear down, the fiber release will start increasing again [15,21].

1.4. Outline

The research aims to investigate the possibilities and needs from a consumer perspective of a filtering device for domestic washing machines. This paper reports upon the criteria for the adoption and acceptance by potential consumers of a new design concept for catching microfibers in a domestic context. Both qualitative and quantitative research was done to understand the critical aspects of the design and the attitude of people toward the idea of the product, as well as the evaluation of existing products. Evaluating these products from a consumer and behavioral perspective is important to explore the likelihood of adoption, thus the potential success of the proposed solutions [26]. In summary, the questions that we aim to answer are: How aware are people of the microfiber problem? What action do people already take? How do people critique existing solutions? What do people consider the most relevant properties concerning a new design? What variables can convince people to buy a product? We initiated a Design Inclusive Research process in order to translate the resulting insights into a new design and test this concept against the nuances of our understandings. The goal of including design into the research process is to create new opportunities for generating knowledge [27]. Design Inclusive Research combines analytic research methods with synthetic/constructive design methods. Consequently, the research approach is composed of three phases as visualized in Figure 1: (i) explorative research actions (analysis), (ii) creative design actions (synthesis), and (iii) evaluative research actions (evaluation).

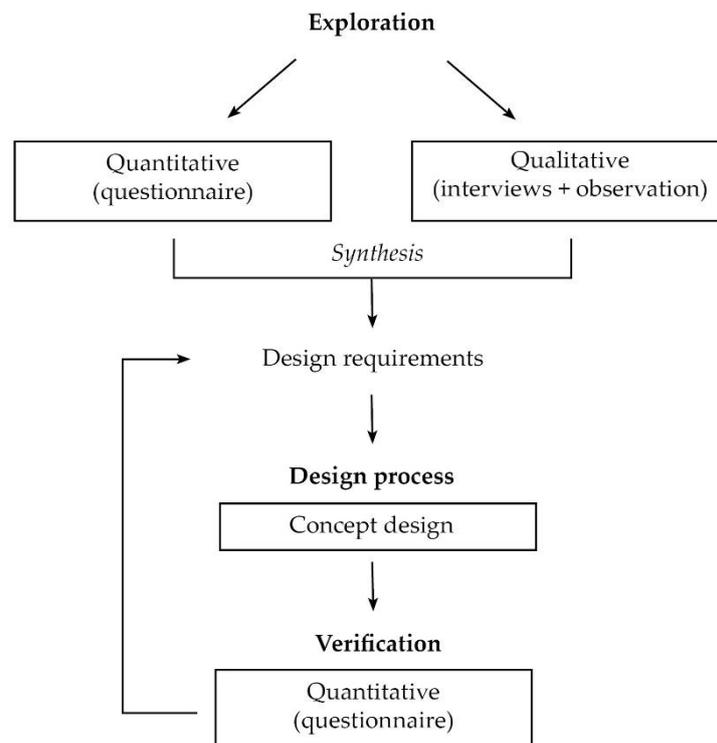


Figure 1. Outline of the research approach.

This research was part of a larger project in which, in addition to this behavior study, research was done to investigate the technical possibilities to catch microfibers when washing clothes. Both research actions happened simultaneously and supported the final design of the new concept.

2. Materials and Methods

2.1. Explorative Research Approach

The executed research is twofold. First, a quantitative study was executed. Next, an in-depth qualitative study was done to understand the reasonings and details behind the findings of the first study.

2.1.1. Quantitative Study with Survey

A structured survey was done using the Qualtrics platform (Utah, USA). In total, we received 434 answers, of which 411 were valid. Invitations to participate to the survey were sent out in Flanders (Belgium) by email or social media with a link to the questionnaire. The sampled population consists of Flemish respondents of all ages. The survey was deliberately not distributed among product developers nor design engineering practitioners and students since they could influence the validity of the sample, as it is assumed that designers have a different view and approach toward product semantics [28]. Snowball sampling [29] was used to recruit a large number of participants at low cost. In order to reach a broad range of socio-economic groups, people of different education and income classes were asked to distribute the survey further among their acquaintances. However, we are aware of the fact that, when using this technique sample, representativeness is not ensured and should be discussed further to define what level of generalization can be done to which population with any level of confidence [30].

Within the respondents, 69% was female and 31% male; 87% of the female respondents do laundry, while among the men, only 55% do their own laundry. This variation is comparable to existing data on washing behavior as reported by Nielsen (2016) [23]. Between age 26 and 40, 98% of women and 86% of men do their laundry themselves, while within the age group of 41–60 years old, 60% of men and 99% of women do their own laundry.

The survey was divided into two main sections. In the first section, the aim was to get insights in consumer awareness on the problem of microfiber pollution and the impact of their washing habits. At first, general demographic multiple-choice questions were asked—i.e., age and gender—to monitor equal distribution. Next, several questions were asked about laundry habits and ecological behavior regarding the washing of clothes—for example, about washing temperatures and the frequency people run their washing machine on a non-full load. Furthermore, the knowledge and awareness of participants about the plastic soup and microfiber pollution were investigated, asking how important they considered these problems. In previous studies, it is shown that better knowledge of environmental issues can, although in a limited way, influence people's ecological buying behavior [31–33]. Consequently, we were interested in discovering how these understandings would influence people's washing behavior.

In the second section, the aim was to investigate the critical aspects for fiber capturing products to change the attitude of people. Therefore, the participants were asked to give their thoughts on existing solutions for microfiber pollution from domestic laundry. The questions were mostly multiple choice (single answer or multiple answer), with two Likert scales and one rank order. Based on these questions, the aim was to consider from a designerly perspective what the most ideal (i.e., user friendly and effective) solutions are for catching microfibers in domestic washing.

2.1.2. Products Included in This Research

Several novel solutions for filtering out microplastics in domestic washing machines have been developed in the last few years. Three varying products that were on the market during the time of

this research were used in the last section of the survey: Cora Ball [34], Guppyfriend [35], and Filtrol 160 [36]. Besides this, more products that tackle this problem already existed but were not on the market yet and thus not included in the research. Examples are XFiltra [37], PlanetCare [38], and FiberFree [39].

- The Cora Ball (Vermont, USA) is inspired by the ability of corals to capture tiny particles from the water. It is placed in the washing machine tub with the clothes, where it captures released fibers. After washing, the fibers must be removed from the Cora Ball by hand. The product costs 29.99 euros, and independent research concluded it captures on average 26% of microfibers [26].
- The Guppyfriend (Germany) is a laundry bag in which the synthetic clothes are put during washing. A fine polyamide mesh captures the fibers. The fibers must be removed by hand after every wash cycle. The product costs around 30 euros.
- The Filtrol 160 (Maine, USA) is an external filter located at the drain of the washing machine. Every 8 to 15 washing cycles the filter bag must be cleaned by turning the bag upside down, after the residue has had time to dry first. The manual suggests emptying the bag outside, thus spreading the microplastics into the environment. The bag will last 1–2 years. The complete product with one filter bag costs 120 euros and is only available in the United States of America. The main purpose of the Filtrol 160 is protecting the septic tank: capturing microfibers is an extra feature.

Since the Filtrol 160 was only available in the United States of America and the Cora Ball had a production delay at the time, only the Guppyfriend was included in the qualitative research part.

2.1.3. Qualitative Observation and In-Depth Interview

In the second phase of the research, qualitative research was done in order to get more in-depth answers to the following questions: (R1) Who is aware of the microfiber problem and to what extent? (R2) What is the difference in the perception of people who already act sustainably in their daily lives versus people who do not? (R3) What are the reasons to (not) be willing to use a product that tackles microfiber pollution? (R4) What are the main problems with the Guppyfriend (a washing bag for synthetic clothes) regarding user experience, effectiveness, price-quality, and time consumption? (R5) What are the relevant properties the new product should have and is the most effective way to convince people to use the new product? A semi-structured interview was constructed to ask people about their awareness of the problem, their knowledge of the Guppyfriend and whether they considered it a good solution. It consisted of a fixed order of (open) questions, so the interviewees could make suggestions and comments, or explain themselves further. The test subjects were asked to test the Guppyfriend in a real-life situation with their own standard washing load and to fill in a task sheet; in the meantime, they were observed, and comments were noted. After the test was finished, they were interviewed further to evaluate their experience with the Guppyfriend. The testing experience ended with general questions about what they would expect from the new product and how they could be convinced to buy it.

In total, eight observations plus interviews were done, with a gender distribution of five women and three men and an age variation of 18–25 (2), 25–60 (3), 60+ (3). Before use, five out of eight people were not aware of the microfiber problem, which is comparable with the results of the quantitative survey. None of the respondents had ever heard of the Guppyfriend or knew its function. Most of them thought it was a washing bag for delicate clothes. This increases the validity of the observations and interviews as people had no previous experience.

The “grounded theory” [40] was applied to analyze the results; in this way, results could be analyzed in a reliable way. The answers were coded and put into categories. This process consists of three phases—open coding, axial coding, and selective coding. Atlas was used to create the codes. The structured questions (mostly using the Likert scale) were analyzed semi-quantitatively.

Before usage, questions were asked regarding the problem of microfiber pollution and its urgency as well as about the test subjects’ first impression of the effectivity of the product and the manner of

cleaning. During product use, participants were asked to fill in a task sheet to allow post evaluation. Questions included the clearness of the manual, the amount and type of clothes that were used for the experiment, whether the clothes fitted within the Guppyfriend bag, and what type of washing detergent was used (liquid, powder, etc.). After usage, questions were asked about the cleanness and smell of the clothes, the actual cleaning of the product, and the overall evaluation of the complete user journey.

2.2. Design and Synthesis

Based on the findings of the explorative phase, a list of requirements was put together as a basis for the design of a new concept. The purpose of the design was to verify the conclusions of the exploration as a whole and explore new possibilities to learn. Moreover, in this design-inclusive research project, the design activities were also used as reflective practice to reason upon the conclusions of the exploration.

2.3. Evaluation

The developed concept was used in a final evaluative survey and distributed among a wide range of people. The survey was distributed in three languages: Dutch, English, and French. The aim of the survey was to identify what people think of the new product concept. What is the degree of acceptance? Who would buy the product at the predetermined price? What payment formula is the most desirable? Price was used as a variable to get insights into people's willingness, as it was mentioned as a crucial factor during the exploration. A structured interview was made in Qualtrics. The survey was distributed online and received 227 valid answers. The questions were mostly multiple choice (single) and two sliders. The sample consists of Belgian and international respondents of all ages. The first blocks asked for demographic data and the eco-friendly behavior level of the respondents. Next, the product was presented and finally, the respondents were asked whether they would buy it or not.

3. Results

3.1. Explorative Quantitative Study

3.1.1. Consumer Awareness Regarding Microfiber Pollution and the Impact of Their Washing Habits

Concerning the respondents' washing behavior, most people (55,4%) wash mostly at 40 °C; 37% wash at 30 °C; and 7% at 60 °C. Only 0.6 % wash regularly at 90 °C, and 57% of respondents always wash a full machine. Regarding the awareness of the plastic soup and microfiber pollution issues, 62% of people over 60 years old are not aware, while 73% of respondents aged between 25 and 40 are aware. This means people over 60 are the least aware compared to other age groups, and people between 25 and 40 are most aware. This is in line with other studies [41]. In total, 68% of the respondents know of the plastic soup problem. In contrast, only 37% know about the existence of microfibers, and its relation to the problem. Respondents under the age of 25 are the least aware of the synthetic fiber problem (29%). People age 41–60 and above 60 are most informed about the problem, but still, less than half of the respondents in those age categories know that synthetic fibers can cause a problem (43%).

3.1.2. Evaluation of Existing Products

Based on the participants' evaluation of the existing products, we found that the most relevant indicated property is effectiveness (1). Durability (2) comes in second place. Usability (3) and price (4) are considered more important than extra time (5) spent. Based on this list, we could conclude that time is considered less relevant compared to the other aspects. Yet, it is important to note that 75% of respondents also indicated that they do not want to spend more than five minutes extra on the product per washing cycle. Appearance (6) is the least important for the majority (78%). Besides, it is interesting to see that, in another question price (48%), usability (18%) and convenience (13%)

are considered the most important factors to decide on buying or not buying a microfiber filtering product. This suggests price is more important to respondents during the purchase decision, whereas effectiveness, durability, and usability are more important during usage. Detailing the durability of the product, almost unanimously, 91% of the respondents want a reusable solution.

Awareness creation and supporting people's sustainable behavior is considered as an important (side)function of these types of products. This was confirmed in the study, as on average, people consider it as important (4/5) to see or know the impact they have on the environment by using the solution. On the other hand, there seemed to be less need to share the environmental impact of the filter with other people (only 1/5 score by most people). In contrast to our expectations, there is no significant difference between the different age categories.

Regarding the physical installation of their washing machine, the drain of the washing machine is easily accessible for 77% of the respondents, which means that 23% (almost a quarter) cannot reach the drain on a frequent basis or after complete installation. Consequently, for those people, the solution offered by removable cartridges mounted at the drain, such as the Filtrol 160, is not applicable.

Considering the economic motivator or demotivator of cost, 42% of the respondents are willing to pay 20 to 50 euros for a solution that lasts 3–5 years. 23% does not want to spend more than 20 euros and only 12% would pay more than 100 euros. A financial advantage when purchasing the product is mostly chosen by people that are willing to pay 20–50 euros and less than 20 euros. Since they do not want to pay too much for the solution, they welcome a financial advantage.

To conclude, 68% of the respondents that do not want to pay more than 20 euro on a solution chose the Cora Ball, because of the low price and its convenience. 23% chose the Filtrol 160, which is a lot more expensive than the Cora ball but gives a more effective and durable impression, confirming the importance of effectivity as stated earlier. Of the respondents that are willing to pay more than 100 euros, 69% chose the Filtrol 160, which is the most expensive solution, although 26% would choose the Cora ball and only 5% the Guppyfriend. Overall, the Guppyfriend is the least favorite solution (16% in total), and the Cora Ball the most popular (49%). From these results, it can be stated that the Filtrol 160 is considered the most effective and durable, but a lot of people are held back by the high price and lack of user-friendliness. The Cora Ball is the most user-friendly and convenient, but people are skeptical about the effectiveness. Next to the functionality and requirements regarding the product itself, external measurements that could persuade people to adopt the product are examined. From an economic perspective, we found that when asked for a desirable reward for their ecological behavior, 49% of the respondents choose a financial advantage when purchasing the product (for example a reduction in price). After that follows a donation to an environmental NGO (23%) and receiving a free product when purchasing the solution (16%). A financial advantage when collecting microfibers (9%) and a voucher (3%) are less popular options.

3.2. Explorative Qualitative Study

Based on the qualitative research, the following results came out. When asked on what would be the best way to make people use the product, seven out of eight responded said it is most important to make people aware of the problem, thus focusing on expanding knowledge and literacy.

During use, most people use fluid detergent (6/8), 3/8 use powder, and 2/8 use capsules. Only one person reported her clothes were less clean in the Guppyfriend, and they all stated their clothes smelled the same as the clothes washed without the Guppyfriend. For half of the respondents, all their synthetic clothes from the washing load fit into the Guppyfriend. The other half had to leave some clothes out of the bag. Four people reported the Guppyfriend was too small to fit all their synthetic clothes. Some suggested making a filter(bag) that includes all of the clothes, for example around the drum. Someone else said the Guppyfriend should be a lot bigger because otherwise they would have to wash their synthetic clothes in a half-empty machine.

Most people were positive about the manual (average of 8/10 considered the manual clear). However, some reported ambiguity with the number of clothes that can fit in the Guppyfriend. The

manual says at one point “3 medium size clothes” and at another point “maximum half full,” which does not always mean the same. Furthermore, it was not always clear what materials should be put inside the Guppyfriend, as it was mentioned that only synthetics should be included. However, not everyone knows which materials are synthetic. Although everyone knew cotton is a natural material, there was some confusion about viscose and cellulose, which are artificial but not synthetic materials. Two people reported they cut out the labels after buying the pieces, so they could not know which clothes to put inside the Guppyfriend. Evaluation of the manual is important to get an idea of how intuitive the product is and how much information should be provided.

Furthermore, respondents were asked how they would intuitively clean the Guppyfriend. Several people (3) answered ‘rinsing under the tap’, which would cause a counterproductive effect. However, after a first thought, they quickly reconsidered and answered they would turn the Guppyfriend inside out to take out the fibers and put them in the bin (residual waste). Two people had questions about the destination of the fibers: “Are they burned? Where do I put them? Recyclable waste, residual waste, or perhaps hazardous waste?” One person asked whether the fibers are recycled and how that could be possible.

When cleaning the Guppyfriend, two people could not find any fibers at all. Five people reported the fibers were too small and not visible enough. Mostly the older interviewees could not see the fibers well. One of them used a magnifying glass. Because of the size of the fibers, the results did not look very spectacular. This demotivated several people. They stated one really has to believe in the impact. Not everyone reacted the same way: one person stated he would not use the Guppyfriend since it does not seem to capture any fibers. However, another one said although they could not see many fibers in the bag, they believed in the impact and would continue using it.

Six out of eight respondents found the cleaning of the Guppyfriend difficult and annoying. The two remaining respondents did not find any fibers. The main reasons for complaints were the small fiber size, the diffusion of the fibers over the whole bag and the disposal of the fibers. A lot of fibers were thrown on the ground or fell on the ground by accident as it was not clear where the fibers were after washing. Some people collected the fibers on a piece of paper, after which they threw the whole package in residual waste. Someone suggested using disposable filters.

Seven out of eight respondents stated they would “sometimes” use the Guppyfriend in the future. Two said they might forget to use it after a while. The overall score given to the usability of the Guppyfriend was 5/10. Seven out of eight respondents thought informing people and making them aware of the negative effects of microplastic fiber pollution was the most important aspect to motivate people. Six respondents wanted to see their impact on the environment.

The order of relevant properties was almost the same as at the survey. Only usability and durability were interchanged. Providing proof of the effectiveness of the solution remains a key factor in convincing people to buy our product. It was mentioned by all eight respondents.

At last, all respondents stated they would prefer a different solution: either a product that filters all the wastewater (2/8), such as the Filtrol 160, or a device built into the machine (6/8). One person suggested shifting from consumer to industrial laundry, but, as previously mentioned, in the literature, it is found that the impact of all household laundry is bigger than that of industrial laundry.

3.3. Preliminary Conclusion Based on the Exploration

Based on the explorative research actions, it can be concluded that

- Besides providing a product, also information should be given. People need to be made aware of the problem and expand their knowledge.
- The most important property is visible effectiveness and proof that the solution works. Therefore, the visibility of the fibers and/or the contact of the users with the fibers seemed to be given as crucial arguments.
- Usability is the second most important factor, with a specific focus on convenience—(i) people should be able to wash all their clothes with the product, so they do not need to think about the

textile material; (ii) people do not easily change their washing behavior; as such, if the effort would be too large, they would probably abandon the product and revert to their old washing routine.

- As the cleaning process is a new step in their washing habits, this phase should be easy and clear. People should not be able to do it the wrong way - as their first reaction is often to rinse it under the tap, which will allow the fibers to enter the wastewater again. Next, the process of cleaning should not require too much time or should not be necessary every time.
- Many respondents also want to know where the fibers will go after disposal, showing that the impact on the environment is very valuable, as can be concluded from the survey.

3.4. Synthesis and Design of the Product Concept

3.4.1. User-Related Design Requirements

The following user-related requirements are extrapolated from the results of the explorative research:

- The operating and cleaning processes should be short and unambiguous;
- The product or marketing of the product should raise awareness of the problem;
- The product should be accessible from the front of the machine;
- The impact should be visible for the user(s), to keep them motivated;
- The scientifically proven effectiveness should be communicated objectively;
- The product should be durable and last for several years;
- The cleaning process should not rely on the visibility of the fibers;
- The location of the fibers should be clear to support optimal cleaning;
- Synthetic materials should not have to be selected or separated first;
- The product should be perceived as sustainable by itself (energy consumption, ...);
- The product should allow a full load to be washed.

3.4.2. Concept Design

The following product Fibio is an external filtering device that captures fibers that are shed by the domestic washing of synthetic clothes. It is placed on top of a front loader washing machine and connected directly to the drain of the washing machine (Figure 2). It fits the top surface of the washing machine (60 x 60 cm) and is 15 cm high. It needs no electricity and works purely mechanically. Other products can still be placed on top and it also serves as a stacking kit to put a dryer on top. The product consists of three filters, that can be removed as drawers. During simultaneous research, the principle of the concept employing three filters (of different mesh sizes) showed a 97% efficiency in preventing the microfibers reaching the wastewater [42]. When the dot (right of the front panel, see Figure 3) is red, the filter is clogged. By pushing the drawer, it opens, and the filter can be cleaned with a vacuum cleaner or a scraper. Since the fibers need to be dry, the user has to wait a couple of hours (approximately half a day).



Figure 2. Fibio product integrated in the washing environment.



Figure 3. Fibio filtering product, showing a clogged filter.

3.5. Evaluation of the Concept

When asked, almost all participants were interested in a product that tackles microplastic fiber pollution from domestic washing machines: in fact, 96% of respondents answered 'yes'. The purpose and working principles were both clear to 98% of respondents. 95% would use the product if they got it for free. The two participants who were willing to use a microfiber filter, but do not want to use this one, indicated that their washing machine is currently completely built-in, so they do not have any place to put the filter on top of their machine.

On average people estimate the product costs 157 euro, whereas the estimated selling prices was calculated to be at least 185 euros. However, 47% of respondents stated they would buy the product for 185 euro. It should be noticed that the largest group of people who would buy the product are people with a master's degree (55%). This is not unexpected since often people with a higher degree have a higher-paid job and thus more financial resources. When looking at the working situation, the majority of self-employed people would buy the product (68%). The explanation for this is similar to the one previously stated. However, this is still a very positive result, since it was predicted the price could pose an issue. No less than 90% would use the product for 20 euro a year. From this, it can be deduced that a rental system, where people rent the product for a certain amount per year, could be a good alternative to just selling the product to customers.

When looking at the people that already live and behave sustainably (have a green energy supplier, use reusable bottles, buy expensive but ecological clothes, etc.), it can be seen that, as expected, mainly, people who already act toward ecological living and sustainability are interested in the product. They would be the early adopters. This intention is most significant for people who pay attention to the origin and material of clothes; 61% of this group would buy the product.

No correlation is found between the number of people in one household or the presence of children, and the willingness to clean the filters. The filter needs to be cleaned every 15–17 washing cycles and takes 10 minutes. The absolute majority of respondents would not mind cleaning the filters with this frequency (95%).

4. Discussion

More demographic questions should have been asked to get more data out of the study, especially the first explorative questionnaire. Furthermore, the participants were selected by snowball sampling, which allows little control on the distribution of the participants.

Regarding the topic of the questionnaire (ecological knowledge and behavior), the answers could be influenced by the participants tending to give the desired answers instead of the reality. Their knowledge is expanded while doing the questionnaire, which influences the answers later. The study lets participants report their intention to buy or use certain products, which does not say anything about actual behavior.

According to the results, more women wash than men, but studies reveal the share of men is increasing [23]. This is due to the higher rate of divorces resulting in a higher amount of men living alone and having to do their laundry [23]. Although most people wash at 40 °C, the number of people that wash at 30 °C is increasing compared to some years ago [23]. There is not enough correlation to state that people who wash at 30 °C are more ecologically minded than people that do not. There are many other potential reasons for this behavior. Here, 57% of respondents always wash a full machine. This number is also increasing due to rising awareness of the importance of sustainability [43]). This means a transition is happening towards more environmentally friendly behavior. Respondents gave contradictory answers regarding the extra time they are willing to spend on using a product that captures microfibers. They agree that using a solution is important, and one should be willing to sacrifice time, but when they are concretely confronted with the actual time, they will have to spend each day, they are less enthusiastic. It is important to take into account that there is a difference in what people say and what they actually do, which is called the attitude-behavior gap [44]. In this research, only people's intention to take action is examined.

Only three products were included in the research, although more solutions exist. The alternatives were not on the market while doing this research (November 2017), but should be included in a larger comparison in the future. The survey results were very descriptive. In further studies, it would be interesting to find stronger correlations between different survey results. The respondents in the quantitative surveys could only give their opinion on the products through pictures, not while using it.

5. Conclusions

Microscopic plastic particles released by synthetic clothes (microfibers) cause considerable environmental problems to the oceans and inland waters. In this research, consumer laundry behavior and knowledge of the problem, supplemented by the possibilities and needs for a filtering device for domestic washing machines that aims to prevent microfibers released by synthetic clothes from reaching the environment, were examined.

Based on a survey with 411 respondents, user observation with eight test subjects, and evaluation of a new design concept by means of a survey with 227 respondents, the following propositions could be constructed:

Proposition 1: In contrast to the fact that the problem of the plastic soup and microplastics is relatively well known, the problem of microfibers is not. Hence, the impact of people's washing behavior is also underestimated/not recognized.

Proposition 2: Effectiveness is seen as the most important characteristic for products that support consumers in their washing habits to catch microfibers. This effectiveness should be not only be scientifically proven, but also visual/experienced by the users to see and recognize their reduced effect

on the environment. Respondents argued that this feedback probably offers the largest opportunity for long term usage.

Proposition 3: Next to effectiveness, durability is considered a very important factor that determines the willingness to adopt a product that tackles the microfiber problem. This is a logical addition to the effectiveness characteristic. Both factors ensure long term usage.

Proposition 4: In order to spend the least amount of time on operating the product, thus encouraging consumers to keep on using the product for a long time, the usage should be straightforward and user friendly. Next to the technical side, the human-centered side is important to consider.

Proposition 5: Cost is seen as a less important factor, but nonetheless something to carefully consider. To distribute the product widely, which is necessary to tackle the plastic fiber issue, people from all socio-economic classes should be able to purchase the product.

Proposition 6: As cleaning is an important and new action in the washing habit, it should be fast, easy and foolproof (i.e., avoid possibility to clean by rinsing for example). The suggested amount of cleaning every 15–17 washing cycles, duration of cleaning: 10 minutes, was considered as achievable.

Current research is limited by the fact that none of the products are used over a longer period of time, whereas this would be essential for microfiber catching. Future research is needed to effectively experience long term behavior change and usage, and to investigate the possibilities to recycle the collected fibers. Many respondents also want to know where the fibers will go after disposing and how they should be disposed optimally. This circular thinking could encourage people better to optimally use a washing machine filter. Additional research can be done to investigate the possibilities to close the loop for the collected fibers.

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