Technology-related Challenges in Smart Clothing – Viewpoints from Ideation Workshops

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***Abstract*— Smart clothing is a booming, growing technology and business branch of wearables. Its users range from sports and entertainment customers to military, and new applications can be found, especially in the care sector, for example, in gamification for health and well-being. We organized 5 ideation workshops to gather ideas about the potential users and uses of smart clothing. The participants brought up several types of technology-related challenges during the workshops. This article introduces these challenges. The results were analyzed using inductive qualitative content analysis. Based on the gathered data, the main challenge groups were found to be ethical concerns, operating features and the technology's reliability, and, for example, the lack of a need-based and user-oriented design process.**

Keywords*— *ideation workshop, smart clothing, technology related challenges, wearable technology

I. Introduction

Wearable electronics have been studied for decades [1][2]. The development of wearable applications has been rapid in recent years and is expected to explode in the near future [3]. Wearable technology was first used, for example, to track physical exercise activity, but now researchers are also interested in applying it to challenges in other fields, e.g., in healthcare, such as the management of diabetes or remote monitoring of the elderly [4]. Thus, wearable technology can revolutionize patient diagnosis, care and treatment [5][6]. Wearable healthcare systems can improve health status and collect large amounts of human health information [6]. For example, wearable technology has become a feasible way to provide cost-efficient and clinically sensitive data for patient assessment [3][5]. Gamification of healthcare is also an emerging topic in addition to wearables in healthcare. The combination of both concepts has recently started to generate research interest [7]. Recent results have shown that, although interest in wearables and gamification definitely exists, their combined added value is not clear among potential consumers [7]. Thus, most people do not yet have any specific functions in mind. The main benefit of wearable devices is generally that they are small, discreet and portable [5][6]. However, as discussed later in this article, this technology still needs to overcome some challenges [3][4][5][8] before its huge potential in various applications, from sports and entertainment to medical devices and gamification of health, can be realized [9].

Smart clothing is a key form of wearable technology in which the technology is integrated into a piece of cloth. Battery-free operation, real-time information collection, comfort, and reliability are the key properties of smart clothing; these guarantee that the smart clothing is easy to use, maintenance free, and can stand harsh and greatly varying conditions. Additionally, the sustainable and green lifecycle from manufacturing to recycling is a must. This includes, e.g., the longevity of the smart clothing in use, the materials and production methods used, and the possibilities of recycling [10]. The United Nations (UN) has declared goals for Sustainable Development that also apply to smart clothes. In addition to fulfilling these goals in the lifecycle of smart clothing, with smart clothes we can enhance the progress towards many of these UN Sustainable Development goals, e.g., Good Health and Well-Being, Reduced Inequalities, and Responsible Consumption and Production.

Smart clothes have sensors and communication systems integrated to them. Thus, a major challenge in current smart clothing is that they require complex electronics and an energy source that accompanies the garment. This increases the price of the garment and limits its use, because the garment requires, for example, recharging or replacing the batteries. The complex electronics that come with the garment also complicate garment maintenance; for example, washing - including mechanical stress, moisture and detergent - is one of the biggest reliability challenges for wearable electronics. Passive RFID (radio frequency identification) technology is cost-effective, light weight and basically maintenance free. The electronic RFID tags that consist of an antenna and an integrated circuit (IC) are remotely addressable, especially in the UHF (ultrahigh frequency) range, hence the basic structure is very simple. A passive RFID tag receives all its energy from an RFID reader and responds by backscattering. Hence, it does not need any battery or other kind of energy storage. The technical part of smart clothing endures as long as the fabric in the garment lasts and if the materials, manufacturing methods and possibly some kind of protective sealing are properly chosen. Variations of backscattered signals from body-attached passive RFID tags have been shown to provide information about body positions and movements [11]-[15],

which, for example, offers new controlling possibilities for body-controlled games. Furthermore, a shirt-integrated antenna, which could be used to activate single RFID IC components placed around the user [15], and versatile passive RFID-based textile-integrated touchpad solutions, have been presented [16][17]. These have also been used as clothing-integrated controllers for games. Thus, passive UHF RFID is one of the key technologies in the wearable electronics sector.

Due to the noticed huge potential of passive UHF RFID based smart clothing, we organized five multidisciplinary workshops for professionals (or future professionals) of different fields in healthcare, as well as engineers from different fields, to discover the potential future users and applications of smart clothes. Several challenges were also raised by the workshop participants during the workshops, and this article introduces these challenges.

II. Methods

We used ideation workshops and inductive qualitative content analysis as the research method in this study. The purpose of the ideation workshops was to spontaneously generate ideas concerning smart clothes, especially by studying their potential users and applications and how smart clothes could be used in practice. The workshops were transcribed into text and the transcribed material was analyzed to discern relevant categories and subcategories.

A. Ideation Workshops as a Research Method

A workshop is a creative and structural working method in which participants work toward a common goal [18]. The goal can be, for example, to create new ideas for some context. It has been stated that good ideas are created when as many ideas as possible are produced [18] and that good ideas are created together [19]. Multiprofessional cooperation is especially fruitful for creativity, because the knowledge and skills of professionals from different fields complement each other [18][20]. Thus, a multiprofessional workshop method can be considered a good choice when the purpose is to create new open-minded ideas that reflect the opinions of different stakeholders.

B. Implementation of Workshops in This Study

Five ideation workshops were organized during spring 2020 for this study. The ideation workshops were originally intended to be organized face to face, but they were implemented on the Zoom video meeting service because of the COVID-19-situation during that time. Fifty professionals from different fields attended the workshops. Table I presents the participants' education or profession.

TABLE I. Workshop participants' education or profession

Participants' education / profession	***N***
Teaching staff (occupational therapy, logopedics, psychology, physiotherapy, technology)	10
Physiotherapist	3
Engineer	2
Speech therapist	2
Occupational therapy student	27
Not published[1]	6

[1]Information is not published, because a person may be identifiable due to the professional title.

The workshops' aim was to bring together a wide range of experts in the fields of engineering, education, social services and health care, and health technology, as well as future experts in these fields, to gain the widest possible multidisciplinary view of smart clothing applications. The number of participants in a single workshop varied from five to fifteen. Five to six researchers participated the workshops in addition to the participants. Video and audio were recorded from each workshop, and screenshots of the ideation slides were taken during the workshops. The videos recorded from the workshops were transcribed. The workshops' duration varied from two to three hours.

These were the research questions presented in the workshops: 1) Who could benefit from smart clothing? 2) What could smart clothing be used for? 3) How could smart clothing be used? For each question, the actual brainstorming session began with a ten-minute silent session during which the participants were allowed to write their ideas on a white board shared on their computer screens. We stressed to them that they should not think about the feasibility of their ideas in practice due to time constraints and to ensure the spontaneous development of new ideas. The participants were asked to freely discuss the ideas they created after working silently. Two or three researchers facilitated the discussion by asking questions or additional information about the ideas written on the white board. Additionally, one-to-three researchers grouped the written ideas into different themes, e.g., ideas related to communication. The purpose of this grouping was to promote the ideation and increase discussion.

C. Qualitative Content Analysis

The study's transcribed workshops were analyzed using qualitative content analysis, a common method for analyzing qualitative data, especially written material. The process in this analysis method is principally similar to all other analysis methods: It has the research question or questions and the collection and analyzing of data, and, finally, it draws conclusions based on the findings [21]. A successful qualitative content analysis requires that the data can be categorized or divided into categories [22][23] that are created in an abstraction process based on the research questions [24]. One big advantage of qualitative research is the data's richness [25]. An important issue is to ensure the trustworthiness of the analysis [24]. The trustworthiness is recommended to be ensured by more than one researcher performing the categorization [24]. Furthermore, it is recommended that one researcher performs the actual categorization work and the other researchers intensely follow the whole categorization and analysis process [24]. Quotations are important for the trustworthiness of a qualitative content analysis [26], but overuse of quotations can make the results unclear [27]. Hence, the researchers must evaluate the proper number of clarifying quotations in their report.

Qualitative content analysis can be performed either deductively or inductively [24]. Using the inductive method means that the categories are formed from the raw data during the categorization process without any forethought about the categories; using the deductive method means the categories are predetermined based on prior knowledge [23][25][28]. Researchers who use the deductive approach have, for example, some theory or other relevant research findings as guidance for the initial categories at the beginning of the analysis phase [23][28]. Regardless of the method used, the qualitative content analysis includes three main phases:

preparation, organization and reporting of the results [24]. The reporting phase properly clarifies the findings to the readers [21].

D. Implementation of Qualitative Content Analysis in This Study

The workshop recordings were transcribed following the workshops. Next, we used inductive qualitative content analysis and formulated the categories from the raw text data without any presuppositions. The first iteration round when formulating the categories was to broadly select all relevant comments from the transcribed material, even those with the slightest relevance. One researcher performed this first round, or Phase 1. At least three researchers were working together in on-line meetings to ensure the trustworthiness of the analysis in the subsequent phases, as suggested in [24]. In Phase 2, the researchers together selected the relevant parts from the Phase 1 material and inductively formulated the categories. One researcher was performing the actual work, e.g., writing, and the other researchers were carefully reading the data and discussing it. The subcategories were defined in Phase 3 from the Phase 2 material. The entire data set from the study contains about 500 ideas created during the workshops. This article focuses on the technology-related challenges raised in the ideation workshops.

III. Results and Discussion

We formulated the categories and subcategories of the smart clothing technology-related challenges introduced by the workshop participants, shown in Table II, as a result of performing qualitative content analysis. Table II presents all the categories and the subcategories by their order of magnitude. In other words, issues in the categories shown higher in Table II were mentioned more often in the original material than issues in the categories shown lower in Table II. Specific subcategories did not emerge in all the categories. However, 3 subsubcategories were even found in the "Reliability" subcategory.

We picked clarifying quotations from the original transcribed material. The quotations are presented in this article with quotation marks and using italic font. If there is a part in parenthesis without italic font, we have added it to clarify the quotation, that part does not exist in the original material.

A. Ethics in Wearables

Table II reveals that "Ethics" was found to be the biggest challenge in smart clothing. Even though the technology itself would be good and helpful in many ways, several ethical issues exist related to the technology and to how it is used. Wearable technology indeed has raised multiple ethical questions, such as privacy and security challenges [29]. It is important to identify and understand these problems from the user's viewpoint. For example, wearable technology is often supposed to support people with disabilities becoming more independent, but that feature requires it to collect data about the user. People with disabilities may be unable to give their informed consent for the wearable technology to collect personal information. This issue was discussed in several workshops, and the following freely translated quotation describes that:

"...what is the point that we can assume that he/she can give the permit, he/she knows what he/she is doing and wants to do so."

TABLE II. Categories and subcategories of the smart clothing technology-related challenges

Categories	***Subcategories***
Ethics	Self-determination Informed consent Data misuse Proper amount of data
Operating features	Automatic, no know-how from the user Versatility, Personalized Indistinguishable Easy-to-use
Reliability	Sensor accuracy Reliability in harsh conditions *Washability* *Mechanical reliability* *Reliability in different weather conditions* Reliable operation Compatibility
Legislation and regulation	
Design process	Need-based User-oriented
Comfort and design	
Data privacy and protection	
Cost, commercial potential	
Health issues	

Ethical issues related to positioning were also discussed in the workshops. Monitoring someone's position or location could be technically possible and quite easily done with smart clothing, but its necessity must always be considered. Not only that, but it must be decided/considered exactly who can grant permission for that positioning. The positioning data can quite easily be misused, and in general someone's positioning or location is also a privacy issue. Another freely translated quotation offers insight into this issue:

"It depends much on what is done with the positioning data, with it you can find out a lot of many things..."

Furthermore, the amount of data collected is a challenge. Medical researchers have long cautioned that more testing is not a recipe for better health [30]. Thus, even though smart clothes could collect real-time data on various issues, we must carefully consider if we really need it. Does the continuous data provide some advantage to the user or is it perhaps a source of stress?

B. Operating Features

The second biggest category of the challenges presented in Table II is "Operating features". Automatic implementation of new smart clothing was found to be very important, especially in this category. Smart clothing is supposed to help people in their daily lives; thus disabled people often use smart clothes. User-friendly implementation of smart clothing for different target groups can be challenging even for people who are familiar with the technology.

Furthermore, the proper amount of automation was another important point raised by the workshop participants. Some automatic features would, in general, be great, but they can be disadvantageous in some cases. For example, you write a message that has some errors and the smart garment sends it automatically, e.g., after some time period, the message may

not be what you would have wanted. This is highlighted in the freely translated quotation:

"when you put something wrong and if it (smart clothing) *sends it automatically. then it goes and that is an issue that I have not thought, really, if it then sends whatever"*

The personalization of smart clothing was one aspect that was deemed important. People's sizes and shapes are different, but so are their interests and preferences [9], and we should not forget about the different abilities of the disabled. The need for personalization of smart clothing especially arose in this study when the discussion concerned disabled people. For example, someone could perhaps move only their left arm and another person could only move their right arm. The smart clothing needs to be personalized according to the users' needs and abilities in these cases. The possibility of personalization is a clear challenge for the technology: It should be adaptive and able to learn, while at the same time its implementations and use should not need any know-how from users or their caregivers.

In addition to ease of use, the technology integrated in smart clothing needs to be indistinguishable and maintenance free, according to our workshop participants. The clothing needs to be just like normal clothing in every way, e.g., what it looks like, how it feels and how it is cared for. This idea can be found in the freely translated quotation:

"…the purpose is that this is just like normal shirt or trousers, or any piece of clothing, and you don't notice the technology in it at all, it would feel just the same"

C. Reliability

Reliability issues of the technologies used in smart clothes were also often discussed in the workshops (see Table II). Here, "Reliability" category covers everything from the technology's mechanical reliability to its compatibility with other devices. Subcategories and even subsubcategories emerged here.

One very important issue is the proper sensitivity and accuracy of the sensors used in the smart clothing. Furthermore, the participants brought up that people would like to use interfaces that are also tolerant of rougher and imprecise handling. This is also related to the personalization of the smart clothing. For example, some people prefer touch surfaces with more force and some with less force, and the smart clothing should reliably sense all kinds of touches. The following freely translated quotation clarifies this:

"…it (smart clothing) *is of no use if it does not understand your touch, but may sense something totally different…"*

Reliability in harsh conditions arose in the "Reliability" category. The smart garment should withstand, e.g., different kinds of weather conditions, washing in a washing machine and rough handling. Its washability in a washing machine was one of the especially important points emphasized. It is said that that it is one of the biggest reasons why we all don't have smart clothes in our wardrobes [31]. Mechanical durability and reliability under use are also important. The smart cloth can be torn or stretched with force. The following freely translated quotation provides insight into this issue:

"...so that it (smart clothing) *would not be immediately broken or too sensitive so that it cannot be taken there* (daycare for special care children)*"*

The technical reliability of smart clothes' operation is extremely important, especially if the smart clothing is a medical device but, of course, also in other use cases. Users must be able to rely on the operation of their smart clothing in every situation. The sufficiency of energy is often a concern in operational reliability. However, the use of a suitable technology, for example, passive RFID technology, eliminates the energy consumption and sufficiency issues. There are also plenty of opportunities to do energy harvesting in smart clothing, which is one way to ensure energy for possibly additional sensors.

Finally, the smart clothing should communicate with other devices and systems to deliver its data somewhere. This requires compatibility with different manufacturers' systems. Furthermore, this requires proper international standardization of the smart clothing branch, which aspects the workshop participants also brought up.

D. Legislation and Regulation

Smart clothing used for medical purposes needs regulatory approval [31], which was discussed in several workshops and categorized under "Legislation and regulation". Many new medical devices were put into use in the past after few clinical trials or scientific evidence. The new devices often but not always improved the clinical outcomes [32]. The use of a new medical device caused harm to the patients or medical professionals in some cases [32]. Legislation and regulations have been created to minimize such devices' risks. However, the approval process for a medical device can take years [31], even if the regulatory bodies are required to act efficiently and in a reasonable time to ensure that beneficial devices can be placed into use as soon as possible [32]. This challenge is clarified in these freely translated quotations:

" ... when it (smart clothing) *is in a hospital it has to have the approval for medical device and so on."*

" ... it (medical approval) *takes ages..."*

The regulatory approval issues must be taken into consideration at a very early development stage of the smart clothing intended for medical use [33]. The strict regulation process is good and necessary, yet it also increases the product's development costs, possibly leading to a more expensive product and a longer time to market.

E. Design Process

Table II shows that two very interesting subcategories arose under the "Design process" category. The participants in this study stated that the design process of a smart clothing should be need based and user oriented. That means that the need for a smart clothing product is first detected by the users or their caregivers, and then the product is developed based on that need. Too often the product is designed and only after that are the end users' needs considered for many devices and applications. The design team often finds it hard to take the end users' needs into account in their design process [34], even though this should be the starting point for the whole design and product development process. The following freely translated quotation points out the core of this issue:

"What are the needs and who defines them."

However, it is often quite hard to discover the users' needs because they may be so abstract and hard to verbalize [34]. The human aspects are, unfortunately, often not considered in

the product development process [9], which reduces the end users' eagerness to use smart clothes [9].

F. Comfort and Design

"Comfort and design" were identified as challenges for smart clothing in several workshops. The following two freely translated quotations describe this issue:

" ... and especially elderly people don't want to wear any virtual armour but it (smart clothing) *should be an easy piece of clothing, T-shirt to wear"*

"... if it is some kind of a handicap-overall it is not nice anymore"

Studies have identified some demands for wearable technologies, such as demands of the body, end use, culture and aesthetics [35]. The demands that a user´s body puts on the technology vary greatly depending on the user. It is generally also important that the technology be seamlessly integrated into the original garment [36]. The technology should not make any changes to the flexibility or feel of the original textile used. For example, if the wearable restricts movement or is too hot or too cold, it becomes uncomfortable for the user [35]. Additionally, if the wearable technology requires the user´s touch, the touchable area's placement affects clothing's comfort for the user [36]. Reference [36] found that most people want the controls to be located in the trousers or on the wrists. Controls in the upper body, such as in shirts or scarfs, are often rejected [36]. The placement and the functions of wearables, depending on the body parts where they are worn, has been mapped out by Ziegler in a very comprehensive work that takes many different aspects of wearables into account, such as active touch areas, social acceptance or gestural interaction [37]. Other than that, the Design Guidelines for Wearability also defines 13 constructs that need to be taken into consideration when designing smart wearables including accessibility, sizing or attachment [38].

The outlook, or the design or aesthetics, of the smart clothing is extremely important [35]. A well-designed outlook increases peoples' interest in the clothes and makes it more attractive to the target group [39]. The wearable's comfort is considered more important than its looks, even though its looks are also important. The aesthetics of a smart clothing is often the most important reason to buy a smart cloth item [40]. Furthermore, if the aesthetics does not please the user the user gives up using the smart clothing item [40]. The personalization of a smart clothing's outlook is also a desirable feature [39], e.g., different colors and cuts could be beneficial for smart clothing adoption. Previous wearable and textile-related technologies asserted that the looks of electronics and their structures could bring new design opportunities to smart clothing [41], but this may not be the case in, e.g., the healthcare environment where the messages, usability and standards of clothing are established.

G. Data Privacy and Protection

Workshop participants considered "Data privacy and protection" to be an important issue to consider when designing and using smart clothing. It is fundamental to define what data are collected and where they are stored, how the data are processed and used and, most importantly, who has access to the data. Smart clothing may collect many kinds of data from the user, even sensitive data such as health-related data, and in many cases sends it in real time to the systems responsible for the data analysis. Health data are often transferred to external entities (e.g., the device manufacturer or a third party) outside the control of the user who is generating this data [42]. Smart clothing technology may emerge as security and privacy problem without proper privacy protections, especially if the data are accessed by a third party without the user's permission.

Data protection is unified by the General Data Protection Regulation (GDPR, regulation 2016/679) throughout the European Union. This assures European citizens of more explicit control of their own personal data. Users may have difficulties in understanding the imposed risks despite this. However, users might feel that they have no other choice than to sacrifice their privacy to obtain the benefits and services [43]. Studies have reported that many people feel positive about clothes used for wireless identification purposes in healthcare and childcare, but the feelings become more negative when more information about the person is added [44].

H. Cost, Commercial Potential

One category in this study's results was the "Cost and commercial potential" of smart clothing. The smart clothing branch is expected to grow significantly. However, at present its business attractiveness is not so good [45], but wearable technology in general is supposed to be a profit-making business area soon [46]. Many aids for people with disabilities are quite expensive nowadays. It is hoped that smart clothing will be a cheaper choice for these needs.

It is important that smart clothing has good commercial potential to ensure their continuous development work. The smart clothing technology should be profitable to the companies involved with it. Important factors in commercializing a product in this business area include careful and well-designed market research at the same time as the product's technical development process [46]. This requires skills and know-how in business development in addition to engineering knowledge [46].

I. Health Issues

Table II's last category ("Health issues") raises an extremely important issue: Does the continuous wearing of smart clothing have some impact on the user's health? Regardless of the technology used, some wireless data transmission technology is used in smart clothing if a real-time connection is wanted. Multiple ways are available to establish the wireless communication, including, e.g., Wi-Fi, Bluetooth, 4G, 5G and passive RFID technology [47][48]. All the wireless communication methods utilize antennas that generate electromagnetic fields (EMF) around them. Studies have been made concerning RF EMF effects on humans, but mainly these concern mobile phones. The results are controversial, but no clear evidence of RF EMF to cause tumors has been shown [49]. However, it has been hypothesized that RF EMF exposure causes neurological effects [49]. Furthermore, the effects of RF EMF on the human body are hard to study due to the relatively short time, about 30 years, that man-made RF EMFs have existed [49]. Health effects may take tens of years to develop [49]. The health issues definitely need further study.

IV. Conclusion

We organized five multidisciplinary ideation workshops with special emphasis on finding innovative, creative and broad new use ideas and user groups for smart clothing. The

workshops created about 500 spontaneous new ideas and discussed the challenges of smart clothing technology. The results revealed many challenges and important issues in the development of smart clothing, including ethics, operating features, reliability issues, legislation and regulation, the design process, comfort and design, cost and commercial potential, and health issues. Ethics was the most discussed topic in the workshops. Discussions are ongoing on the ethics of the technology, and people and companies are becoming increasingly more aware of the ethical viewpoints. The operating features and reliability were also mentioned often in the workshops. The other categories had fewer mentions, but many important challenges for smart clothing emerged, e.g., the requirement for need-based and user-oriented design and development of smart clothing. Further work is needed to better understand the challenge areas found in this study. However, these results are extremely useful for further developing smart clothing, which has new applications, especially in the caring sector, for example in gamification for health and well-being.

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