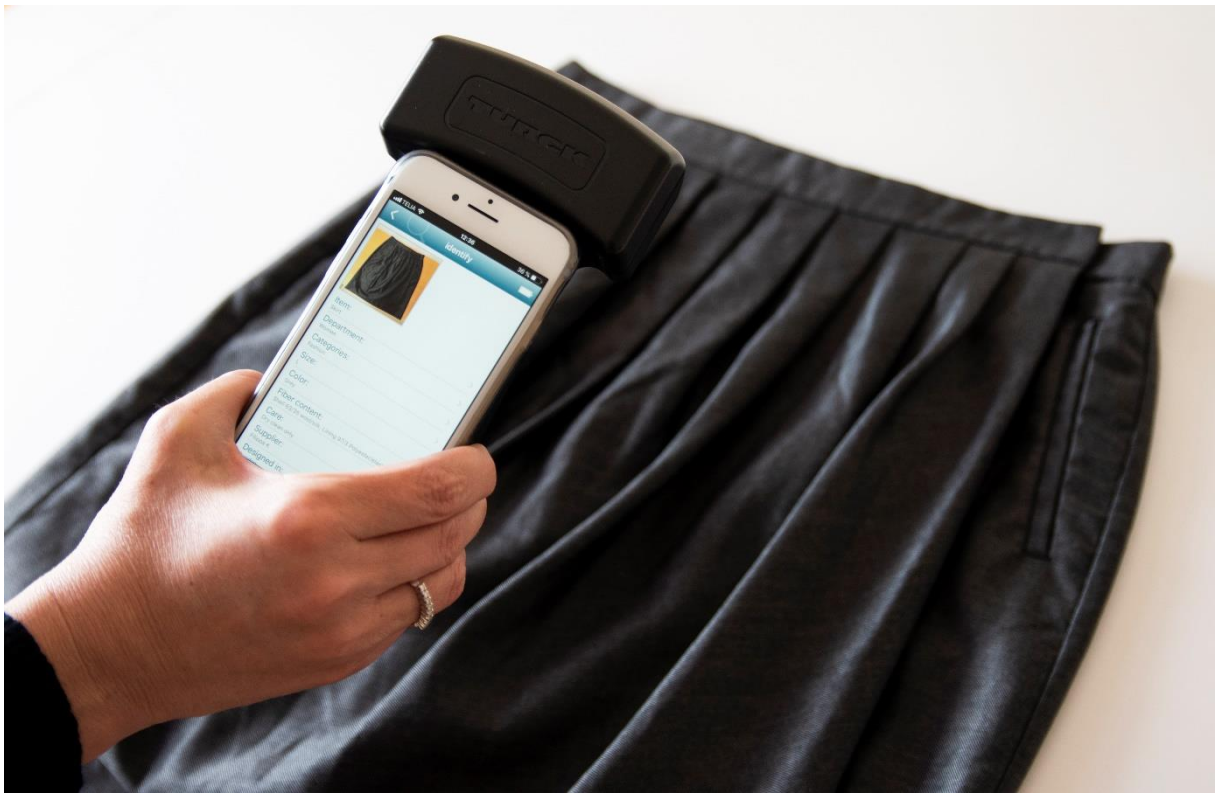
Innovationer för ett Hållbart Samhälle 2018

RFID for transparency, traceability and end-of-life handling for textiles



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Summary

To investigate possible solutions for efficient handling of the increasing amounts of textiles and garments being discarded each year, this project was granted funding from Vinnova under the call *Innovationer för ett Hållbart Samhälle 2018*. The project was finalised on the 30th of June 2021 and the consortium comprised some 20 companies, which represented many businesses within the range from research and development, textile and fashion, sorting and recycling, charity and second-hand, trimmings and smart labelling through standardisation.

The main objectives were to investigate and build knowledge regarding the possibilities to utilise a digital information system, adapted for the textile and fashion industry, based on RFID technology, where information availability, transparency and traceability would be crucial to enable and facilitate handling of textiles at their end-of-life.

The information, such as fibre content, dyeing systems, possible chemical content, fabric construction, production date and much more, possible to store in a database system is coupled to RFID tags, integrated in textiles and garments. Each RFID tag comprises a unique identity code, which at the sorting facility is used to look up and retrieve information required for the sorting into correct category for either reuse or recycling. The project rather early concluded that a future solution for textiles handling, certainly is possible to construct and reach high safety and integrity levels, as well as contribute efficiently.

However, the digital information carriers most likely will diverse and comprise a mixture of several digital information technologies such as NFC, QR code, 2D matrix, and not RFID solely. The main reason for this is the interaction with customers, which is very important and more easily conducted with systems compatible with smart phones since an RFID system requires separate reader(s) and antenna(s). Nevertheless, RFID technology is more powerful and have superior features in terms of it is possible to read an RFID tag at longer distances and without showing the tag to the reader. Also, many tags can be read almost simultaneously, which gives the possibility to considerably speed up a sorting process.

A minor, manual sorting trial, based on RFID technology, was performed within the project which revealed there is a potential for improved sorting and prising of the garments, especially if the sorters are less skilled and experienced. It is also possible to automate the RFID technology-based sorting process by means of programming, hence certain parameters such as fibre content, colour, brand, etc. could be looked for.

The processes for information gathering and transfer into the digital information system is a challenge since the textile and fashion industry is highly decentralised and consist of complex supply chain networks. It is essential that this could be done as effortlessly as possible for the brand owners since they have already slimmed organisations and many operations to accomplish. By means of strictly adapted APIs, either incorporated into PLM systems or possible to combine externally to the PLM systems, a so called product description file shall be produced in a well-defined and standardised format, such as those information models developed by GS1 and circular.fashion. The data shall thereafter be transferred into a database, which could either be a traditional or distributed database, e.g. a distributed data sharing network such as GDSN defined by GS1.

Also, the project has assessed using a blockchain-based database but concluded that this is an unnecessarily complex technology, which comprises relatively low storage and transaction capacity, which is less suitable for the fashion industry putting millions of products at the market annually. However, it is an organisational or political question whether to use blockchain or another form of database, however a traditional or distributed database is going to be more efficient.

Personal integrity is an important issue, which has been discussed from the beginning of the project, not to jeopardise any customers privacy in terms of making it possible to "read" apparel intendedly on the street, e.g. for criminal intentions to find expensive garments. The investigation performed within the project has found that RFID tags have the possibility of inherent security capabilities, which has been defined in the standard communication protocol. GS1 has published the specification which defines the protocol that used by the tag and the reader to communicate.

RFID tags encryption and untraceable capabilities are required to provide privacy and data security. At point of sale, an encryption key could be used to activate the tag's untraceable capability. Then, at the sorting facility the tag can be unlocked by an authorised reader by means of finding the correct encryption key in a complex sequence of message operations. Consequently, both tags and readers need to identify themselves by authentication operations, to assure authorised readers are used, e.g. at sorting facilities or in stores.

Restricted data is available regarding RFID tags manufacturing processes and the related environmental footprints caused by them. Further investigation is therefore required prior to the "ready-to-go"-button is pushed for a digital information system based on RFID technology, for end-of-life handling of textiles. However, associated and continuing work will be performed within the EU funded project HEREWEAR, which is an ongoing project where both RISE and circular.fashion have the possibility to transfer knowledge from this project and continue this important work.

Return on investment cost calculation results show that an in-store RFID based information system enables significant time and cost savings during inventory operations. In addition, it reduces the need for overproduction since stores and warehouses stock control are considerably improved. In the improved inventory and logistics operations, RFID tags are used on hangtags, together with price tag, brand label, and other relevant information.

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1 Project background

"Retail involves complex textile materials composed of several different fiber types, with different dyeing systems and surface treatments. To enable traceability and ensure an effective sorting process, able to take into consideration fiber composition and chemical content in used textiles, new adaptive methods are needed for identification of textile products. The use of digital information carriers integrated into garments has the potential to greatly increase future traceability throughout the supply chain, but also to facilitate subsequent processes and lay the foundation for circular textile value chains. A number of areas are in need of in-depth analysis and increased know ledge to enable a future digital system for handling of textiles, built around information carriers that follow a garment. A system based on RFID-tags, with multiple functionalities responding to the needs of different actors in the textile value chain, is the future vision, and the ultimate goal where this project will play an important role for building the foundation. The specific objective of this project is to build knowledge and competence in regard to:

- *Information system model*
- *System for data collection*
- *Overview of existing standards and mapping of standardization need*
- *Cost calculations and evaluation of ROI*
- *Implications of integrating digital information carriers in textile products*

The suggested system towards which we are working has implications on several of the Agenda 2030 goals, especially numbers 8, 11, 12 and 13. We are addressing mainly the areas environment and sustainable cities according to the call."

A lot has happened since this text above was written in the application form, laying the ground basis for this project that was going to be named Tex.IT. Just to clarify the Agenda 2030 goals mentioned, their short titles are: 8 – Decent work and economic growth, 11 – Sustainable cities and communities, 12 – Responsible consumption and production, and 13 – Climate action.

Some important aspects at political level, both nationally within Sweden, and at European level, is that the textile area lately has been highlighted and put focus on, to manage to reach circular value chains and the important circular economy. From e.g. the so called January agreement in 2019, which is a 73 points list agreed on by the Swedish government together with Liberalerna and Centerpartiet, where point number 38 states that, to be able to strengthen the development of a resource-efficient, circular and bio-based economy, a broad review of the regulations for the recycling as well as waste and residual products management is needed. Additional steps that make it easier for households to recycle and reuse must be taken, among other things by introducing producer responsibility for textiles. Possible viable ways to greatly increase the reuse and recycling of textiles must be tested where the industry and non-profit actors are involved. [1]

Also, the current president (since 2019) of the European Commission (EC), Ursula von der Leyen, early pointed out textiles as a focus area to be dealt with to reach circular value chains and a circular economy. Also, the EC Circular Economy Action Plan explicitly states that

digital solutions, such as tagging and labelling, should be considered as enablers to increase the availability of information, traceability and transparency. Access to reliable information and traceability will be crucial to achieve circular textile flows when it comes to textile reuse and recycling. [2]

The project has been conducted by RISE IVF AB, together with the following project participants: AB Ludvig Svensson, Björkåfrihet, Boer Group Recycling Solutions, Boxon AB, circular.fashion UG, European Outdoor Group (EOG), FIDRA UK, Fristads Kansas AB, Gina Tricot AB, GS1 Sweden, Wargön Innovation AB, Peak Performance Production AB, RISE AB – avd. Smart hårdava, RISE AB – avd. Mobilitet och system, Rudholm & Haak, SIS - Swedish Institute for Standards, Stadium Aktiebolag, TEKO - Sveriges Textil och Modeföretag Service AB, TPC Textile AB and TST Sweden AB.

2 Textile reuse and recycling – Introduction

The aim of the Tex.IT project is to increase the reuse and recycling of textiles by providing better information about the textiles to sorting facilities. The idea is to use RFID tags to identify textiles and then use the identity of the textile to retrieve information, which has been stored about it, to make sorting of textiles more efficient.

Section 5 presents research on which information is needed when sorting for reuse and recycling and how this information can be encoded into a machine-readable format. We have performed interviews with sorting companies, and we conclude that sorting for reuse needs information such as brand, size, season and production date. This information is used in valuation and sales of garments. When sorting for recycling material composition and treatments are important to determine which recycling process is suitable for a textile. For encoding the information the project chose, instead of developing our own information model, to partner with the company circular.fashion, which has developed an information model which to a large extent meets the identified requirements. We also conclude that the GDSN by GS1 has an information model describing the material content of textiles, but this model is too simple to capture all the required information but could perhaps be expanded upon in the future.

Section 7 presents research on how the information about the textile can be collected. The information must be collected from multiple sources in the value chain because different information originates at different places. For instance, chemical composition of fibers is known by the fiber manufacturer, not directly by the brand company.

Further on, section 7.6 is about storing and distributing the information to be available at the sorting facility when it is needed. Essentially the system must perform a service of storing textile information so it can be located and retrieved by RFID product code. GDSN by GS1 already offers a service which allows one to retrieve product data by product code, so it is a possible candidate as an implementation, or if desired a dedicated service could be built and implemented instead.

Section 8 presents research on security and privacy. Active RFID tags on textiles represents a privacy risk for consumers since persons could be traced or identified through the tags which can be read from a distance without being noticed. We perform a survey what kind of

security and privacy features are available in RFID tag standards. We conclude by recommending that tags are locked through encrypted authentication when the textiles are sold to consumers so they cannot be read in the public. We then present an architecture for a system which lets sorting facilities unlock the tags when they receive the textiles.

Section 9 combines the conclusions from the previous sections into a suggested solution.

3 RIFD tags and RFID technology possibilities

On 16.1.2018, the European Commission published a communication to the European parliament, the council, the European economic and social committee, and the committee of the regions. This communication is on the implementation of the circular economy package regarding options to address the interface between chemical, product and waste legislation [8]. In this document, the need for access to relevant information on products for all actors in the value chain is expressed. The document highlights the need for information systems, innovative tracing technologies and strategies which could enable relevant information to flow along article supply chains and reach recyclers.

RFID, short for Radio Frequency IDentification, is one digital tracing technology that is already used in the laundry service management, i.e. textiles utilised within healthcare, hotels and restaurants, to keep track on the textile products circulating between the laundry and the site for use. There are two types of RFID tags, passive and active, of which the passive type is the alternative for use to incorporate in textiles. A passive RFID tag mainly consists of a carrying material for the microchip and the antenna circuit, but it has no battery, i.e. no power source of its own. When an RFID reader sends out electromagnetic waves, e.g. during active scanning or the tag being within the range of the RFID reader's field, a current is induced in the tag's antenna. This current provides enough energy for the tag to send out a response signal, which includes information about the tag's unique identity code. In turn, this unique identity code is entered into a database, where it can be linked to larger amounts of data related to this product that is carrying the tag. Figure 1 shows the basic RFID function principle (a) and b) various passive RFID tag types.

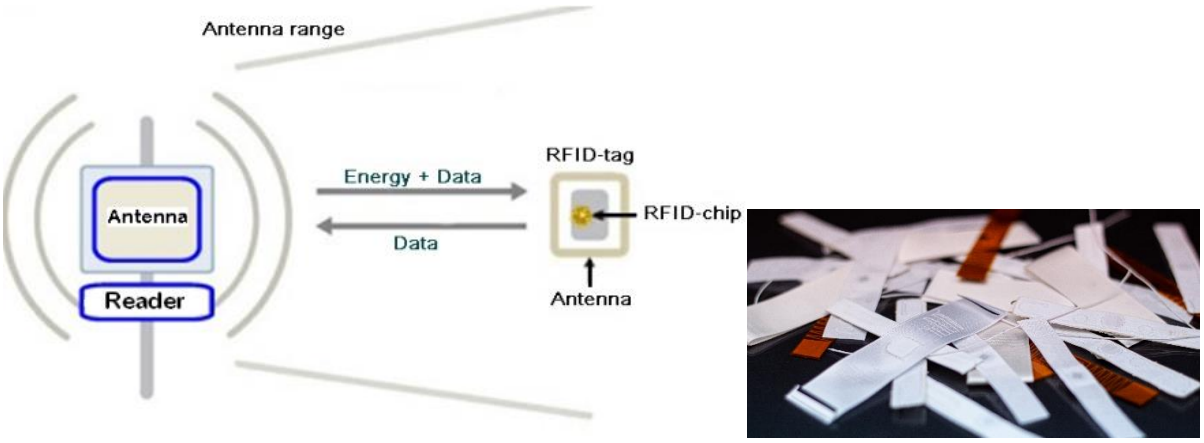

Figure 1: a) Passive RFID technology function, b) Various types of passive RFID tags

In section 7 and section 8, more details are available regarding the information system architecture and tag security issues, respectively, and in section 10.2 environmental aspects are given.

RFID technology has developed rapidly in recent decades and is a very attractive potential solution for textile materials. An RFID tag can be connected to a large amount of data, available in a database, and is read when it is within range of a reader. At reading, the tag can be integrated in the middle of the garment and covered with fabric without affecting the quality of the reading. This greatly facilitates handling compared to, e.g. barcode and/or QR code systems, which can neither be read from a distance, when hidden inside the garment or in a bulk (it needs direct visualisation), nor carry the same amount of identity data, since number of digits allowed in the unique identity code is limited compared to RFID tags.

An RFID system can be used adaptively and allows sorting of textiles based on the parameters specified. For example, it is possible to base sorting on rather simple parameters such as colours and sizes (for reuse) or process parameters such as the dyeing system used, which is very important for chemical recycling processes e.g. depolymerisation. Alternatively, the system would allow sorting out textiles containing a certain undesired chemical, which has been regulated since the garment was produced. However, all these parameters depend on the information validity and that it is made available from the fashion brand companies responsible for putting the textile products on the market. If the information is not there or incorrect, the sorting results will be deceptive. However, the up-coming directive regarding EPR (extended producer responsibility) will most likely contribute to fashion brands acting responsibly in terms of providing correct information to enable a safe and efficient end-of-life handling of their products.

An established RFID technology-based information system, directly influences the possibility for achieving higher second-hand values through parameters such as brand, season or production year, etc. Also, complete and available material compositions will increase the possibility to select correct material recycling technology, returning it into circular material systems as a resource, hence preventing waste.

In addition, RFID technology can assist manufacturers, wholesalers and retailers, as well as end-users and consumers, through improved information across the entire life cycle and value chain. In sorting facilities as well as in stores, the technology has significant effects on the working environment as several monotone and time-consuming steps can be automated. In order for a system like this to be possible, it needs to appeal to all actors in the textile value chain, something that will not only aid in implementation but also to carry the cost of the technology, see further ROI cost calculations under section 11.

4 Textile value chains

A textile value chain is not easily described, since there most often are several actors involved at all, so called tier levels. Normally one talks about four (4) textile tiering levels according to the following:

- Tier 1: Finished goods assemblers and subcontractors
- Tier 2: Weavers, Knitters, Nonwoven manufacturers, as well as Dyers, Printers, Finishers and Laminators, etc.
- Tier 3: Fibres, Feather/Down Processers, Yarn Spinners, Film and Tape Manufacturers, etc.
- Tier 4: Raw material suppliers

In parallel to these actors, there is also a highly complex chemicals supply chain, since the textile industry is consuming a huge amount of chemicals at each tier level, see the textile materials and chemical supply web example in Figure 2. [6]

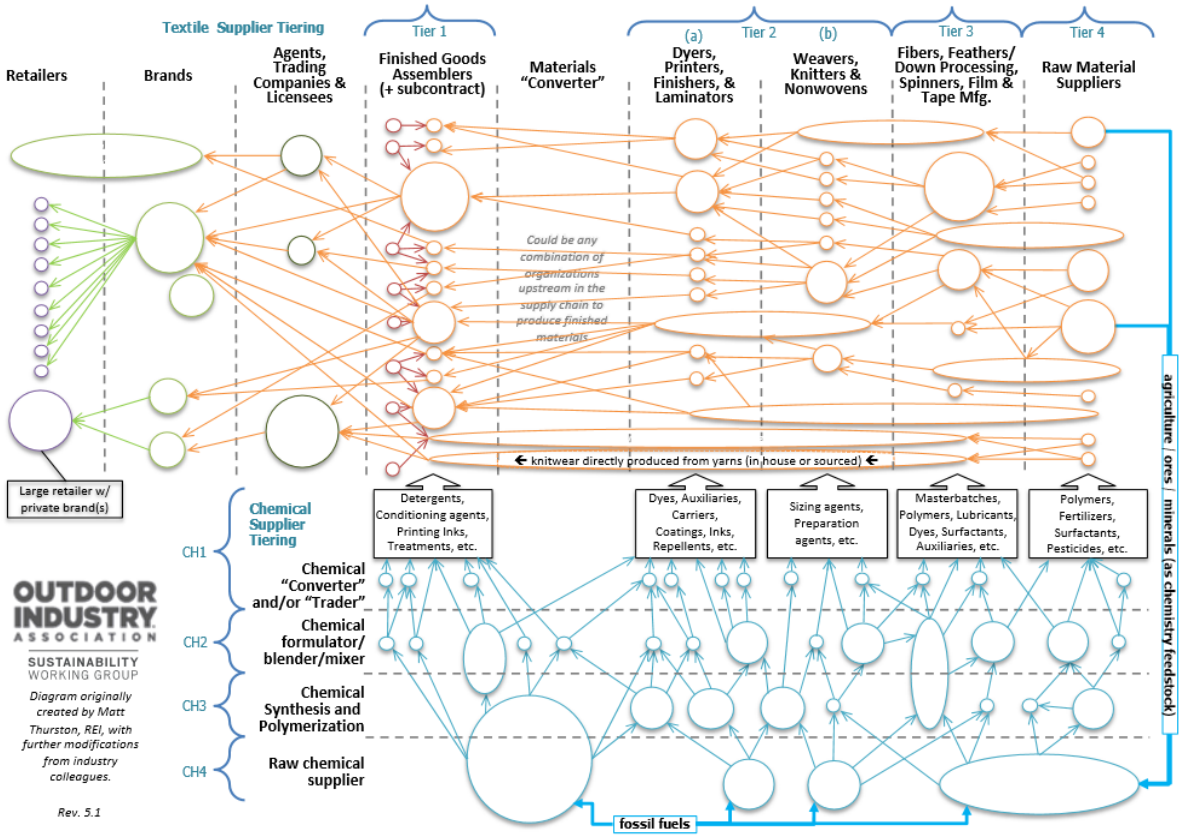

Figure 2: The textile and textile chemistry supply "web" [6]

4.1 Textile and fashion brand companies' RFID reflections and experiences

Experiences and thoughts about RFID technology as an enabler for enhanced effectiveness or facilitator throughout the textile value chain is perceived quite differently dependant on which part of the textile sector one investigates. A fashion retailer brand, a work wear company, a textile manufacturing company, or a sportswear company, all have their own experiences and need or no need for the technology. Thoughts and experiences from the project participants are shared below.

AB Ludvig Svensson

Svensson is based on a wide range of textiles with roots in the Scandinavian fashion tradition and with over 130 years of experience in textile crafts. To be at the forefront of quality, design and function, Svensson are constantly working on developing their process, technology and material. Production primarily takes place in Kinna, Sweden.

Svensson control and own the entire manufacturing process, from the drawing board and the choice of yarn and raw materials to the desired solution and the finished product. This provides unique opportunities to influence and develop each part of the process. This is complemented by a network of good suppliers. Svensson are therefore able to offer customers great flexibility and unique solutions according to their specific demands and requirements – whatever the size of the project.

Svensson has for many years investigated the possible positive effects of RFID technology and concluded that it could be very useful in the climate screens area since it facilitates the procedure of keeping track of the screens, their age, when they were installed. But also control when it is time to exchange a screen, hence not jeopardise the cultivation climate quality, but also continuously investigate screen quality and conduct product development based on such RFID information feedback.

The first purpose was to use one technique to mark the screens. This technology would help with logic as well as during use in the greenhouse. Since these two areas set very different requirements, two different marking systems will probably be needed. One for internal handling during production and storage and one system for when the screen is in use in the greenhouse. To solve the later it requires more research and optimization. The climate in the greenhouse places demands on readers, tags and antennas.

Fristads AB

Fristads is a Swedish work wear company, which a couple of years ago, investigated the possibilities of introducing an RFID based information system, to facilitate keeping track of related documentation for products/garments in their assortment that require CE marking. Normally an information package is attached to these kinds of products/garments, but at the point of sale or slightly after, this information is removed (cut off) from the product/garment and the information is most likely lost. The investigation indicated that considerable costs are related to RFID technology systems, which resulted in no further action at that point.

However, Fristads has continued working within the area of digitalisation and recently participated in forming a project regarding digitalisation, communication, and traceability of garments together with Wargön Innovation, among others, to achieve regional circular textile models and explore communication and interaction possibilities between different parties.

Gina Tricot

Gina Tricot is a Swedish fashion brand, which during the recent couple of years, has implemented an RFID technology system. Almost all products are equipped with hangtags carrying an RFID tag together with a bar code. The RFID system is adapted to facilitate Gina Tricot's store inventory procedures, as well as warehouse activities, such as receiving check of goods, packages preparation and handling of returns within the e-commerce sector, etc.

The RFID system has radically improved the overall inventory efficiency. Earlier they could spend days, up to weeks, on performing store inventory, but is now by means of the RFID system done within a time frame of hours. A lot of time is saved as well as rather hard monotone work.

Also, in terms of goods handling and to keep track of purchase orders, the RFID system has improved logistic control and efficiency, which perhaps has brought the most important consequence in terms of reduced overproduction due to less losses and improved control of stock and inventory.

In addition, Gina Tricot contributed with valuable company information and details regarding the RFID system into the ROI cost calculations performed and described further in section 11.1.

Peak Performance

Peak Performance is also a Swedish fashion brand, which has not implemented the use of RFID technology, yet. However, Peak Performance has during this project gradually realised that there probably are possible savings to gain, both in terms of store inventory efficiency, product authenticity, as well as information availability for down-stream activities and actors, such as the second-hand sector and textile recyclers. They also see the implementation of RFID/NFC tags into products as a way of interacting with the end consumers as well as adding extra value for them.

Also, Peak Performance participated extensively in and shared valuable company information to the ROI cost calculations performed and described further in section 11.1.

Stadium

Stadium is a Swedish sport and sportswear company, with a combined assortment of well-established external sportswear brands as well as own brands. A majority of the products are equipped with hangtags containing RFID tags combined with bar codes and QR codes. Similarly, to the experiences described by Gina Tricot, Stadium can confirm the considerable efficiency improvement, regarding store inventory procedures, when RFID technology is applied. Also, when a certain product has unintendedly been moved to the "wrong shelf" within a store, and a customer requests its availability, the RFID technology is superior manual efforts, in terms of locating this product. All this free up valuable manhours and store staff have more time to focus on the customer meetings.

Furthermore, Stadium has contributed with valuable company information and details regarding their RFID system to the ROI cost calculations performed and described further in section 11.1.

TPC Textile

TPC Textile is a textile production company, with several clients among fashion and textile brands, both Swedish and international. TPC Textile is working as a link between the fashion brand companies and the production facilities, which mainly are located in Asian countries. TPC Textile had limited experience from RFID technology prior to this project, however traceability and transparency issues have steadily increased to occur during recent years.

One of TPC Textile's clients has for example joined the TrusTrace platform[1], aiming at reaching full transparency throughout supply chains, e.g. where textiles is one of the main sectors.

Furthermore, TPC Textile has provided excellent knowledge regarding how the textile production operates and how, where and to what extent information is available and trustworthy. This information is very valuable in terms of how to retrieve important data and what prerequisites is required to transfer it into an information system.

TST Sweden

TST Sweden is a Swedish work wear company, developing textile products for the most extreme industrial conditions. Main part of TST Sweden's products are classified as PPE, i.e. personal protective equipment, and ought to be CE marked to ensure they comply to the requirements of Regulation (EU) 2016/425. [13] Similarly, to Fristads experiences regarding CE marking of workwear, there is a rather extensive documentation package required to follow each CE-marked product. By means of an RFID technology-based information system, this information could be digitally stored in a safe manner and it could be easily retrieved whenever needed by means of an integrated RFID tag in each product.

Currently, to use the RFID information system for circular material flows for work wear and PPE is not an option, since these products are used in industrial environments, where they risk to be contaminated from possible harmful chemical substances that are handled. Also, to recycle contaminated textiles is challenging, both for the user of the recycled material, and the recycling process (chemical recycling) conditions is put at risk to be disturbed.

Companies supporting textile and fashion brands, in terms of labels, trimmings and packaging have experiences and thoughts about RFID, and to what extent the technology could contribute. Project participants in this sector and their reflections are given below.

Boxon

Boxon is a company working with packaging solutions and smart labelling within the range of sectors from best-before dates on food packaging to labelling management within fashion companies with hundreds of suppliers in several countries. The packaging concepts provide full traceability and create efficient control and logistical advantages.

Boxon offers solutions from small care labels to global standard tags for transport and logistics solutions, in terms of QR codes, RFID codes and everything in between. To customise these smart labels, they work a lot with data capture and data transfer to the tags.

Rudholm Group

Rudholm Group is a company that supplies trimmings to the textile industry, in terms of care labels, various types of etiquettes/tags equipped with digital information carriers, e.g. RFID, bar codes, and QR codes. They also supply other trims such as hangtags, woven labels and packaging solutions.

Rudholm works with a couple of digital information gathering systems to enable preparation/customisation of the labels to their various clients, incorporating each client's

[1] https://trustrace.com/

specific data. Therefore, data gathering and information transformation into smart labels, in some cases related to RFID, is already in the business within Rudholm Group at a daily basis.

4.2 The Pilot – Market survey regarding digital information carriers

Early in the project it was discussed that an investigation would be interesting to conduct regarding how widespread and deep the knowledge is about digital information technologies among the companies within the textile sector. This got a working title as "The Pilot" and intended to assess how available information is within the companies as well as how credible this information is.

The survey was prepared by RISE, together with GS1 Sweden and TEKO, the Swedish trade and employers' association for companies working in the textile and fashion industry. TEKO, then helped to send out the survey among member companies within their environmental group. In addition the EOG, an industry group of brands, retailers, technology providers, and national associations representing the European outdoor sector, sent out the survey among their member companies, in order to reach out to an even wider group of companies within Europe, since TEKO member companies are limited to the Swedish market.

The complete set of survey questions are enclosed as Appendix A1.

Reply frequency

According to TEKO, who conduct market surveys now and then, it is somewhat expected that about 30% of the survey receivers reply. This was also the case, when the TEKO survey was finalized and evaluated. However, a considerably lower share of replies were obtained from the EOG survey, approximately 15%, which may (speculations only) relate to that the project was not conducted by any of the EOG member companies and that RISE is an unknown Swedish organisation to the majority of these companies. Figure 3 shows the introduction part of the EOG survey.

Figure 3: EOG survey introduction.

Company size and sectors represented in the survey(s)

All sectors and number of companies representing each specific sector are summarized in the compiled diagram in Figure 4 below. All in all, the number of companies responding to the TEKO and the EOG surveys, were 35 and 13, respectively, i.e. totally 48 companies representing 12 different sectors. Some companies represent more than one sector. The majority, 32 companies, are middle-sized occupying between 11 – 249 employees, while there were only 5 small and 11 large sized companies replying to the survey(s).

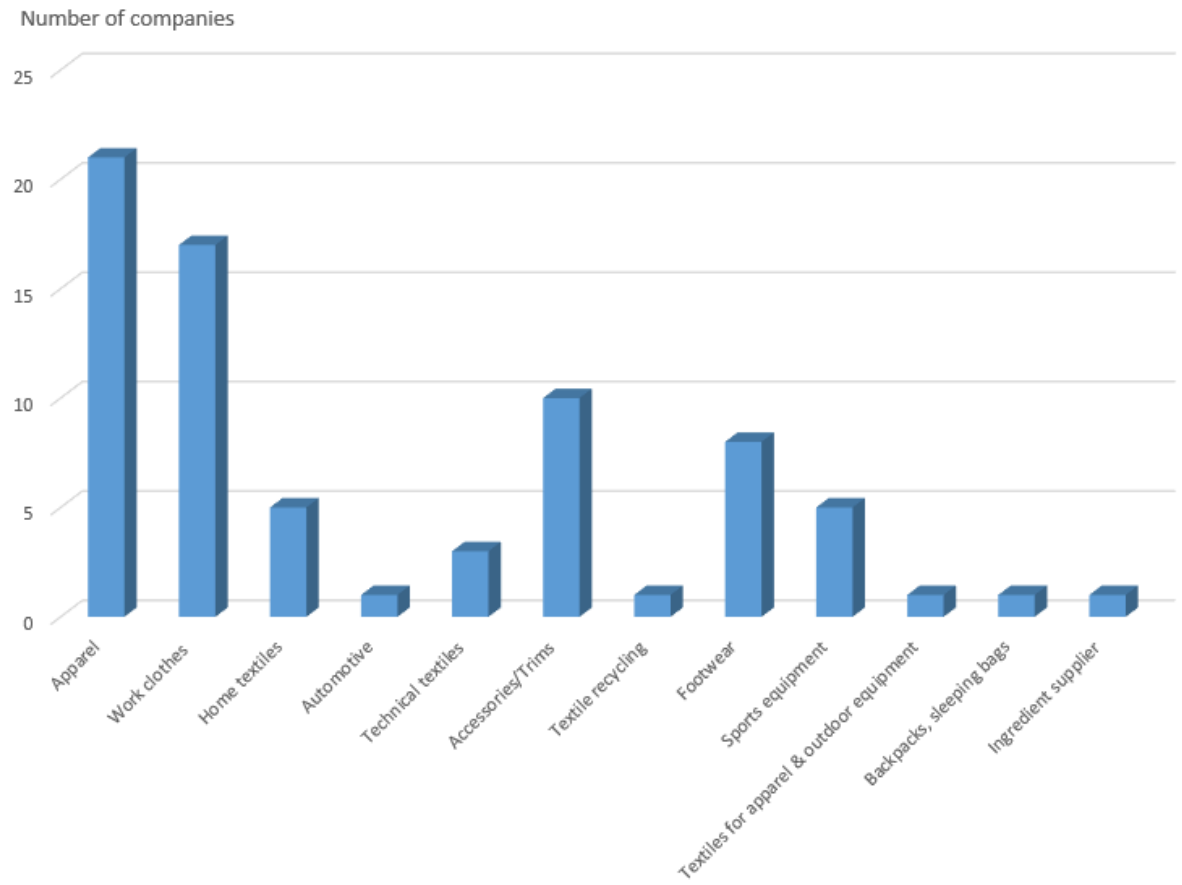

Figure 4: Compiled summary of company sectors represented in the surveys.

Information technologies awareness

As expected, the most well-known digital information technology is the barcode, which all responding companies know about, closely followed by the QR code, which only one company did not know about. RFID is familiar to a majority of the responding companies, approximately 77%, while NFC and Data matrix are the least known digital information technologies, with approximately one third (1/3) of the companies aware of these. Compiled results from the two surveys regarding information technology awareness are found in Figure 5.

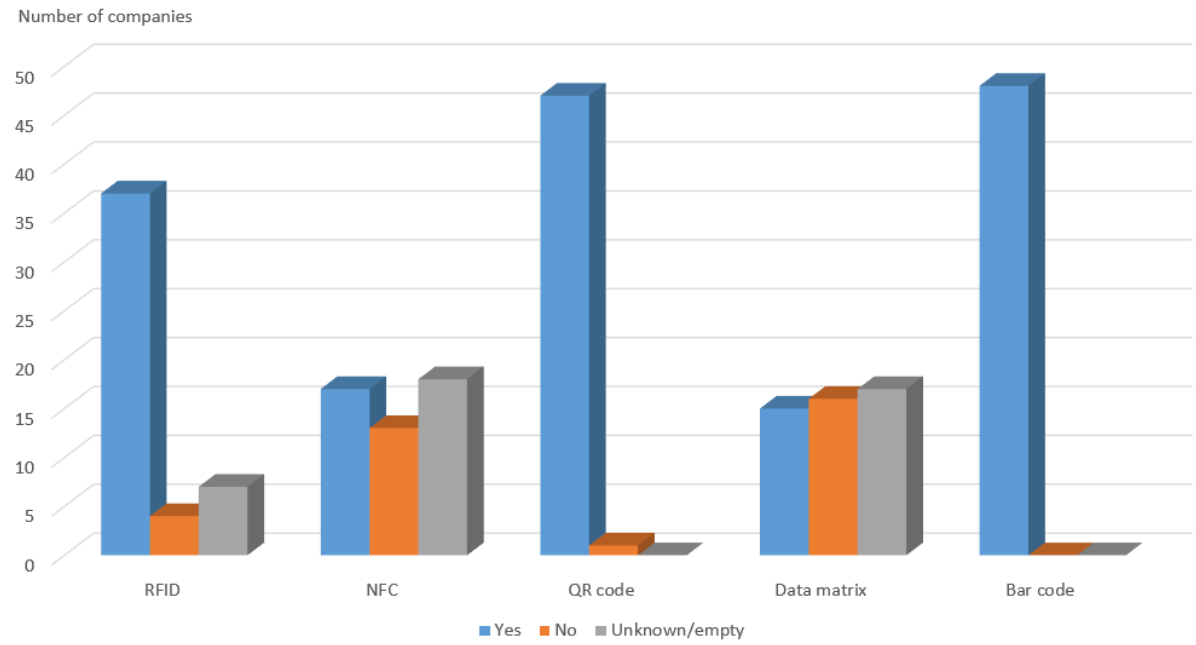

Figure 5: Compiled summary of information technologies awareness.

Inventory procedures

It is obvious from the compiled survey results, that one third (1/3) of the companies, do inventory by means of a manual procedure. Some 25% of the companies uses a combined manual and information technology-based methodology, while as much as 17% use a combination of information technologies. 4% respond they do not know or do not have a warehouse hence inventory is not performed, while an equal part has skipped this question. Figure 6 gives an overview of the different procedures used among the responding companies.

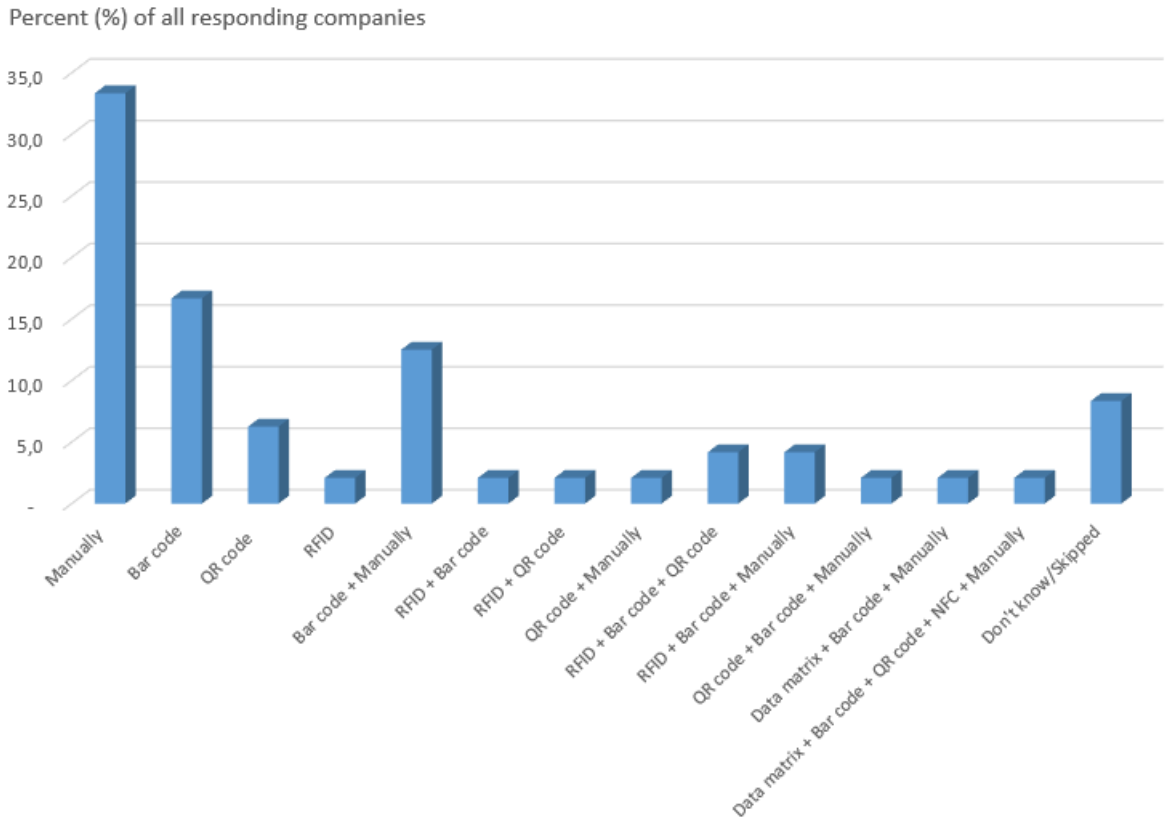

Figure 6: Compiled results for inventory procedures.

Information availability and credibility

To facilitate textile products handling at "end-of-life" during a sorting process for recycling or reuse, the use of digital information carriers is likely to be a facilitator *if* the required information is available and trustworthy. Figure 7 and Figure 8 show that data is not very easily available, but neither unavailable, as well as not completely credible but neither worthless, respectively. The two questions asked were:

If you had to produce detailed information regarding the manufacture of any of your company's products (for example, the use of chemicals in a dyeing process), how easy would it be? Results in Figure 7.

If you obtained information from your suppliers, as set out in question 11, how credible do you think it is likely to be? Results in Figure 8.

To compare these results with the information regarding where the responding companies have their production located, and from where they purchase the main textile materials, results are gathered in Figure 9 and Figure 10, respectively. One could assume it is easier to retrieve information, if the production and purchase activities are performed within the EU or European countries, compared to countries located farther away. However, most of the project participant brand companies have very good relations with their suppliers, and even sub-suppliers, via the main suppliers or own staff located close to where the production takes place. Issues such as linguistic misunderstanding could consequently be avoided.

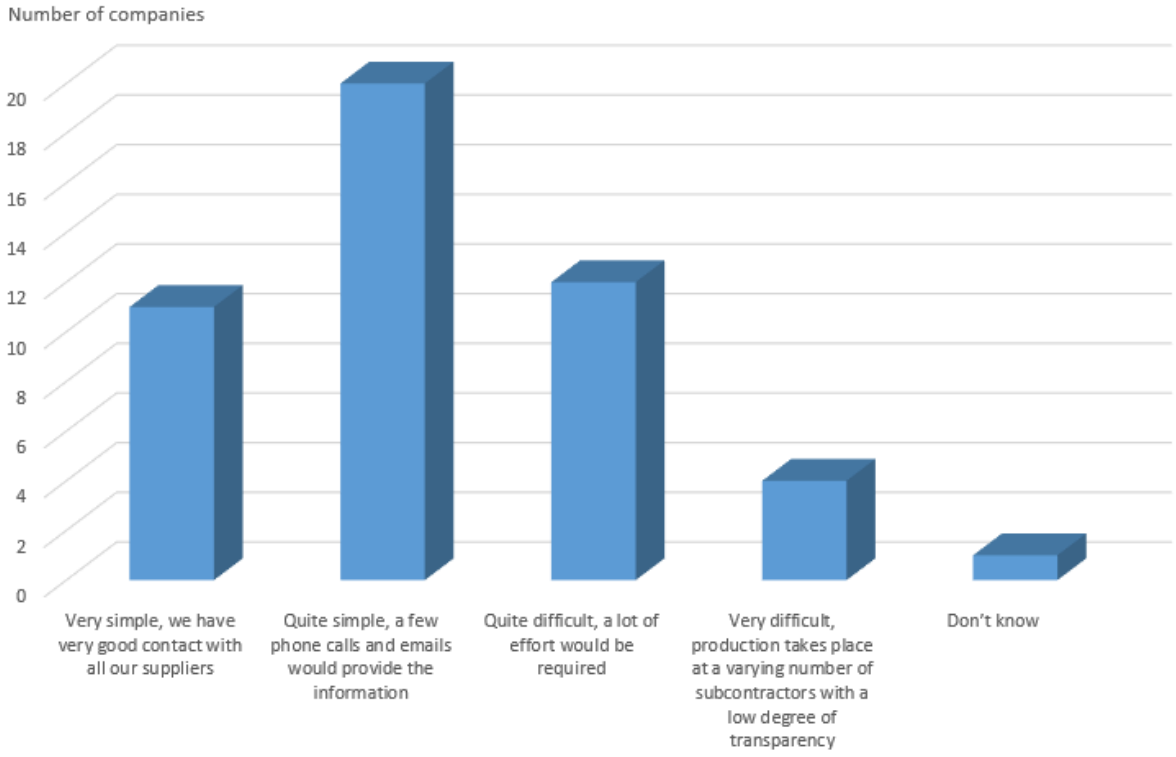

Figure 7: Compiled results regarding information availability

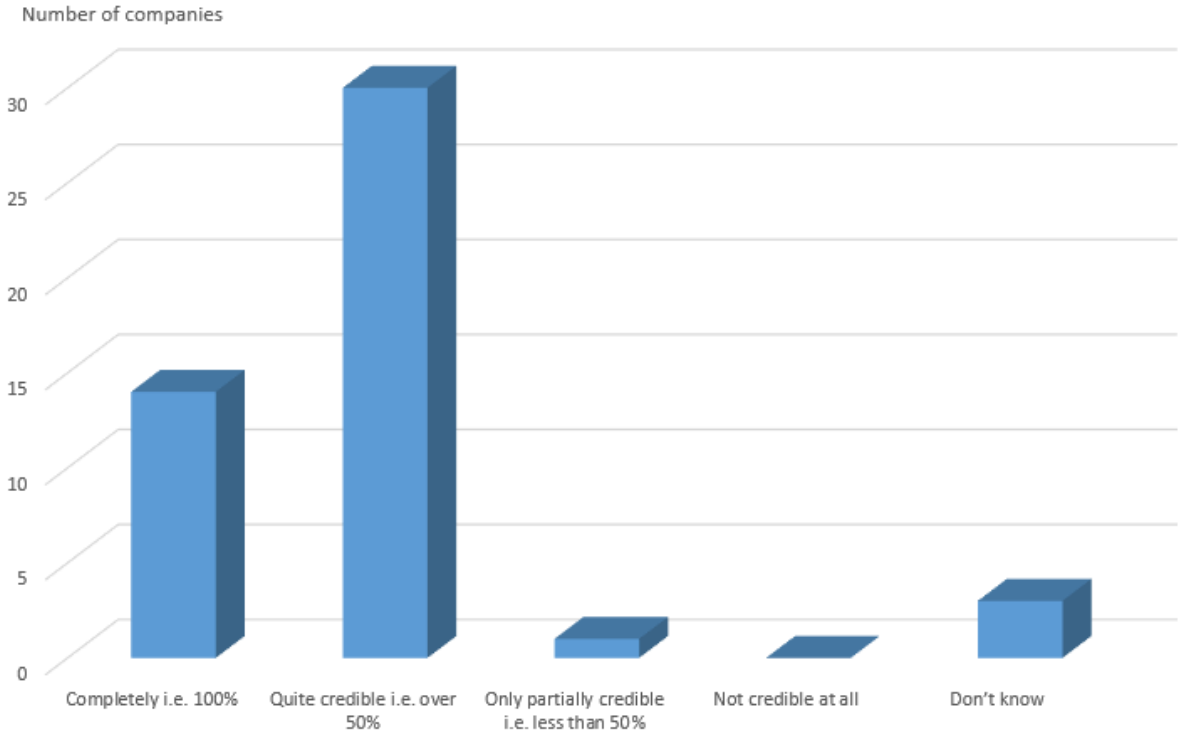

Figure 8: Compiled results regarding information credibility

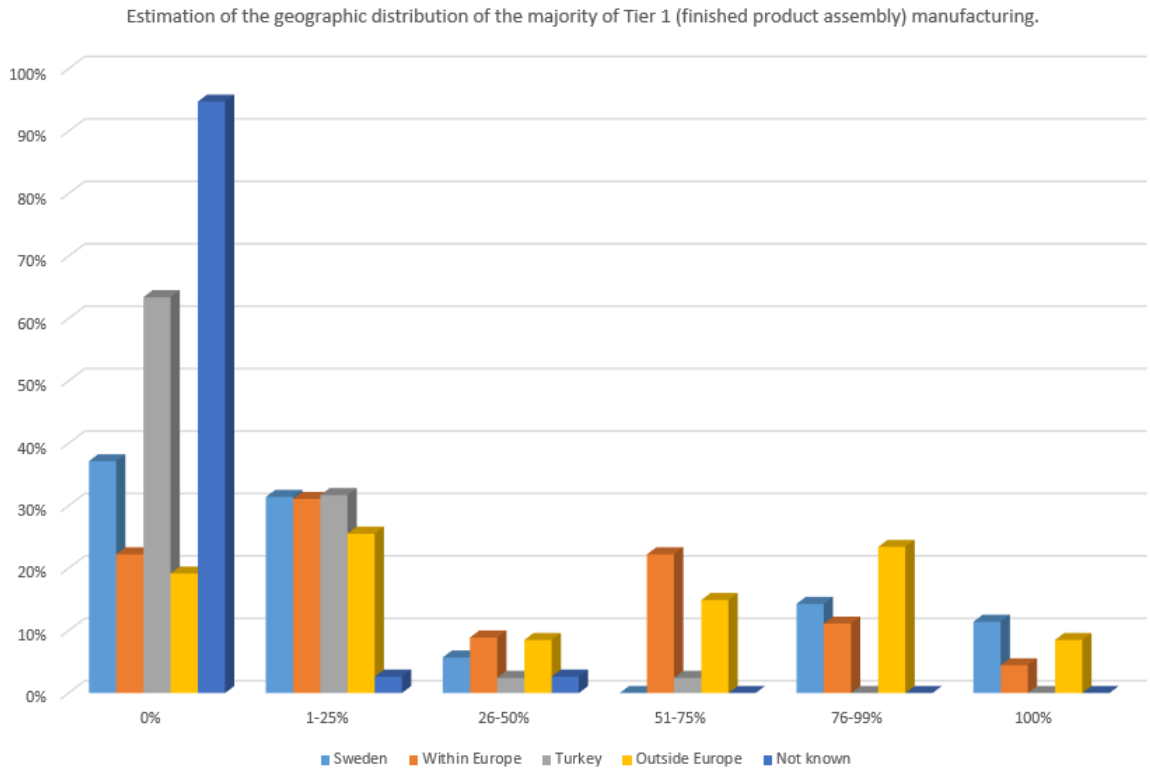

Figure 9: Estimated geographic distribution of tier 1 production

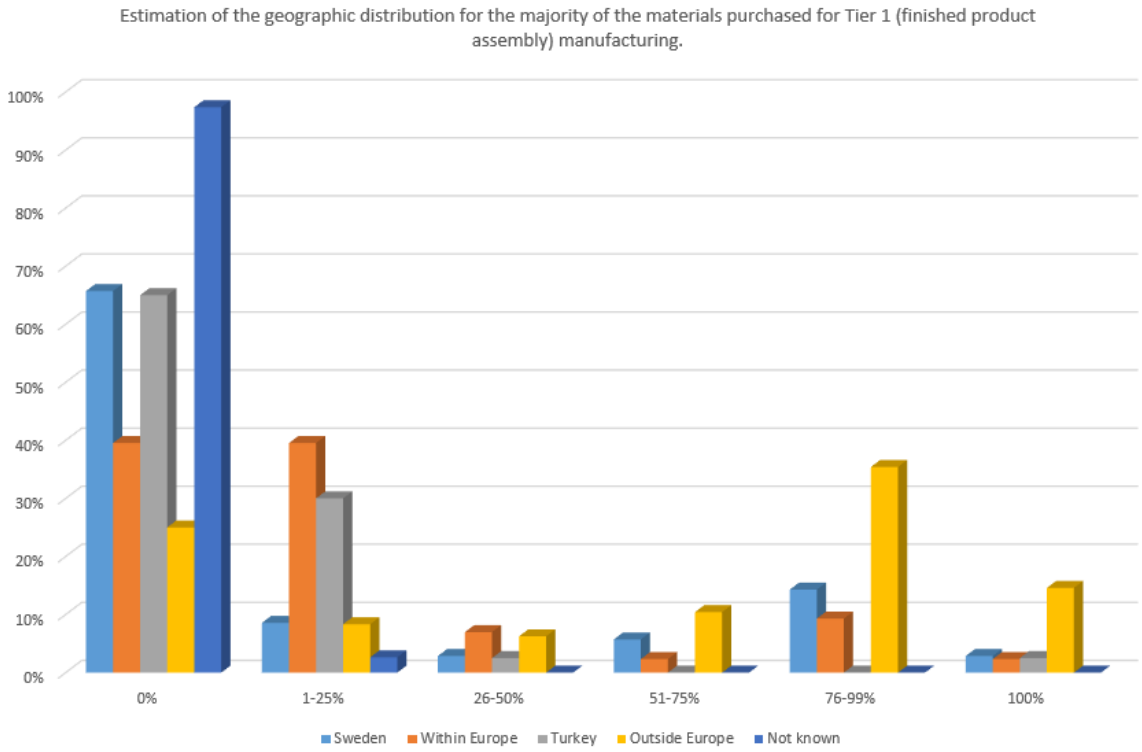

Figure 10: Estimated geographic distribution of textile materials purchase for tier 1 production.

IPR issues and expectations of digital information carriers as a possible solution

One question in the survey performed was; if the companies ever have encountered counterfeits and/or intellectual property problems, such as patents, trademarks, designs, etc.? Results are given in Figure 11. Less than half, or approximately 42% of the responding companies, had experienced counterfeiting or IPR (Immaterial Property Rights) problems. Slightly more than one third (35%) had not such experiences, while the rest did not know anything about it.

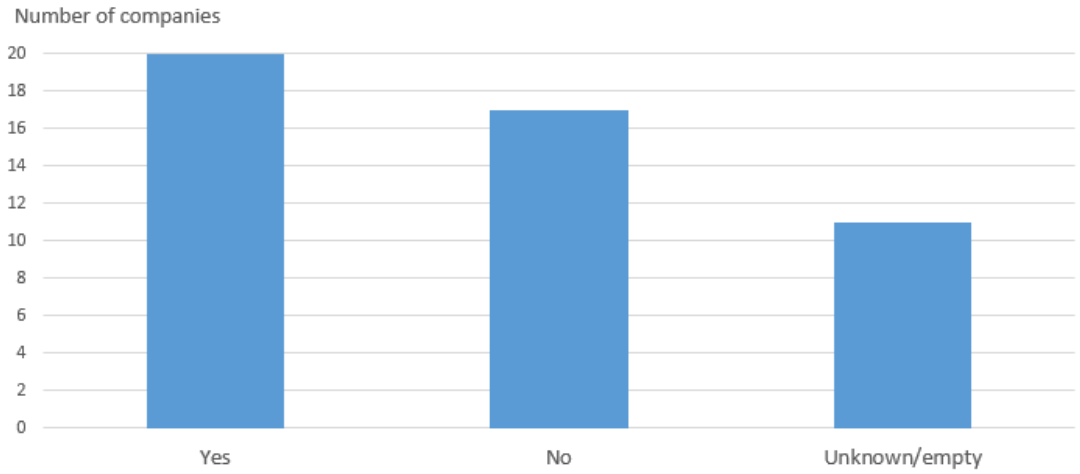

Figure 11: Experiences from counterfeits or IPR problems.

The companies that answered *yes* to the counterfeits or IPR problems question were then asked; to what extent they think digital information carriers could prevent counterfeiting and/or intellectual property problems for their business? Results are given in Figure 12 and it is obvious that nobody believe information technology can prevent these problems completely. Less than one third (30%) think it would prevent for the most part, meaning more than 50% of the counterfeits and/or IPR problems are prevented by means of digital information carriers, while as much as 50% of the responding companies which have suffered, think it brings limited or no protection to these problems. 20% of the responders are uncertain regarding this question.

The eight (8) companies out of the total 48 companies, that replied they had *not* suffered any counterfeit and/or IPR problems, did answer that they do believe digital information carriers could prevent these problems for the most part, i.e. to more than 50%.

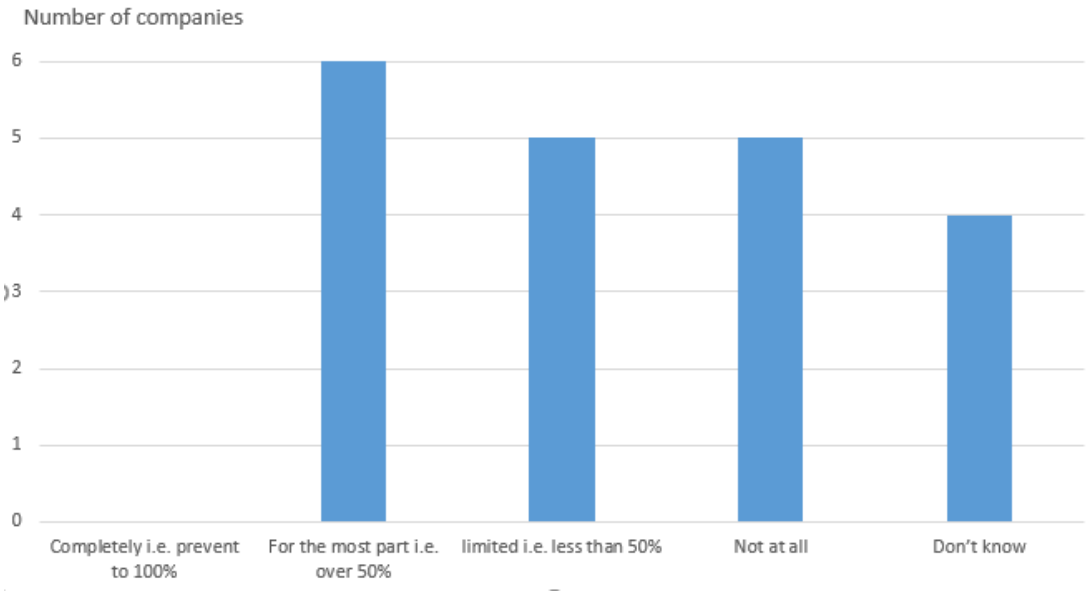

Figure 12: Expectations on digital information carriers to solve counterfeit and/or IPR problems.

4.3 Transports and logistics in the textile value chain

The transport operations within the textile value chain are mainly carried out by local freight companies when goods are transferred between different manufacturers within the same region, e.g. when a woven fabric shall be moved to a dyeing mill and thereafter to the sewing factory. Then, in general, when the final products are ready for shipment, larger transporting companies, i.e. carriers or forwarding agents, are hired to serve as the link between the manufacturing company and the brand company.

The only traceability available on the market along the logistics chain, is on the outside of the cartons/pallets that are transported. These IDs are generally referred to as shipment ID and are unique per carrier. Global trade item number (GTIN) is most often linked to international trade and then to countries outside the EU. There are different types of documents used in international trade, but none that are traceable electronically and globally.

In most cases the fashion brand companies have control of the transport operations that take place after Tier 1 only, see Figure 2. The tracking that takes place prior to Tier 1, currently is at batch or lot level in production. A batch could be shared many times along the value chain, and rarely has satisfactory documentation to be able to be traced all the way as there is no technology to follow at a lower level than at batch level. The difficulty is to trace the material during shipping, as the material is not traced individually in the transport stage without the labeled and traceable package. Each package may contain several materials, from different production lots, as well as one batch could be divided into several packages during shipping.

If the products are equipped with RFID tags (in hangtags), these are used in logistic processes, such as receive checks, when goods are delivered to warehouses, stores, etc. The use of RFID technology in these operations is clearly advantageous, based on the high level

of accuracy and instant result. Also, the RFID technology enables the staff to search for a specific item missing, see more details in section 11.1.

5 Textiles sorting and information requirements

One of the tasks in the Tex.IT project was to define an information model for an IT system capable of representing information about garments. The information model must be able to represent the information which is needed at the sorting facility to make sorting more efficient. This section presents research on this topic, what information is needed, and possible methods for encoding it.

5.1 Sorting process hierarchy

The textile sorting process should consider the EU waste hierarchy, see Figure 13, which aims at retaining as high inherent value as possible in the textile items and materials. However, highest priority is to reduce consumption and minimise the out-take of new material resources from our planet. This means, the very best option is to use what is already in your closet until the garments are worn out.

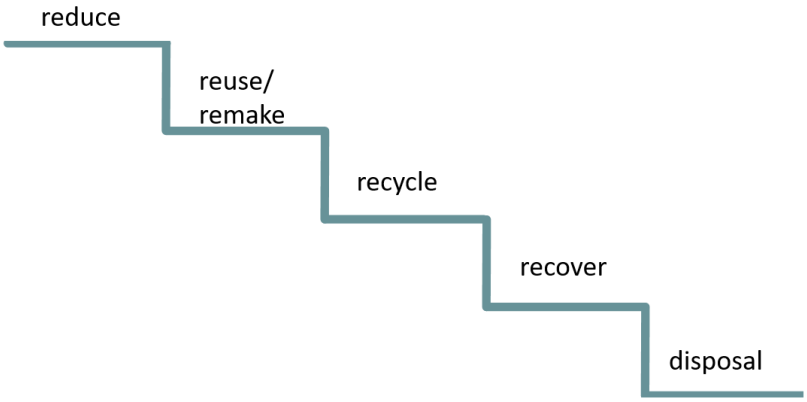

Figure 13: The EU waste hierarchy

5.2 Reuse/Remake Process

Secondly best, if garments that are still useable are handed in to charity organisations (through their collection channels like recycling centers, recycling stations, outdoor collection boxes, indoor collection bins and their own second-hand stores), in-store textile collection bins, or similar, the sorting process for reuse must be applied, to strive for keeping them in the use-phase loop as long as possible. LCA studies within the Mistra research program Future Fashion (2011-2019), show clear evidence that if a garment could be kept in the use-phase twice as long as today, the environmental impact considerably decreases. [3]

At the same level as reuse the remake term is found, which means if possible, reuse the textile materials for something else and transfer it into a remake process. This will retain the material value unchanged, which is preferable, since approximately 80% of the overall

environmental impact, measured during a garment lifetime, is generated from the production phase. [3] A good example of a successful remake process is the fashion brand Rave Review. They found and sorted out rejected home textiles at sorting facilities such as Wargön Innovation and through the sorting facility of Björkåfrihet, where material orders to RaveReview have been issued since 2019 ongoing. The fabrics were then remade into high quality garments, see Figure 14.

Figure 14: Screen shot from Rave Review home page. [4]

5.2.1 Björkåfrihet – RFID possibilities in the second-hand and sorting sector

The non-profit organisation Björkåfrihet, project participant in Tex.IT, has specified and described several areas where RFID technology potentially could contribute to future improvements in the second-hand industry. In Appendix A2, Björkåfrihet gives an overview about these areas, i.e. collecting, sorting, pricing, logistics, recycling and business models.

Björkåfrihet has also contributed with important and relevant information regarding sorting parameters summarised in Table 1.

5.2.2 Boer Group Recycling Solutions – large scale sorting prerequisites

Project participant Boer Group Recycling Solutions, a large-scale sorting and recycling company, was early in the project involved investigating the potential of using RFID technology in the textile sorting process. Appendix A3 comprises the comprehensive presentation prepared by Boer Group, regarding the RFID technology related to textile sorting.

Also, based on the Appendix A3 presentation, the most important parameters required for industrial scale sorting have been summarised in Table 1. Parameters such as brand name, product category, production date, colour and gender are very important to enable sorting based on clients demand and inquires.

5.3 Recycling process

The next, third level in the waste hierarchy would be to sort textiles for recycling if they are not possible to reuse nor remake into something else. Two possible recycling routes are feasible, mechanical recycling and chemical recycling, respectively. Today, large scale mechanical recycling is often done to produce material categories such as insulation or filling materials for various applications. No sophisticated sorting processes are therefore performed based on e.g. colour, fibre content, or similar, since the material ends up as a so called down-cycled fraction, a material that is of lower economic value compared to the original material value. If the mechanical recycling on the other hand is performed based on colour sorting and material content it is possible to re-spin the fibers into a new yarn and make a new fabric from it, however most likely with support from mixing in a certain amount of virgin fibers (what amount is required is very much depending on the recycled fibers quality, and the selected virgin fiber type) to achieve sufficiently good quality of the new recycled yarn.

The chemical recycling processes are beginning to reach a somewhat industrial/commercial scale, but limited textile materials still are possible to recycle through chemical processes. The most mature technologies can recycle cotton-based textiles (close to 100% pure cotton), polycotton (polyester-cotton-blend) textile materials, pure polyester materials, as well as nylon (polyamide) materials. Many companies have developing processes ongoing and a comprehensive summary of these could be find in Lifestyle & Design Cluster's report, published in January 2020. [5]

However, to recycle cotton into cotton is only possible through mechanical recycling. Chemical recycling of cotton textiles will result in so called man-made cellulosic fibers and/or regenerated cellulosic fibers.

Garments and textile products, too complex and/or too contaminated or treated with harmful chemicals, must be transferred to the second lowest step in the waste hierarchy – recovery, where the material is safely destructed by means of incineration combined with energy recovery. Lastly, which shall be avoided is to send the textile waste off to landfill.

5.4 Sorting process schematic structure

Figure 15 shows the stages of the sorting process at a sorting facility. The diagram shows steps where the garment RFID could be read and the information about the garment would be useful for making sorting decisions if such a system is built and made available.

RFID tags can be scanned from a distance and in bulk simultaneously. A bag could be scanned without having to open it and by retrieving the garment information, so planning of sorting could begin even before the bags are opened. Knowing mostly what kinds of garments there are or knowing that there are specific items to be retrieved during sorting could for instance be used for capacity planning at a sorting line or recycling equipment.

In the detailed sorting, the garment information could either be used for automated processing or displayed to humans doing manual sorting.

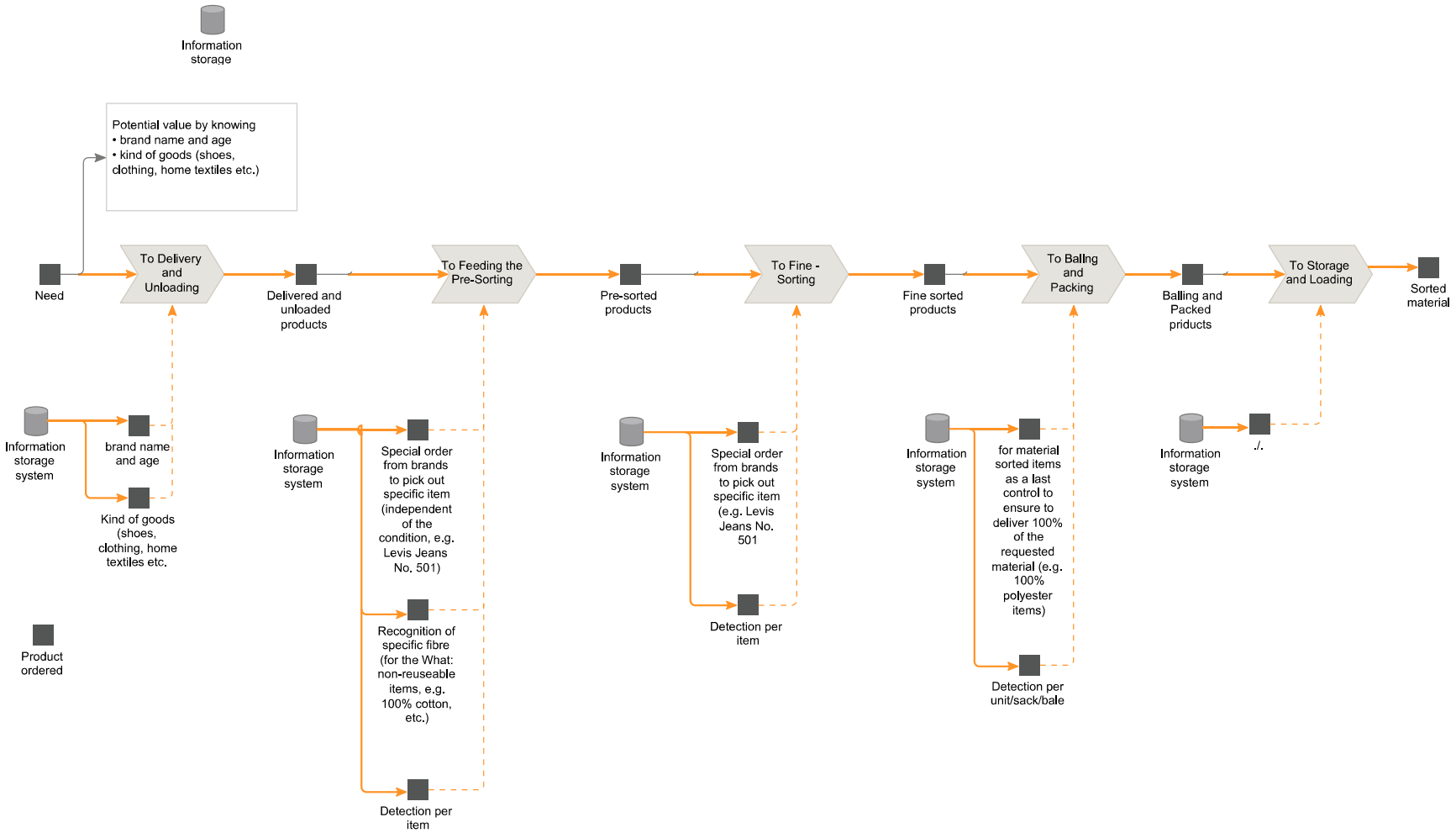

Figure 15: Sorting process schematic structure (illustration by LearningWell)

5.5 Information requirements

To gather requirements about the needs of the sorting facilities, interviews were performed with sorting companies and textile manufacturers participating in the Tex.IT project. In addition, textile recycling companies were asked, regarding their process prerequisites and requirements concerning textile materials.

Sorting for reuse is primarily focused on resell value and the condition of the garment. The original sales price and the brand name are a first indication of the resell value, but the value is also determined by factors such as the age (fashion style) and condition of the garment. The sorting will result that the garment will be sold in Sweden or another Western European country, exported to a lower price market, or sorted for recycling or destruction.

When sorting for recycling, it is important to know the kind of material the garment is made of. The various recycling processes are specific for the kind of material. It is also important to know what kind of other chemicals are present, such as dye stuff or finishing treatments. Some kinds of garments cannot be effectively recycled because of their construction, like for example a ski jacket of multiple layers of materials. In Table 1, sorting requirements for different purposes are summarised.

Table 1: Information requirements summary within the sorting, second-hand and recycling sectors.

No.	Input from company within sector: Parameter	Sorting		Second-hand/reuse and sorting		Mechanical recycling	Chemical recycling
		Reuse	Re-cycling	Reuse	Recycling (future rfid)	Recycling	Recycling
1	Product name	X					
2	Brand name	X			X		
3	Production date (or year)	X			X		
4	Product category	X					
5	Gender	X					
6	Colour (main colour)	X	X			X	X
7	Fiber content (complete details)	X	X	X	X	X	X
8	Materials for non-textile items		X	X	X	X	X
9	Chemicals		X		X	X	X
10	Degree of Fashion (Modegrad)			X			
11	Price as new			X			
12	Condition			X		X	
13	Origin of production (country)			X	X		
14	Material construction				X	X	
15	Finishing agents/treatments					X	X

However, it is important to remember the data addresses different stakeholders. For consumers only minor information part will be shown on a digital product site, e.g. in a web shop. Example: Zalando Product Site: '*Embroidered Sweatshirt*', which mainly includes commercial data like descriptions, photos, etc., hence this information need to be human-readable.

For the textile sorting stage, the data processing shall be automated. The person at the sorting station will mainly see the output of the algorithm. The same thing must happen when textiles are sorted for recycling and calculated results is mainly needed, including product data like information about the different production steps (location, what dye-stuff/print-stuff have been used, etc). Therefore, these primarily need to be machine-readable and well standardized.

Standardization of colours would also be preferable and some options to consider basing a colour definitions list on would be *Pantone® Color Systems – For Textiles*[2], *NCS – Natural Colour System®* [3]or Colour Index™[4].

Some data is consequently needed both within the textile and fashion brands own business systems, as well as in a sorting software. Therefore, this kind of information needs to be stored machine-readable and possible to be transformed into a human-readable format.

5.6 Chemicals and chemical aspects

Information about harmful or potentially harmful chemicals that possibly can be found in textile materials and products, will be crucial in future circular material systems to protect both humans and the environment, from especially hazardous ones. For example, if a batch of textile products is handed in for mechanical recycling and it is *not* noticed that they contain a certain hazardous substance, e.g. a finishing agent, it is a considerable risk that this substance will be further spread to other textile materials that are simultaneously recycled, or end up in other products. Perhaps in a somewhat worst case, the mechanically recycled textile material will be used as stuffing in a kid's toy, if the producer is not a responsible company, where the hazardous chemical risk to cause harm.

Fidra is a non-governmental organisation (NGO) within the UK, which for several years has been working with issues dealing with chemicals in textiles, and specifically textiles used in the furniture sector. Fidra's work within the project has been summarised in Appendix A4, where Fidra describes the possibilities that RFID technology can bring in terms of transparency from a chemicals content perspective through the furnishing supply chains.

The textile and fashion brands participating in this project have all so called 'substances restriction lists' (RSL), where problematic chemicals are listed and consequently banned to be used in the production of their products. Almost all RSL follow strictly the REACH legislation,

[2] https://www.pantone.com/eu/en/color-systems/for-textiles
[3] https://ncscolour.com/sv/ncs/
[4] https://colour-index.com/

since it otherwise is impossible to introduce products to the European market, which do not comply.

6 Standards

SIS, the Swedish Institute for Standards, has conducted a project, to evaluate the need of standards to catalyse implementation of RFID tags in garments. The project was funded by the Swedish Environmental Protection Agency within the framework of the regulatory letter from the Ministry of the Environment for the year 2020. [7] Textiles are highlighted as a focus area and by 2025, municipalities will be responsible for the collection of textiles and preparation for reuse or recycling instead of being discarded as household waste.

The work has been performed within the Task Group (TG) 1 – Digital Information Carriers under the leadership of SIS. Mapping activities has been carried out regarding what valid standards are available within the area of digital information carriers. Today, the necessary information required on how to handle textile materials at "end-of-life" is missing. By standardising an information structure adapted to the textile industry, the foundation can be laid for an efficient circular system for textile materials handling.

Main conclusion from this mapping project is that there is a need for common ways to define and structure the data to be available at "end-of-life" or end-of-first, second, etc. use and to verify data validity as well as data security. This in turn will facilitate the development of additional standards in the field. The full report (in Swedish language) is enclosed this report as Appendix A5.

Following the mapping project, a technical specification (TS) has started to be prepared by the Swedish working group AG 09 'Miljöaspekter' (environmental aspects), under the SIS Technical Committee SIS/TK160 Textil. [8] The TS will serve as a base for a future ISO standard regarding information requirements for end-of-life handling of textiles.

In parallel to the Tex.IT project, Sweden has been given the secretariat at ISO level for the international working group ISO/TC 38/WG 35 – Environmental aspects, and leads this standardisation work via SIS. WG 35 aims at developing an ISO standard towards a common understanding regarding terminology within the textile environmental area, to better utilise textile resources and minimise e.g. greenwashing. A draft standard regarding vocabulary has been developed: ISO 5157, Textiles — Environmental aspects — Vocabulary (Enquiry expected July 2021). Contributing work has been performed within the corresponding Swedish group AG 09, described above. [8] The draft will be available for commenting in a public enquiry in the autumn 2021.

Standardisation work is based on consensus, which is a time-consuming process. A draft undergoes a formal set of ballots and commenting periods in the development process, which lasts for approximately 36 months to final approval. ISO 5157 is expected to be published in 2022.

The strength of standardisation is the robust consensus process. This also includes the referencing to other standards when possible, to prevent reinventing the wheel. This is the case also in textiles, where other technical committees within ISO and CEN (European standardisation organisation) are developing standards are of relevance. For instance, standards from the plastics committee and circular economy will be paramount to use as reference. Other relevant ongoing standardisation is especially in the field of circular economy, where standards are being developed that will have a fundamental impact to many sectors including textiles.

7 Information model and system architecture

As a starting point for the development of an information system, an excel file was created and filled with as much textile value chain parameters and information as possibly identified, divided into differentiated levels. First level intended to include parameters and information regarding the textile and/or fashion brand company, responsible for a certain product or number of products put on the market. The second level included parameters referring to each product, the third level included information regarding any kind of labelling, e.g. environmental labelling and the fourth level covered the material related details. The two remaining levels fifth and sixth, comprised information about the manufacturing processes and the chemicals used during manufacturing, respectively.

The *one* tab, in the excel file, which gathers all possible information required to completely describe a textile product from fibre to finalised product is enclosed as Appendix A6.

7.1 Bill of Materials

The fashion industry already works with a document called Bill of Materials, BOM, which is a description of the garment and its component parts and possibly assembly instructions. The BOM is used for inventory management, production planning, ordering, and pricing. From the point of view of the Tex.IT project, the BOM provides a description of the garment, but it is for the following reasons, not sufficient to meet the information needs for sorting into reuse or recycling categories.

- BOM files do not follow any standardized format.
- BOM files are often in a natural language rather than a format which is directly machine interpretable.
- BOM files appear in different languages depending on the locations of the businesses using them.
- BOM files are primarily used for production planning and making orders, so the information content is limited to what is needed for these purposes and they do not generally contain all the information which is needed at a sorting facility for reuse or recycling.

7.2 The circular.fashion information model

As explained, the bill of materials itself is not a workable solution for providing information to the sorting process. It is necessary to define a file format for describing a garment from the point of view of the needs of the sorting processes.

During the project it became clear there are some other initiatives ongoing, e.g. Eon group (US) and circular.fashion (DE). circular.fashion, who cooperated with the Tex.IT project participant Nicole Kösegi representing The Boer Group, investigated the possibility to become a project participant. The information model developed by circular.fashion was evaluated and it was determined that this information model satisfied most requirements identified in the Excel sheet and circular.fashion was invited to join the project, instead of the project developing another information model from scratch. The circular.fashion information model is available on github [21] and is currently licensed under GPL 3, with intentions to make it an official standard.

7.3 GDSN information model

Another information model to consider is the Textile Material definition in the Global Data Synchronisation Network, GDSN [14], defined by GS1's global user community [15]. GDSN is an information system in which information about products can be shared between trading partners in a network of data pools. Product data in the GDSN is normally created and maintained by the producer or brand owner. The GDSN standard for product data consists of several information modules of which the Textile Material Information module is the one that allows declaration of textile material contents. To analyze whether the GDSN standard for product data sharing would be sufficient an analysis beyond the Textile Material Information Module must be done. Data elements relevant also for non-textile product categories are found in other GDSN Information Modules. Examples are season and gender (both in the Marketing Information Module), and colour (in the Trade Item Description Module), that are available in the standard, all in coded format. There are a few information elements that can currently be provided as free text form only. However, since all GS1 standards are constantly maintained, new features can be added to support new needs. The GDSN standard still lacks sufficient detail in treatments and other chemical composition needed for materials recycling. Nevertheless, it might be possible to expand the capabilities of this information model in the future, instead of defining a new one.

7.4 Sample use cases

We use several use cases for illustration and exploration of the sorting process and the information processing needs. The use cases are categorized based on whether the sorting facility is sorting for reuse or for recycling, though naturally a facility could perform both kinds

of sorting. Sorting for reuse should be made in the same building or at close logistic junction for efficiency environmentally. To finance a big sorting structure including sorting for recycling, sorting for reuse must be included to financially cover the sorting for recycling.

The use cases labelled "RU" are about reuse and those with the label "RC" are about recycling. The use cases exemplify typical needs for sorting information. Appendix A7 shows how the circular.fashion information model can be used to express the needed information in machine readable form for each use case. Making information in this form available at the sorting facility could assist in sorting, either by controlling sorting machinery or by being presented to human workers.

Use case RU1 – Premium item

In this use case the garment to be sorted is a down coat from an expensive brand. The garment is in good condition. It should be sorted for reuse on the European market, and it is desirable to know the origin of the down so this information can be provided to the potential customers when the coat is sold at a second-hand store.

When the garment reaches the sorter, the description of the garment can be shown to the sorter. The sorter will see that it is a well-known brand, and the production date is only a few years ago. The sorter will inspect the condition of the jacket and then sort it into the premium second-hand fraction.

Use case RU2 – Lower grade item

In this use case the garment to be sorted is a cotton blend pullover. It is in fine shape, but out of style for the western European market. It should be sorted for reuse in lower income countries.

In this case the sorter can see from the garment description that it is not an expensive brand and that the production date is almost a decade ago, so the item will be out of style. However, since the garment is in good shape, it is sorted into the fraction for non-premium second-hand.

Use case RU3 – Rejected item

In this use case the garment is a cotton T-shirt with a stretched out of shape, frayed edges, and holes at several seams. It should be sorted for shipment to a material recycling facility.

The sorter can see the poor condition and the garment description can be displayed so the sorter knows it is made of cotton.

Use case RU4 – Sorting for remake

In this case the textile is a bed throw. It is in good shape, but not marketable, so it should be sorted for remaking into something else.

In this case the sorter itself likely just makes a human judgement that a bed throw is not sellable as second-hand, but the information of the material content from the garment description will be useful for the manufacturer who will remake it into something else, like a coat for instance.

Use case RC1 – Cotton recycling

In this use case the garment is the worn-out T-shirt from use case RU3 when it arrives at the recycling facility. The T-shirt is pure cotton but possesses too low fibre quality to enable mechanical recycling, so it should be sorted to a chemical recycling process suitable for pure cotton textiles.

In this case the information that the garment is made of pure cotton facilitates the decision, preferably in an automated sorting system it can be sorted into the correct fraction.

Use case RC2 – Cotton blend which cannot be recycled

In this case the garment is a pair of blue jeans. The jeans contain 8% elastane, so they cannot be recycled.

The garment description file will show that the jeans are not made of pure cotton, but contain 8% elastane, so the sorter will know that it cannot be recycled in their process (too high elastane content).

Use case RC3 – Polyester recycling

In this use case the garment is a pair of worn-out training tights, impossible to sort for mechanical recycling (too poor fibre quality), hence it should be sorted to a chemical recycling process adapted for pure polyester textiles comprising dyestuffs possible to extract from the polyester material.

In this case the information that the garment is made of pure polyester and is dyed by means of a specific dyestuff, possible to extract, will facilitate the decision (preferably in an automated sorting system) it can be sorted into correct recycling fraction. However, for the moment being there are no publicly available information for the industry to use, regarding which dyestuffs are or are not possible to extract, why this use case must be put on hold for future research to resolve.

Use case RC4 – Rejected item

In this use case the garment is a worn-out ski jacket. It cannot be recycled because it contains layers of multiple different materials, glued and taped seams, and several non-textile details such as zippers, metal buttons, and also a RECCO transponder to enable finding a person in case of an avalanche incident. Since the jacket is totally worn-out, there is no second-hand value left in it, and the multi-material design and construction disables it to be recycled, the garment will be sorted into the waste stream, which will be sent off to an energy recovery process (i.e., incineration).

7.5 Information gathering

In the previous section we presented research on how to represent the information about textiles which is needed at the sorting facilities. In this section we present research on how this

information can be gathered, stored and distributed so it is available at the sorting facility at the time of sorting. This can be divided into two main aspects.

Firstly, the needed information of a garment must be gathered into a garment description file following the information model schema, as was presented in the previous section of this report.

Secondly, the garment description file must be stored and distributed so the sorting facility can get access to it when the corresponding garment arrives for sorting.

7.5.1 Sourcing the information for the garment description

A complication is that the required information for the garment description originates from different actors in the full supply chain. For instance, the required description of the chemical composition of the garment components might not be available at the brand or the garment manufacturer, but rather at a company which produces fibers.

In the previous section we looked at the bill of materials. The bill of materials has many limitations which makes it unsuitable to function as the garment description in the sorting process. Nevertheless, the bill of materials is a central information element which encompasses the make of the garment. Therefore, the bill of materials appears to be the key point for driving the process of collecting the garment information. The bill of materials contains a description of the material components required as well as metadata about the garment such as season, size, colour, etc.

As noted previously, the bill of materials does not contain all the required information, but it is a starting point which lists all the components of the garment which must be described. If the bill of materials is enhanced so it contains all the information required for sorting, then the garment description file can be constructed from the bill of materials.

These requirements on the bill of materials imply in turn that suppliers of components must provide the required information so it can be collected into the bill of materials. This is likely a major hurdle towards adoption of a system like this since information formats are not unified across different companies. For instance, colour coding is done differently by different companies. To solve this problem, the garment description information model must be standardized and play a role in standardizing the formats of information gathering.

Figure 16 illustrates how required information must be gathered from suppliers into the bill of materials which then should be used to derive the garment description file.

In addition to the information from the suppliers, some information required for sorting will come directly from the brand or manufacturer, like for instance the season of the garment.

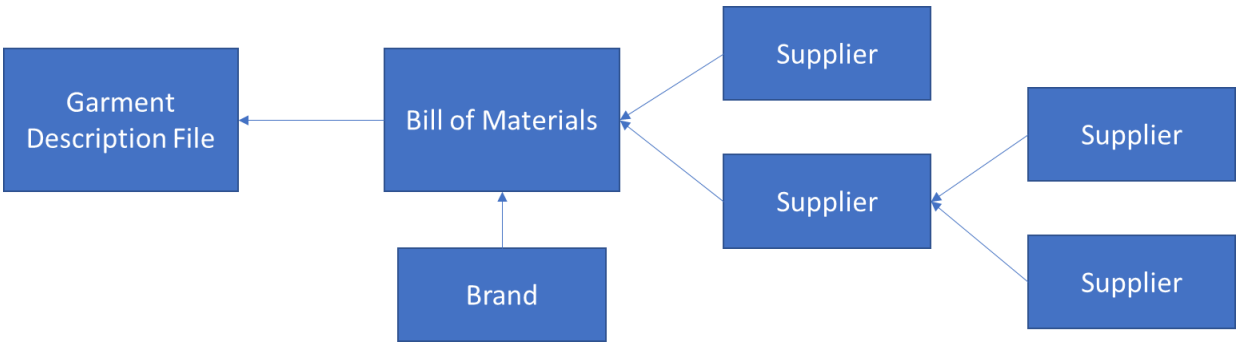

Figure 16: Garment description information must be sourced from the brand itself and the suppliers of the materials and components. The bill of materials is the coordination point for this process.

7.5.2 Creating the garment description

Garment producers typically work with a Product Lifecycle Management, PLM, software. The PLM software is used to perform tasks among others related to the design, planning, manufacturing, and pricing. The bill of materials is managed in the PLM software.

The BOM can be used to generate the garment description file, assuming the required information has been collected from suppliers and is present on the BOM. The process should be done by a software component, which is called the garment description file generator.

In general, there are two conceivable architectures for how to implement the generator component in an automated manner. It could be implemented as a part of the PLM software by the vendor of the PLM software, or perhaps by a third party if the PLM software allows for custom software extensions. Or it could be implemented as an external component which accesses the information in the PLM software. Finally, if the bill of materials cannot be accessed in machine-readable fashion, then the garment description must be generated manually.

7.5.3 PLM software contains garment information generator component

Figure 17 illustrates the case in which the PLM software has been enhanced with a component which can produce the garment description file. This could be done by the vendor of the PLM software itself or as an extension to the PLM software, depending on the capabilities of the PLM software and the willingness of the PLM software vendor to provide this function.

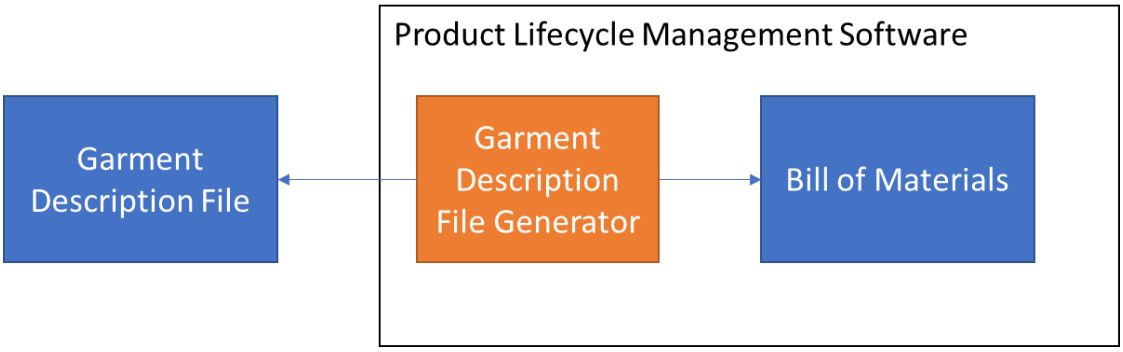

Figure 17: Illustration of an architecture where the PLM software has a component to generate the garment description file.

The generator module is a part of the PLM system and accesses the bill of materials, retrieves the required information from it and outputs the garment description file which is exported from the PLM software and can be stored in the information storage system (see the next section).

7.5.4 External program produces garment description

Alternatively, if the PLM software cannot be extended because it does not offer a capability to accept custom software extensions and the vendor is not interested in implementing a generator module, the generator module could still be implemented if the bill of materials contains the required information and the PLM software has an integration API. Integration APIs in the form of HTTP/REST services are commonly available in modern enterprise software, such as PLM systems. Figure 18 illustrates this alternative.

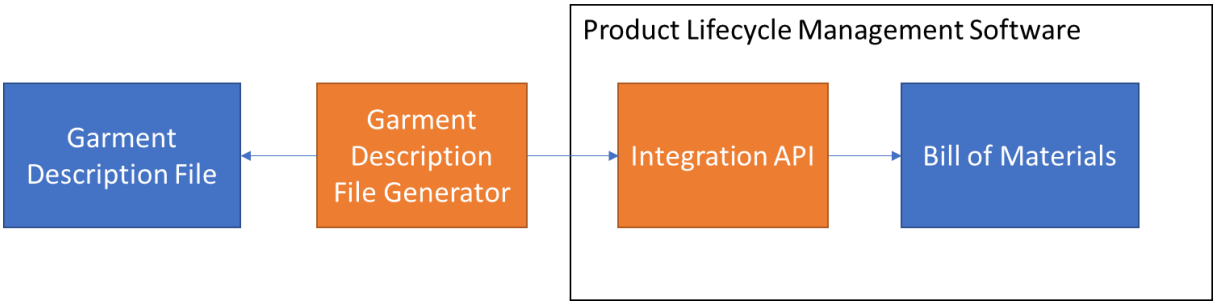

Figure 18: Architecture for the case when the garment description is produced by an external program.

In this case the generator module is a computer program which is external to the PLM software. The generator accesses the bill of materials indirectly through the integration API of the PLM software and generates and outputs the garment description file, which can then be stored in the information storage system.

7.5.5 Manual generation of the garment description

If the PLM software neither can be made to produce the garment description nor the PLM software has an API to provide the bill of materials in a well-defined machine-readable format,

then another approach which can be considered is to export the bill of materials as a human readable document from the PLM software and produce the garment description from this document.

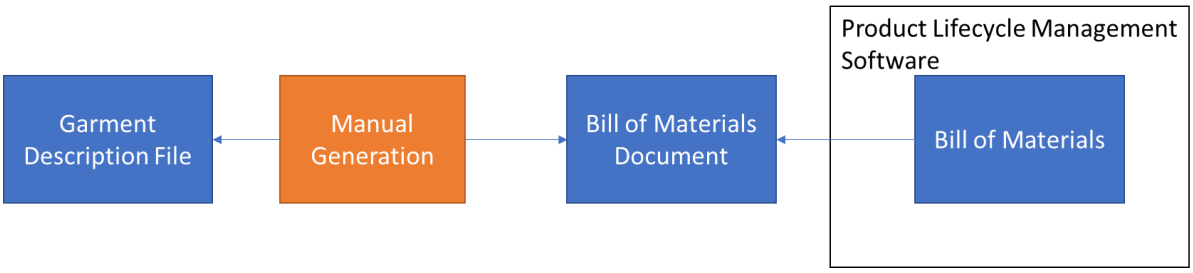

Figure 19: Manual generation of the garment description file.

This approach is unlikely to work well. A bill of materials document exported from the PLM software is produced for human consumption. It will be written in a natural language and formatted for reading by humans. When the bill of materials is represented in this manner, for example as a PDF document, the data is no longer structured in a well-defined machine-readable format, so it is complicated and error prone to interpret the contents with an automated software program. So, producing the garment description will likely be a manual process. Figure 19 illustrates this approach. Note that even though the process is manual there must still be a software tool for generating the garment description file since most people are not comfortable with working directly with data formats such as XML.

A likely complication with this approach is that unless the PLM software is enhanced for the specific purpose of generating a garment description file, it is unlikely that all required information will be available in the BOM document which is exported for human consumption. This means that some of the required information must be gathered by a manual process by contacting suppliers for getting this information.

Working with an exported BOM document might be necessary as a last resort in a small-scale business which does not have the IT capabilities to automate the generation of the garment description file. However, this is not going to be efficient for anything but businesses with the very smallest of volumes of production.

7.6 Information storage, distribution and lookup

The idea in the Tex.IT project is to tag each garment with an RFID tag with a unique identifier. Storing the full garment description on the tag is considered infeasible because the memory capacity of a low-cost tag is small. A low-cost tag might have memory only for the product code and if it has user memory, a typical size of it is 512 bits. The garment description files in the appendix of this report are already in the range of 1 – 2 kBytes, even while they are artificially small since they cover only the example use cases that have been used in the project, and not full

descriptions of garments. Additionally, the data transfer rate from the tag is relatively slow, which would mean that there is not enough time to read the tags in the sorting process if they store large files. Instead, the garment description must be stored in a separate database, and the tag id is used to find it.

Another benefit of storing the garment description file in a database is that it would be intractable to update the garment description if it is stored on the tag when the garment has been sold and no longer available to the manufacturer. Updating the garment description could be useful to correct errors or to provide updated information. A possible need to update the information could perhaps be that regulations about chemical use might change. For instance, a mattress cover might be treated with a flame retardant, which is later prohibited, so it should not be sorted for reuse or recycle.

The identifier and the garment description file corresponding to the specific garment must be stored so the sorting facilities can find the garment information when the garment arrives at the facility at a later point in time. Note that a single garment description file can be referenced by multiple unique garment/tag identifiers in case the garments have the same composition, colour, size, and other properties.

There are multiple challenges with providing and accessing this storage.

- Garment supply chains and production facilities are located globally in various places.
- It may be hard to predict when and where a garment will show up for sorting.
- The brand or manufacturer of the garment might no longer be in business when the garment arrives for sorting.
- The garment industry is decentralized and there is no natural single operator of the data storage.
- The number of garments to be potentially stored in the system is large.
- Some of the suppliers may consider some of the material makeup information to be business confidential trade secrets.
- The tag identifier must survive the garment lifetime and be readable when the garment arrives for sorting.

7.6.1 Blockchain

The initial project plan mentioned the possibility of using a blockchain for storing and distributing the information required at the sorting facility. A blockchain has the benefit that it is a decentralized database and does not depend on any single operator for security and reliability, which might be an advantage in the garment industry which itself is decentralized. However, blockchains also have drawbacks in the form of more complex operations and relatively low transaction and storage capacity.

Ultimately it is an organizational or political question whether to use a blockchain or another form of database. If the global garment industry can be made to organize one or a few providers of the storage service, a traditional or distributed database is going to be more efficient. Within

the Tex.IT project, since there are many other more immediate challenges in just collecting and presenting the required information in a uniform, ultimately standardized manner, we have chosen to keep things simple for now and not recommend developing a blockchain solution at this stage. A regular database will at this stage be simpler and offer a more cost-efficient way to solve the more immediate issues. Once these have been solved and the matter comes to deciding how to manage the operations and continuity of the system, the option of using a blockchain or another form of decentralized storage can be revisited.

7.6.2 Basic functional requirements

Fundamentally, the operations required to meet the requirements of the sorting process are very simple. Access to the database is mediated through an API, perhaps HTTPS/REST based since this is currently a popular technology for public APIs.

Essentially, at a simplistic conceptual level, only two operations are needed. One to store a garment description for a garment which has been tagged by a specific id in an RIFD tag and another to look up the garment description corresponding to a given id retrieved from an RFID tag on a garment. These two operations are represented by two functions in Figure 20. In an actual implementation there would be more functionality, like a function to authenticate to the service or a function to retrieve data in bulk operations for increased efficiency.

The first function "putGarment" does not return any value ("void" means that no data is returned) and takes two arguments, the garment id as a string and a byte array which contains the garment description file. The given file is stored in the database as the description of the garment with the given id. This function can also be used to update the description by replacing an already stored file. Updates might be needed for instance if environmental regulations change and more information about the chemical composition of garments is needed after they were sold.

The second function takes the garment id as an argument and returns a byte array containing the garment description file of the garment with the given id.

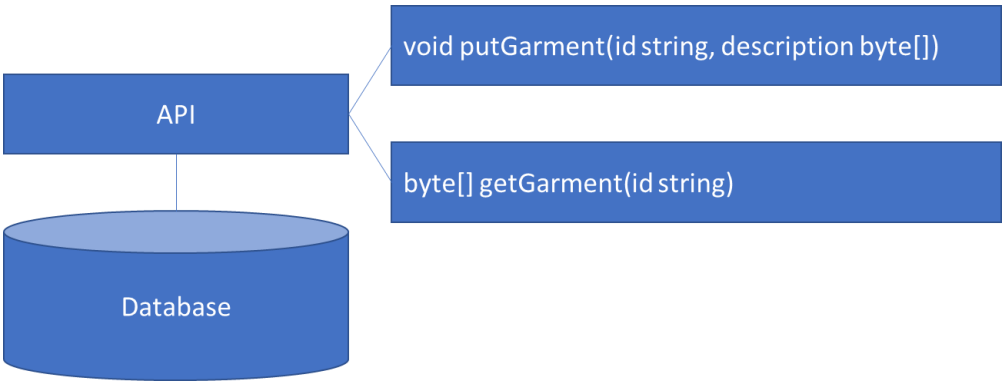

Figure 20: Basic functional requirements

7.6.3 Performance and caching

It is important that the information is available quickly during the sorting process. Making remote calls to a global database at the time of sorting might be too slow for some automated sorting. This can be mitigated by a local cache, see Figure 21. A cache is a smaller data store more closely located and accessed more quickly than the underlying primary storage. Data in a cache is kept only temporarily to improve performance.

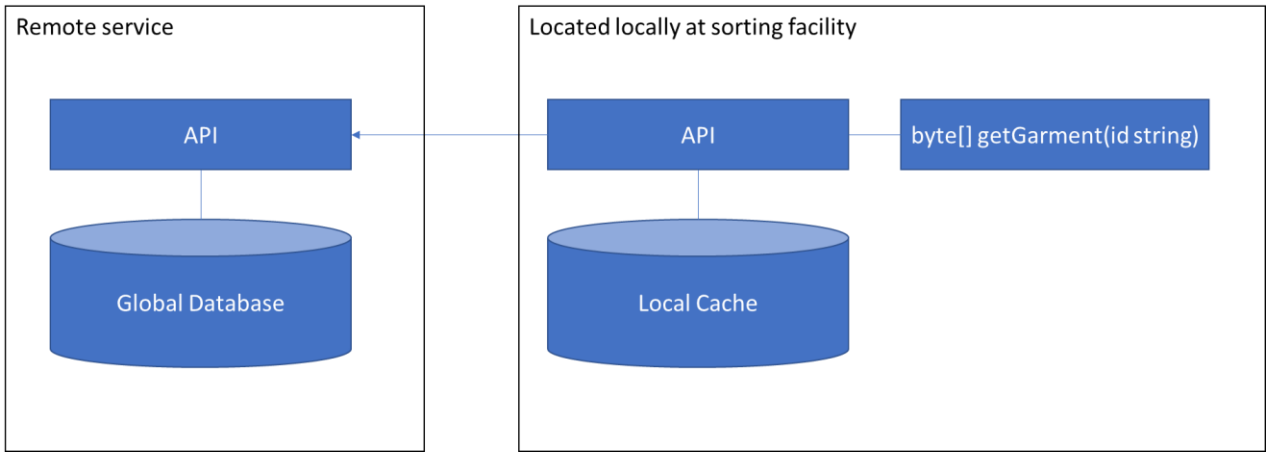

Figure 21: Performance and caching

When a bag of garments is received at the sorting facility and is scheduled to be sorted in the near term, perhaps during the next day, it can be scanned, and all the garment ids are read from the RFID tags contained in the bag. As the bag is waiting to be processed, the system at the sorting facility can take all the garment ids and look up their description files from the global database through a remote service and store copies in the local cache.

When the garments are processed in the sorting facility, the data will be available locally in the cache and can be retrieved very quickly (with low latency) so the sorting process can proceed with high speed.

The data in the cache can then be expired, either by a confirmation from the system that sorting has been completed for a given garment, or by automatic expiration of some period of time, say within three days, by which time the garments will have been processed.

7.6.4 GDSN

The Global Data Synchronization Network, GDSN, [14], is a distributed data sharing network defined by GS1. It allows sharing product information through supply chains. The information is

defined through standardized XML[5] schemas[6] and is transmitted using the EDIINT AS2[7] protocol, which is based on S/MIME[8] messages transmitted over HTTP[9].

The network is based on subscription model, so parties can subscribe to updates to product data over the network. The GDSN could be an option to use instead of implementing a new system.

7.7 Conclusions and recommendations

The format for the garment description file should be standardized. This is necessary since it would not be feasible to implement IT systems for sorting facilities which could interpret any non-standard format. There are simply too many vendors of PLM software to be able to keep up with all proprietary formats if each vendor defines their own format.

Adoption could perhaps be a challenge because the main benefit of the system is provided at the time of sorting at the end of the life of a garment. This means that at each prior step in the life cycle of a garment, gathering and tracking the garment information might appear as just a cost, with no obvious benefit to the manufacturer or the brand, apart from relevant information required for communication with clients. However, the sorting process may also generate data of high value for the brand owners since they probably can utilize the data to monitor their circularity performance. Also, the return on investment (ROI) investigation, and cost calculations in section 11 implies there are significant values for the brands to gain from adopting this kind of information system, e.g. at inventory and logistic activities.

To facilitate adoption, it would be good to provide a reference implementation of the garment description information model as an open-source library. If a permissible open-source license is used, providing this library would make it simpler for PLM vendors to implement this functionality in their products.

The open-source library should provide functionality to assist the vendors in implementation, such as:

- The definition of the garment description file format in the form of a grammar.
- A parser of garment description files.
- A programming interface to access the file contents.

[5] XML, eXtensible Markup Language, is a text-based machine-readable encoding of information.
[6] A schema refers to a definition for the structure of an XML document. The schema provides a specification for how information must be encoded for a specific kind of XML document and can be used to validate that the document follows the specified structure.
[7] EDIINT AS2 is a protocol for performing EDI, Electronic Data Interchange, over the Internet. EDI is about digital exchange of data such as invoices and purchase orders between businesses. It was traditionally done through dedicated data lines, but Internet provides a more cost-efficient alternative today.
[8] S/MIME is a data format for encrypting and/or digitally signing data. It was originally developed for securing email messages but is also used in other contexts.
[9] HTTP, HyperText Transfer Protocol, is the standard protocol used to access data on the world wide web.

- A programming interface to provide file contents and to serialize it to an external file.
- A programming interface to perform queries and searches in the file contents.
- Connectors to the APIs of the data storage and distribution services, most likely using web protocols such as HTTP.

8 Security and privacy

Using RFID tags and making the textile information available may constitute information security and privacy risks. In this section we look at the risks and how they can be mitigated.

There are risks from two sources: the use of RFID tags and storing and distributing the garment descriptions.

8.1 Securing the garment descriptions

The information about the garment construction is potentially a security risk to the businesses if parts of this information is considered business confidential. At first glance, what has been seen within this project, the information about the textiles does not appear to be highly sensitive. Information such as the type of fiber, size, season, etc., are already visible on a hang tag for instance.

However, this might change in the future if it becomes evident that more detailed information is needed for recycling processes. Chemical recipes might be considered trade secrets. If this is the case, perhaps it may be possible to define standardized recycling processes and a textile could indicate which process it is suitable for, without revealing detailed makeup of the chemical recipe.

If it is necessary to have business confidential information in the garment description, then the garment descriptions must be protected by access control. The garment descriptions are assumed to be stored in a database which is accessed by a remote API. The API layer must implement this access control.

Implementing access control in an API which provides access to data is a very common situation in modern IT applications and the technologies are readily available as common components, patterns, and practices. So technically this is a relatively easy problem to solve. The challenge lies in that the textile industry is large and diverse and it cannot be predicted exactly when and where a garment will show up for sorting.

The global scale of the textile industry means that if the information is truly sensitive, then collecting it in a single place becomes a problem. This central database would become a major security risk and possibly not acceptable for the companies to use. If so, it would be necessary to decentralize the lookup of the information so that each business can store its information in its

preferred location and a directory service of some kind is used to find the location of the storage when the information of a garment is retrieved. However, this issue is solvable with basic, commonly used technology. One example is the recently released standard GS1 Digital Link, which is built on well accepted web technologies and describe how GS1 standards for identification, data carriers (including RFID) and web technologies ca be used to support the connection of a physical product with its digital representation in a decentralized environment. The same id/data carrier can also be used to support all steps of the supply chain.

The issue that a garment can show up in unpredictable places means that access to the garment information must be made available to all these sorting facilities. The more parties have access to the information, the more risk there is that some of them abuses the information, either by intent or by becoming a springboard for attack against the system.

However, there is technically nothing to prevent setting up access control to the information based on a risk analysis and defined access control policies. A simple policy would be that all sorting facilities get access to all information, but if this is deemed too risky, then perhaps the information could be restricted based on sales region, presuming that garments are mostly used and sorted in the same region where they were purchased.

8.2 RFID security and privacy

Use of RFID tags themselves may constitute risks for both businesses and for consumers.

The National Institute of Standards and Technology, NIST, in the USA has provided a report [16] with guidance around RFID security to US government agencies and the private sector. The guide contains a comprehensive review of security and privacy risks from the use of RFID tags. In the EU, the European Commission has issued a recommendation [17] that all RFID operators should conduct a privacy impact assessment, PIA. GS1 has made available a tool [18] in the form of a macro enabled Excel sheet to aid in performing this assessment. The assessment is based on identifying risk areas and then providing controls to manage the risks.

Overall, there are risks both for organizations operating tags and for consumers.

In terms of the companies in the textiles industry, to mention just a few examples of risks, thieves might be reading tags to plan thefts, tags could be used for competitive intelligence or tags could be copied to falsify goods. A full analysis of the risks for the companies is not feasible for us to do within the Tex.IT project because it depends on how RFID are deployed for logistics and other use by the companies and the risk management strategy the companies choose.

It is perhaps unlikely that the garment industry would deploy use of RFID for the sole purpose of sorting textiles, rather the applications of RFID in general are growing anyway in logistics and retail for reasons of the efficiencies RFID enables. Thus, within the Tex.IT we put the emphasis on the potential additional risks that arise from the Tex.IT requirements on the use of RFID and expect that the many basic security and privacy risks of RFID in logistics and retail are handled

within the scope of the general deployment of RFID in the textiles industry. Naturally, this assumption might turn out to be wrong, in which case the treatment of this topic within the Tex.IT project will not be sufficient, but it represents a starting point in either case.

A key difference in the case of the Tex.IT idea is that the tag must live through the whole lifetime of the garment and cannot be permanently killed or removed at the time it is purchased by the consumer.

That the tag is live is a privacy risk since the tag could be used to track consumers wearing the tagged garment. The seller of a garment might know the identity of the person wearing the garment. Or the clothing worn by a person could be scanned in a situation where the person is identified and then registered on file, say when the person is making a purchase in a store for other items and is identified through a credit card or a customer loyalty card.

The motivations for tracking people could be for marketing purposes. This already happens on a massive scale through mobile phone apps and WWW cookies, so the demand for collecting information about consumers certainly is there.

Because the project idea crucially depends on the tag being functional until the sorting process and the privacy risks are real, we have put an emphasis on exploring the privacy risk to consumers to ensure that there are solutions to these issues. Without a solution the whole idea of using RFID to facilitate sorting would become moot.

8.2.1 Consumer privacy threats

The concern for consumer privacy is that a tag has a unique id. If someone knows who purchased a garment with a tag with a given id and then finds this tag on a person, it is likely that the person wearing it is the identified person, thus allowing tracking of this person whenever they arrive at a reader, say at the entrance of a store.

Even if the garment is not identified with any specific personal identity, reading the tag would still reveal that it is the same person on each occasion. And the tag might be connected to an identity later, by several different means, such as wearing another tag which is identified or making some other purchase.

Solving this issue is technically non-trivial. One could consider simply encrypting the id on the tag. In this case reading the tag contents will return encrypted data and no one could interpret what the tag id is without access to the correct decryption key. However, this does not solve the privacy issue. The tag will still respond with encrypted data, which itself will be unique and static, so it can be used for tracking the tag. A proper authentication protocol without static messages will be required.

Li, Deng and Bertino [19] have a review of the academic literature on this topic and one could categorize the solutions to this problem into two broad categories. One category of solutions is based on the idea of updating the tag id each time it is read. The other category is in the form of challenge-response protocols. In a challenge-response protocol the reader will send a message to

the tag and the tag will respond, but both these messages contain random numbers so they will never repeat, however using the correct decryption key, the tag identity can be read from the message exchange.

A challenge with all these protocols is that they depend on shared secrets in one form or other, so they introduce a key distribution problem, see the section on this topic further ahead in this report.

8.2.2 Tag security capabilities

This section looks at the security capabilities of RFID tags as they have been defined in the standard communication protocol. GS1 has published the specification [GS1] which defines the protocol which the reader and the tag use to communicate. The protocol is defined as a state machine in the tag with messages sent between the reader and tag.

The full protocol is not explained in this report, rather we focus on relevant security features. There are many other parts to the protocol, such is mechanisms avoiding collisions between tags when they are read in bulk. Other commands let the reader to read or write the contents of the tag. The tag can also be killed.

The specification includes some security features, but these are optional to implement and not all tags do so. There are also different variants of the security features.

A key feature which is needed is authentication. With authentication we mean a protocol that can establish the identity or legitimacy of a communicating party. In the context of RFID tags the communicating parties are the tag and the reader. Note that there are two directions of authentication here.

Authentication of the tag means that the reader can establish the legitimacy of the tag. Authentication of the reader is the reverse, that is, the tag can establish that the reader is legitimate.

In the context of Tex.IT reader authentication is needed so the tag will identify itself to only legitimate, authorized readers at the sorting facility (or other authorized readers if so defined). By authenticating the reader before responding with the product code, malicious readers cannot read the tags for tracking people.

Authentication of the tag is also relevant since it prevents falsification or duplication of tags. This is useful for brand protection for instance, but here we focus on the consumer privacy concern, so reader authentication is the more significant one for our purposes.

The RFID standards define two ways for authentication: by password or through cryptographic authentication protocols.

The RFID communication protocol is defined as a state machine and one of the defines states is a state called “Secured” to which it can be moved by the reader through authentication by either providing a password or by an encrypted security protocol. If the tag implements security, then

some operations require that the tag be first moved to the Secured state before those operations can be performed. For instance, the tag could be set up so reading the tag requires the Secured state. That means that the reader must know the tag password or be able to authenticate using encrypted protocols before it can perform these operations, such as reading the tag in this example, since reading will fail if the reader cannot move the tag to the Secured state.

One of the privileged operations is a command called "Untraceable" which allows hiding tag memory contents from view. This feature is suitable for protecting consumer privacy and we look at it in the next few sections after an explanation of tag passwords and cryptographic authentication.

8.2.3 Tag passwords

A tag may have an access password which can be associated with privileges. The password is a 32-bit number.

The reader may use the command "Access" to provide the password and move the tag into the Secured state. The password is transmitted in two parts.

1. The reader asks the tag to generate and transmit a 16-bit random number.
2. The reader uses XOR to add the random number with the first half of the password and sends this masked value to the tag.
3. The tag generates a second 16-bit random number.
4. The reader uses XOR to add the second random number with the second half of the password and sends this masked value to the tag.

This protocol provides some minor protection since the reader never transmits the password in clear text and the transmission range of the tag is shorter than that of the reader. However, this protocol is not secure because someone who can listen in to the messages can easily recover the password by unmasking the masked messages with the two random numbers simply by repeating the XOR operation.

This also means that keeping the password secret is difficult since the components and people who do the reading of the tags have access to these messages and can recover the password, even if the password would be stored in a secure storage, like a key server.

The conclusion is that tag passwords are not secure enough to protect consumer privacy in a system like this.

8.2.4 Cryptographic authentication

A tag may support security through security protocols based on encryption. The tag can contain up to 256 encryption keys for use in the security protocols.

A reader may initiate encrypted communication through the "Authenticate" command. This command has a field, cryptographic suite indicator, which indicates which cryptographic suite is being used. A cryptographic suite is a protocol specification for the secure communication

between the reader and the tag. The possible values for the cryptographic suite indicator have been sectioned and reserved for various standardization organizations to define.

ISO/IEC have defined several cryptographic suites in parts to the ISO/IEC 29167 standard, starting with ISO/IEC 29167-10.

The contents of the Authenticate command message is defined in the applicable cryptographic suite specification and varies from protocol to protocol. Secure communication is wrapped within messages called AuthComm or SecureComm. Again, the contents of these messages depend on the specifics of the cryptographic suite in use.

Encrypted communication provides much better security than password-based access and it is the recommended solution in this project.

8.2.5 Untraceable command and privilege

The RFID standard protocol provides a command called "Untraceable" which can be used to control access to the memory of the tag. This command is optional to implement, so not all tags will support it. However, it provides the privacy protection which we desire and is standardized, so it is the recommended solution in this project.

The RFID specification defines that the tag access password or the encryption keys can be associated with privileges. A privilege is the authorization to perform some restricted operation on the tag when the tag is in the secure state. Recall that a tag gets to the secure state by authentication through the access password or a key.

"Untraceable" is one of the privileges. This privilege provides two features to a reader which has authenticated with an authorized key: 1) it allows execution of the Untraceable command which can be used to restrict visibility of the tag contents, and 2) it allows access to the restricted parts of the memory of the tag.

The contents of the tag can be hidden from unauthorized access with the Untraceable command by performing the following steps:

1. Initially, at manufacture, set up the tag so there is a key which has the untraceable privilege.
2. Use a reader to authenticate to the tag using the key.
3. Use the Untraceable command to restrict access to the memory contents of the tag, including a part of or the whole electronic product code.

Now the tag contents cannot be read by readers who are not authorized with the correct key. To read the tag, use a reader which can authenticate correctly.

1. Use a reader to authenticate to the tag using the key.
2. Read the tag contents, which will work since the key has the untraceable privilege.

The tag can be unlocked as well:

1. Use a reader to authenticate to the tag using the key.
2. Use the Untraceable command to remove the access restrictions to the tag memory.

Using these commands, it is possible to restrict access to the tag when the garment is handed over to the consumer at the checkout from the seller of the garment. Because the tag is restricted, it cannot be scanned by unauthorized parties, so consumer privacy is protected. To allow the sorting facility to read the tag, the tag can be unlocked. Further ahead in this report, we show a system architecture in which authorized sorting facilities can request tags to be unlocked so they can be read during sorting.

8.2.6 Key management

Encryption requires encryption keys so keys must be embedded in the tags and readers or servers supporting reading operations. The process of making the correct encryption keys available to the right components is part of key management. Key management and distribution must be done securely, or the security of the system can be compromised. Badly performed key management can reveal keys to unauthorized parties, let unauthorized parties replace legitimate keys with compromised ones or make the system non-functional by interfering with it.

There are two categories of encryption algorithms in terms of how they make use of keys.

Symmetric encryption means that the same key is used for both encryption and decryption. Thus, the sender and receiver possess the same key and the key must be kept secret from other parties.

Asymmetric encryption (also called “public key encryption”) uses a pair of two different, but mathematically related keys. One of the keys is used for encryption and the other is used for decryption. The key used for encryption cannot be used to decrypt or to deduce the decryption key, so it does not need to be kept secret and is therefore called the “public key”. The key used for decryption naturally must be kept secret and is called the “private key”. For two-way communication, two pairs of keys are required, one pair for each direction of the communication.

The public-private key pair can also be used in the reverse order to make digital signatures. This is done by encrypting a hash of a message with the private key. The public key is used to decrypt the signature and if the hash is correct, it is confirmed that it was generated with the private key.

Asymmetric encryption has benefits for making key distribution simpler since the public key is not required to be kept secret.

For the textile sorting application, the difficult part of key distribution is to arrange so the sorting facilities can access encrypted tags. There are several factors which makes key distribution in the Tex.IT system hard.

There are many tags, which potentially could mean that there are many keys to manage. This is further complicated because a tag should not be identifiable (or it can be used to track people

wearing the tag), so one question is how the reader can know which encryption key among many possible to use when communicating with a specific tag.

If keys are compromised it is very difficult to replace them because it would mean that a tag must be reprogrammed which would require product recall to perform the key replacement operation on the tag.

It is difficult to predict which key is needed where and when because the arrival of the textiles with the tags to the sorting facilities is unpredictable. A tag might show up years later in another country than in which the textile was produced or sold, meaning that sorting facilities potentially might need to access any tag of the global system. The encryption keys needed for accessing tags must be potentially available to many, most or all sorting facilities. If keys are widely distributed, the risk that the keys are compromised at some point grows.

The suggested solution to solve these issues is to not distribute encryption keys to the sorting facilities. Instead, the system should provide a remote access protocol to key management servers which can perform key operations to authorized sorting facilities, without revealing the keys to the sorting facilities. The section on the suggested solution explains this in more detail.

8.2.7 GDSN

The GDSN network is an existing network, which we saw in the previous sections could be used for storage and distribution of the information about the textiles. However, it does not solve the problem of masking and unlocking a tag through remote access. Therefore, the GDSN network on itself is not sufficient to provide for the needs of the system we envision.

9 Suggested solution

In this section we take the conclusions about data storage and distribution and security and privacy and present a suggested solution architecture for data distribution. The suggested architecture for data collection was already presented in the previous section on information gathering. Figure 22 shows the suggested data distribution solution architecture.

At the sorting facility there is a component called “Sorting Planner”. This represents the computer system located at the sorting facility which manages the reading of the tags and the use of the textile information.

The sorting planner has access to an RFID reader which it can use to communicate with tags. A cache memory or database is used to store textile information for fast lookup during the sorting process. The textile information is either displayed on a display to humans or used to control sorting machines.

To make the textile information available to sorting facilities, there are storage services which provide access to tags and to textile information. There may be multiple providers of these

services globally and different textile producers and brands have their preferred service provider where they store their textile data.

The tag access service is used to get access to the information on encrypted tags. The tag access service uses an encryption key service to maintain a database of encryption keys to all the tags which are managed by this service. The textile information service has a database about textile information. This information is referenced by product codes as identified by tags and stored using the information model which is discussed elsewhere in this report. GDSN is a possible realization of this service.

The system should support that there will be many sorting facilities and storage service providers to avoid a centralized monopoly for these services. Therefore, there is a need for directory services to identify and locate them. A tag services locator is used by the sorting facilities to locate the storage service provider which manages the information for a given tag. In cases when GS1 standards (GTINs in barcodes and/or RFID tags) are used for product identification, it is a natural next step to upgrade to GS1s new standard called GS1 Digital Link. In this case the GS1 identifier in each data carrier is encoded as part of a web address, enabling the brand owner to point out where different types of data related to the product is located and can be retrieved, including sorting facilities. An authentication and authorization service are used by the storage service providers to authenticate and authorized sorting facilities when they connect to these services.

The solution assumes that tags implement encryption and the untraceable capability. When a garment (or other textile) is purchased and handed over to the customer (or earlier), the untraceable capability is turned on using an encryption key. The full product code is hidden, but a section of the memory of the tag is left open. This open memory section is used to store two pieces of data:

- A storage service provider id.
- A symmetric encryption key set id or a reader public key identifier.

The storage service provider id indicates which of the many possible storage service providers manages the information about this tag and the associated textile.

The encryption key set id is an indicator for the tag access service to help it find the correct key to use with the tag. It is important that the tag cannot be identified based on which key it is using. This problem can be avoided by having many possible keys in a set. The tag access service can request a challenge from the tag and then perform an exhaustive search among the keys in the set to identify the specific key on the tag.

If the tag can perform asymmetric encryption, the tag can instead return the public key which the tag expects the reader to authenticate with. Assuming that many tags have been preloaded with the same reader public key, then this key does not identify the tag, and the tag access service will directly know which key it must use to authenticate to the tag.

Note that there is a risk that a person could be identified or tracked by fingerprinting the person from the combination of tags the person is carrying on them. Each tag can be made to respond with the key set identifier or public key and although no tag can be uniquely identified from this, if there are many key set identifiers or public keys in circulation, the specific combination of different identifiers from the multiple tags might become unique to the person with the tags.

To avoid this, the same key set identifier or public keys should be used often so that it is unlikely that unique combinations are formed. Ensuring this requires some statistical modeling of tag use and distribution to estimate the risk and to mitigate the risk. These estimates have not been performed in the Tex.IT project.

Figure 23 shows the interactions between the components to access the tag. When a textile arrives to the sorting facility the tag is accessed and the information about the textile is retrieved before sorting. Since there are multiple steps in this process which involve calls to remote services over the internet, it might take too long to access the tag and retrieve the information during the actual sorting process.

Messages 1-3 show how the sorting planner retrieves the public information from the tag, which is still encrypted and locked at this point. This public information consists of the storage service locator id and the key set id (or reader public key).

Message 4 shows how the sorting planner uses the tag services locator directory service to find which storage service manages this tag. It does so by providing the storage service locator id to the tag services locator, which knows the identity and location of the storage service associated with any storage service locator id.

Message 5 shows the sorting planner requesting the appropriate tag access service to unlock the tag. Before the tag access service does this, it authenticates and authorizes the sorting facility. This is necessary or malicious parties could invoke the tag access service and unlock tags. The tag access service does this through message 6, calling out to an authentication and authorization service which maintains the identities of known, approved sorting facilities.

Once the authority of the sorting facility has been confirmed, the tag access service will search for the key in its database. If the tag uses asymmetric encryption, the corresponding private key be directly identified from the public key. If symmetric encryption is used, the key management server needs to perform an exhaustive search over the set of keys indicated by the encryption key set identifier provided by the tag. The protocol must contain a message which the key management server can use to recognize that it has found the correct key, that is when it can correctly decrypt this message.

When the correct key has been identified, the tag access service can perform a protocol to authenticate to the tag and turn off the untraceable protection on the memory of tag. This will consist of a series of messages between the tag access service and the tag. These messages are forwarded between them by the sorting planner and the reader. Messages 8-10 indicate this

communication, though in reality there will be multiple messages exchanges back and forth to complete the whole process of unlocking the tag.

The tag is now unlocked, and the sorting planner can read the product code from the tag, as shown in messages 11-14.

Message 15 shows that the sorting planner then uses the product code to retrieve the description of the textile from the textile information service. The textile information service authenticates and authorizes the sorting facility in message 16. This step could be skipped if it is determined that the information about the textiles is not confidential and can be public. The textile information is returned to the sorting planner in message 17.

Lastly, in message 18, the sorting planner stores the textile information in its cache memory or database, so it is quickly available when the textile goes through the sorting process itself.

Figure 24 shows the sorting process. The textile arrives at the reader. In messages 1-4 the sorting planner reads the product code from the tag. This is now possible since the tag has been unlocked. Next in message 5 it gets the textile description from the cache. It now has the description of the textile and it can either display it to a human (message 6) and/or control sorting machinery (message 7).

The cache can expire through a timeout, a size limit or through explicit message when the sorting is known to be complete. Neither option is shown in the figures.

9.1 Other use of tags

Encrypting the tag makes the tag unavailable for unauthorized users. This can complicate the use of the tag for other purposes than the sorting process. If a tag cannot be read, then the tag is no longer useful for business or logistics purposes or for customer relationship management.

One option is to make sure that the tag is encrypted only at the point of sale when the customer receives the textile. In this manner the tag can be used for all the normal purposes of the businesses of the value chain without any special procedures.

However, there may be other needs for the tag after the textile is handed over to the customer. The tag might be needed if the customer returns the purchase. Or the brand might want to let the customers scan the tag to provide services or communications, perhaps like providing care instructions or maintenance services. The same product id could also be encoded in a QR code on the garment for consumer interaction, and fallback in the sorting process if the RFID tag cannot be read. In the same manner as the sorting facility can access the tag through the tag access service, these other users could be allowed to access the tag.

Figure 25 shows the sequence of operations when another user of some kind accesses the tag. The procedure is essentially the same as when the sorting facility requests the tag to be unlocked, but instead of unlocking the tag, the tag access service returns the contents of the tag.

Naturally, the service could also unlock the tag if this is needed, like for a returned item which is going back to the shelf in a shop, provided that the authorization service has been configured to allow this.

The authorization service makes sure that only anticipated, authorized users can read the tag contents. As an additional precaution the authorization service could maintain access logs and monitor access to the tags so abusive access of tags can be detected. For instance, a retail shop likely needs the permissions to access and unlock tags since they require to handle returns. To prevent the shop from using their permitted access for tracking people in their stores, there can be a limit on the number of accesses the shop is expected to perform. If there is a consistent pattern of many accesses, then this will be a warning sign that the shop is doing something unexpected and needs to be investigated.

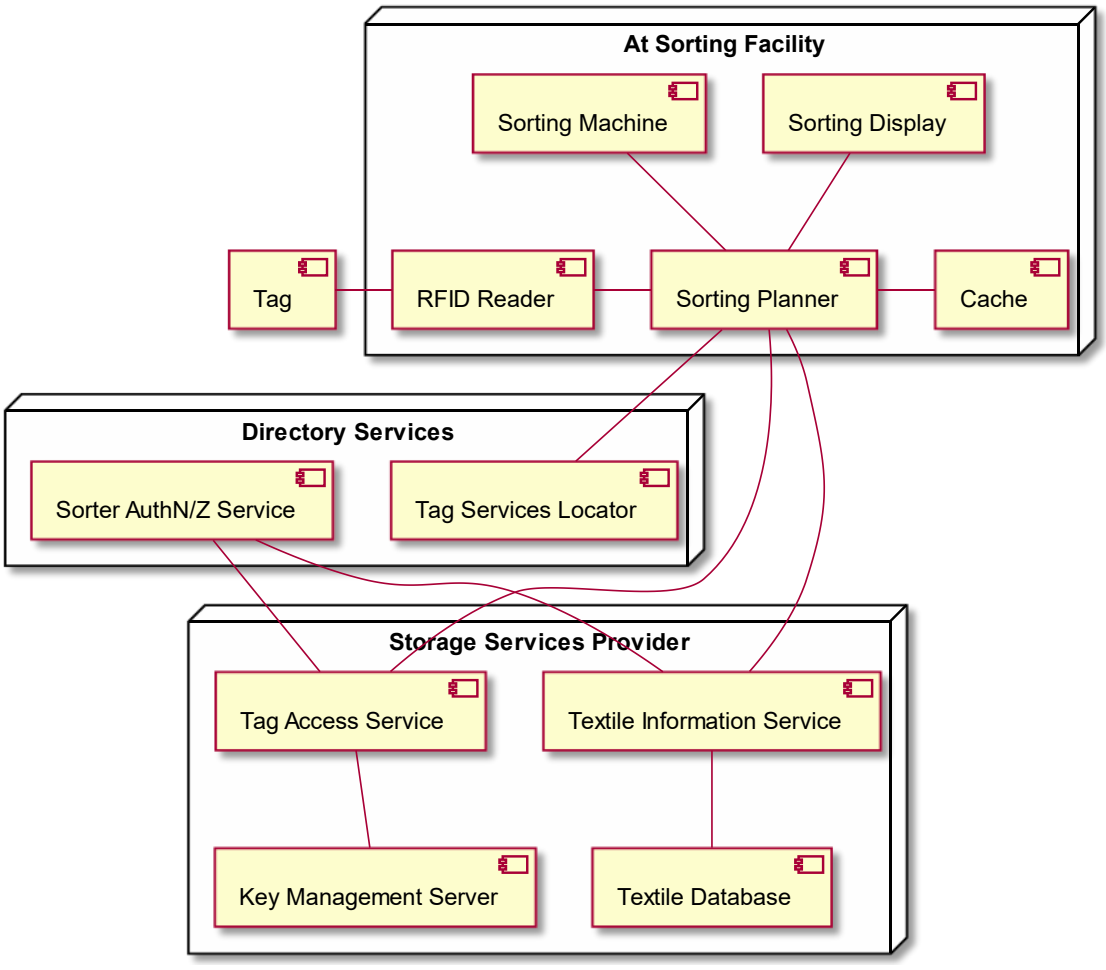

Figure 22: Data storage and distribution architecture.

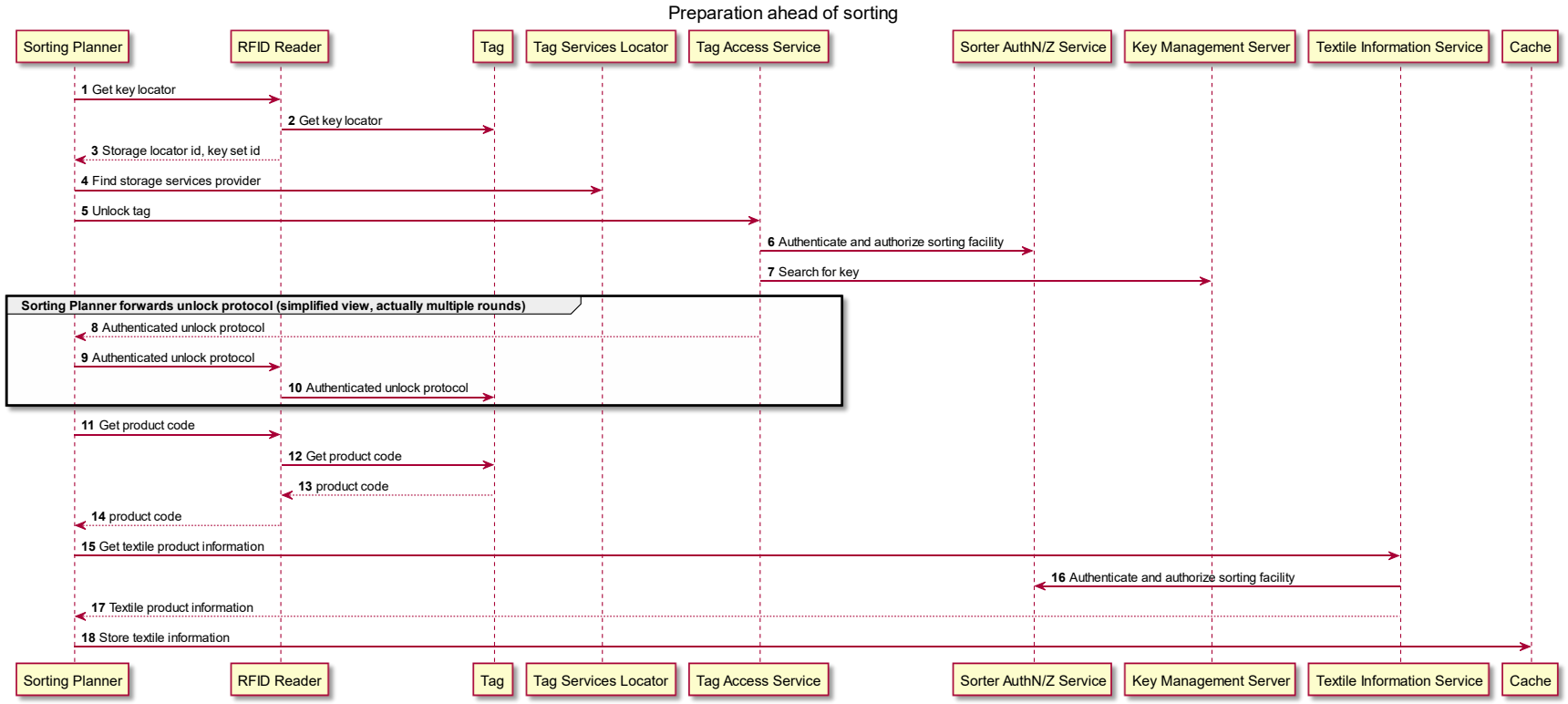

Figure 23: Sequence of messages to retrieve a garment description file.

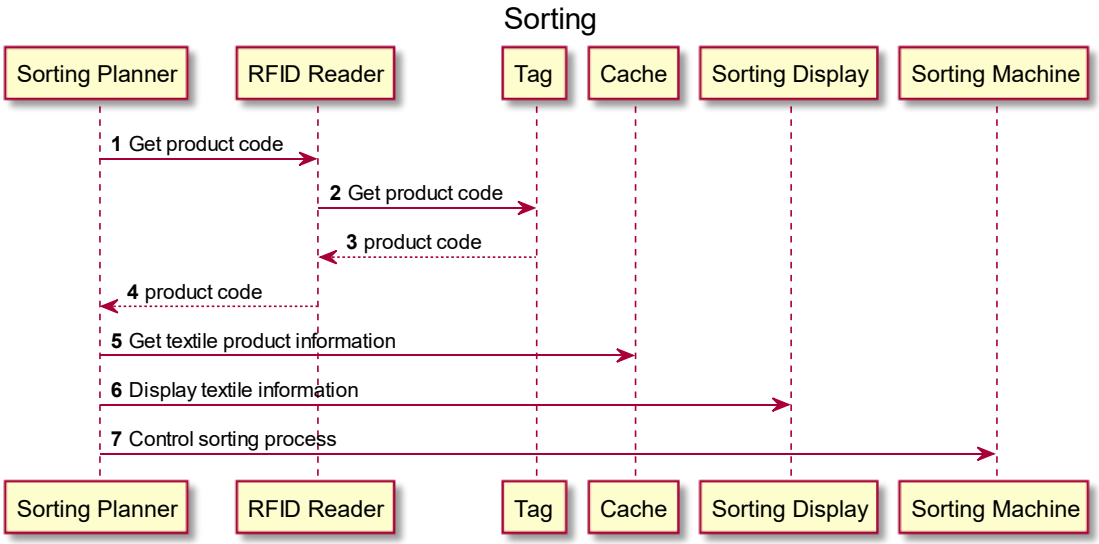

Figure 24: Sequence of messages to access garment description at time of sorting.

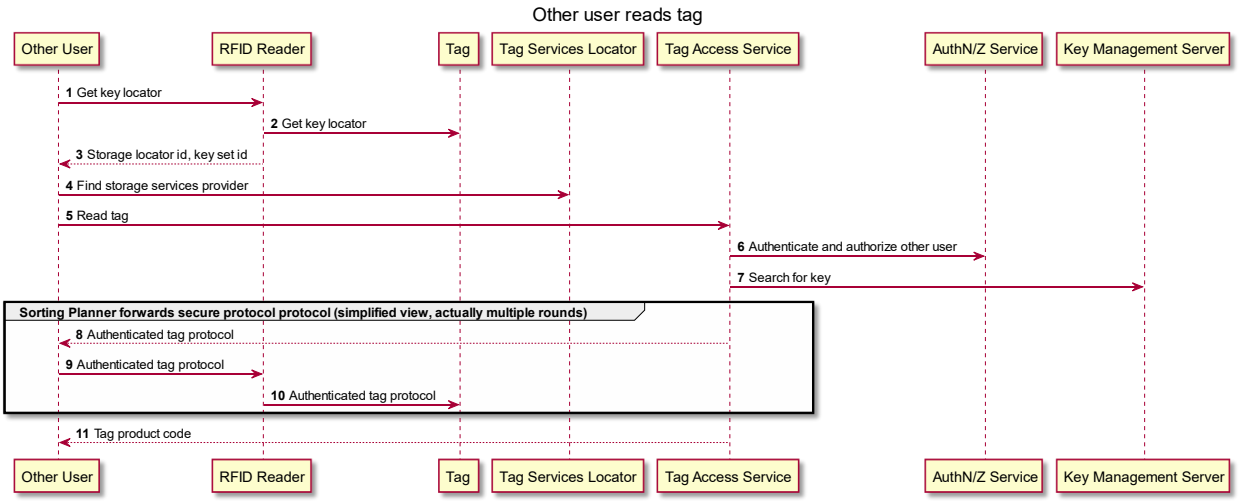

Figure 25: Sequence of messages to access tag content for other use than sorting.

10 Consequences and concerns from RFID tags

One important aspect required to consider, beside the data security and privacy issues described earlier, prior to just definitely introduce RFID technology in the textile value chain, is the environmental aspects. To introduce millions and yet millions of RFID tags to the textile market, one per garment produced, will cause footprints environmentally from the tags manufacturing processes. More about this is found in section 10.2.

Also, the chemicals restriction legislation for electronic equipment at EU level, the RoHS directive, currently entail products equipped with electronic devices (even passive RFID tags) to be CE marked. More about this in section 10.1.

10.1 RFID and the importance of harmonised legislation

During the first half of the Tex.IT project, the European directive RoHS, on the restriction of the use of certain hazardous substances in electrical and electronic equipment (EEE), was thoroughly investigated. Meetings were arranged to inform responsible authorities and politicians, and to highlight the inconsistency between the EU Commission's new Circular Action Plan [2] encouraging use of new technologies, such as digital tagging for increased traceability and circularity, contrary the almost simultaneously introduced obstacle to use the same tags, by means of implementing the new EEE category in the RoHS directive. In July 2019, category 11 ("Other EEE not covered by any of the categories …") was introduced in the RoHS directive, Annex I. [11] This implies CE labelling is required for products i.e. a "simple" white t-shirt, equipped with RFID tags.

The investigation performed within the frames of the Tex.IT project, resulted in the article "*RFID for Transparency, Traceability and End-of-Life handling of Textiles - The Importance of Harmonized Legislation*", which concludes that "A directive such as the RoHS directive, that may enforce CE-labelling of garments with integrated passive RFID tags, would be a large obstacle for the development towards circular value chains." [10] The article was published by Juniper Publishers [12] and the full article is enclosed as Appendix A8.

10.2 Environmental impact

Introduction of an RFID technology-based information system to the textile and fashion industry would improve transparency and traceability. However, not to forget, there is needed one physical RFID tag, to be incorporated in each new garment put on the market. Each tag consists of various materials in terms of textiles, metals, adhesives, etc., which gives a weight of about 0.3-0.4 gram per tag. [22] Dry and wet inlays are used with the distinction of RFID microchips and antenna are either attached to a carrier substrate (dry) or the microchip and antenna are attached to a material, usually PET (polyethylene terephthalate) or PVC (polyvinyl chloride) with an adhesive added (wet). [23] More recently, there are paperboard face tags that have a white paper or a polymer coating on the face, which improves the ability to print logos and numbers. [23] There are also many other RFID chip and antenna construction materials including mylar or polyester films. Many of these materials are an environmental burden especially as the number of tags used, only in the retail (textile and fashion) sector, exceed 8 billion per year [23]. With the earlier mentioned weight per tag, this summarises to non-neglectable amounts of materials required for the RFID tags production.

While there are several potential benefits, RFID technology also comes at a cost, both economically and regarding resource demand for production and generated waste. To estimate the contribution of RFID tag production to the overall impact of a garment and balance it against expected benefits, quantitative data for the tags (materials, processing, wights) are required as well as reliable data on how tags improve recycling and reuse rates. Qualitative information was provided during the project and showed need for further research, which will be continued as it's included in the ongoing EU project HEREWEAR[10], with RISE as a work package leader for sustainability assessment and circular.fashion as continuing research partner. Further on, a submission to the currently open EU Horizon call

[10] https://herewear.eu/

"Increasing the circularity in textiles, plastics and/or electronics value chains" (HORIZON-CL6-2021-CIRCBIO-01-04) is in preparation and will include research on data gaps identified here.

Based on literature [24] [25] describing RFID tags with quantitative data for materials and processes, a very basic and broad initial life cycle assessment was calculated with software SimaPro 9 and Ecoinvent 3.6 data. The results showed that selection of materials does influence the overall environmental impact and also that simple passive tags with a small contribution of electronics have a lower environmental impact compared to tags which contain printed circuit boards (PCB). None of the RFID tags for which data are available is suitable for applications in apparel over the entire life cycle (non-washable tags), thus the results are indicative.

Initial evaluation of the environmental impact related to the tags was based on literature data [24] [25] due to lack of published information. Note that the publication addresses RFID without further specifying suitable applications and is several years old, thus not representing the current state of the art.

Three options were described in two separate papers [24 [25], 'names' and colours refer to Figure 26:

- A PCB RFID, with a miniaturised printed circuit board – 'PCB_Kanth' (orange)
- An RFID with a polymer-based layer (PVC) and copper – 'RFID_Kanth' (light green)
- An RFID with a paper-based layer and aluminium – 'RFID_KanthpaperAl' (dark green)

Comparing all three options with categories that are set as default for an environmental product declaration (EPD) shows that the more complex and heavier PCB design has a much higher impact in all categories, see Figure 26. The highest contribution is set to 100% as a reference, and it is for all categories attributed to the PCB RFID. The two other options, which are more similar regarding function and applications, are much closer to each other. For ozone layer depletion the polymer-based application shows a higher bar, corresponding to a higher environmental impact.

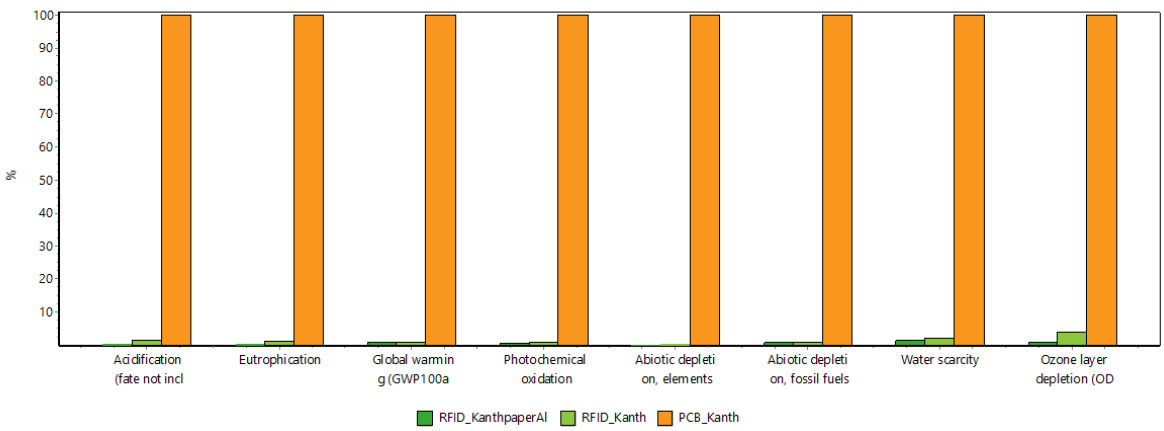

Figure 26: Comparison of three different RFID designs, values for materials and weights based on literature

Since the results for two options are close, a direct comparison is provided in Figure 27 to improve visibility of the differences. The paper/aluminium design has a lower environmental impact in most categories, largest difference is recorded for the category abiotic resource depletion, where copper and aluminium contribute respectively.

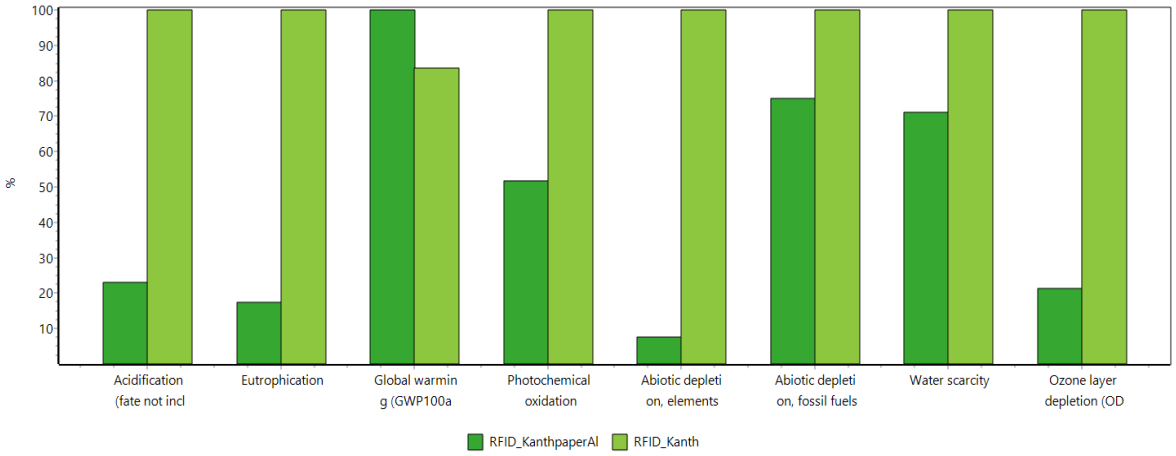

Figure 27: Comparison of two different RFID designs, values for materials and weights based on literature

For a future investigation of RFID tags and antennas used in textile and apparel, it is crucial to retrieve data on materials used for this purpose. An initial recommendation based on the results shown here, could be that a slim and lean design reduces the potential impact as well as material choice and avoiding scarce materials contributes to a reduced impact.

11 Return on investment (ROI) and cost calculations

Three case studies have been the basis of analysis, as RFID/NFC implementation ROI has various effects depending on many factors, such as where you are in the value chain, what type of content/data you add, if you go for a hang tag or embedded tag, what type of business model you run, what marketing budget you have, etc.

The three case studies were:

1. Supply chain and in-store efficiency for brands
2. Sorting precision, which includes a proof of concept trial for value extraction in reuse sorting
3. Circularity based business models, aiming at decoupling growth from material use

In Appendix A9, a broader/visual presentation of the segment is available.

11.1 Supply chain and in-store efficiency for brands

This case study is applicable in all types of economies, linear as well as circular. It is assumed that hang tags are used. Schematically, two general benefits can be seen implementing RFID/NFC; (i) Increased accuracy in the supply chain (ii) In-store time saving and accuracy. These lead to several positive effects, while the most prominent ones are (a) a decreased need for "planned overproduction" (due to broken size assortments) and (b) more time for sales staff to do what they are hired to do, leading to a higher turnover per store. A reported increase in retail job satisfaction is a large extra bonus as well.

Figure 28 and Figure 29 illustrates a scenario wherein RFID has been implemented in a retail chain, using hang tags. Data has been retrieved from brands and complemented with data from relevant literature. The key overall finding and conclusion is that it is an attractive investment. In-store staff report a revolutionary feel on the time saving effect on e.g. inventory counting.

Note, an additional assumption has been made with regards to CE-marking (if embedded tags would be used) and its potential cost per product group produced by the brand. If this cost would materialize, it would, even in a best-case scenario, lead to a negative ROI.

Inbound data	**Brand**
Revenue	
Total turnover [SEK/year]	**1 100 000 000**
Stores	825 000 000
E-commerce	275 000 000
E-commerce percentage [%]	25%
Average unit order value [SEK/item]	80
Add. Supply chain costs [SEK/item]	120
Retail markup [%]	75%
Average unit return [SEK/item]	350
Number of brand stores	80
Turnover per store [SEK/year]	10 312 500
Number of sold units in stores [items/year]	2 357 143
Number of sold units via e-commerce [items/year]	785 714
Total number of units sold [items/year]	**3 142 857**
Number of product types	5 000
Costs	
Hourly salary - sales representive [SEK/h]	350
Cost per tag [SEK/tag]	1
CE-marking cost, per product type [SEK/type]	20 000
Software license & installation [SEK per month and store]	350
Hardware - all scanners [SEK per month and store]	350
Maintenance and support [SEK per month and store]	200

Figure 28: Inbound data for calculations.

		Sensitivity		
KPI impact	**W/O RFID (base)**	**W RFID (low)**	**W RFID (high)**	**Potential [%]**
Warehouse and store inventory accuracy [%]	70-85%	99,8%	-	15-30%
"Planned" overproduction [%]	15%	10%	5%	10-15%
Average store turnover increase [%]	-	2%	8%	2-10%
Number of inventory counts per year	2	52	26	add. no
Time spent per inventory count [h/count]	40	0,25	-	-99%
Time spent recieving goods into inventory [h/month]	25	5	-	-80%
Time spent on back-to-front replenishment [h/month]	25	12,5	-	-50%
	-	-		
Summarized efficiency and cost impact	**W/O RFID (base)**	**W RFID (low)**	**W RFID (high)**	
Increased profit				
Total personnel time savings in store [h/per store and year]	680	223	217	
Total ordered items per year (including e-commerce) [pieces/year]	3 614 286	3 457 143	3 300 000	
Total order value (including e-commerce) [SEK/year]	289 142 857	276 571 429	264 000 000	
Total increase turnover [SEK/year]	1 100 000 000	1 122 000 000	1 188 000 000	
Increased costs				
RFID tag costs [SEK/year]		3 457 143	3 300 000	
RFID software, hardware & maintaince in store costs [SEK/year]		864 000	864 000	
Total CE marking cost for all product types [SEK]		*140 000 000*	-	
Summary	**W/O RFID (base)**	**W RFID (low)**	**W RFID (high)**	
TOTAL increased profit [SEK/year]	-	34 571 429	113 142 857	
TOTAL increased costs [SEK/year]	-	4 321 143	4 164 000	
RESULT INCREASE [SEK/year]	**-**	**30 250 286**	**108 978 857**	
MARGIN INCREASE [%]	**-**	**3%**	**10%**	

Figure 29: RFID effects on KPIs and ROI.

11.2 Sorting precision

In Appendix A9, several sorting perspectives are included. Below, the key result stemming from a sorting trial conducted at Wargön Innovations pilot sorting facility is presented. The intention of the test was to, while conducting "classical" reuse sorting, find out what information was preferred by the sorters to be able to more precise in their decision making and how if/it affected decision price setting. Approximately 70 garments were prepared. Half had RFID-tags with (dummy) information including material, colour, price as new, brand and more. Two experienced sorters (Annika and Sofia) sorted through the batch twice:

- First time without any additional information. Only traditional manual sorting.
- Second time with extra information from RFID (in half of the garments)

Results can be seen in Figure 30 and Figure 31. Results included the indication that *Price as new* and *Age of garment* were the two most important information points. The additional information provided practical guidance in approx. half of the tagged garments. The perceived value of the batch did not differ with or without RFID, except for a few price increases for Sofia.

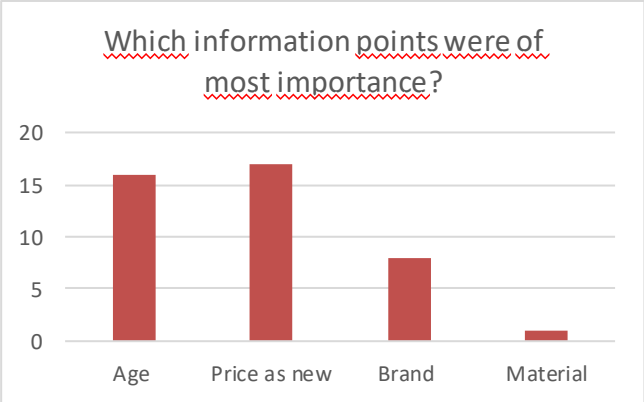

Figure 30: Main factors affecting the price setting.

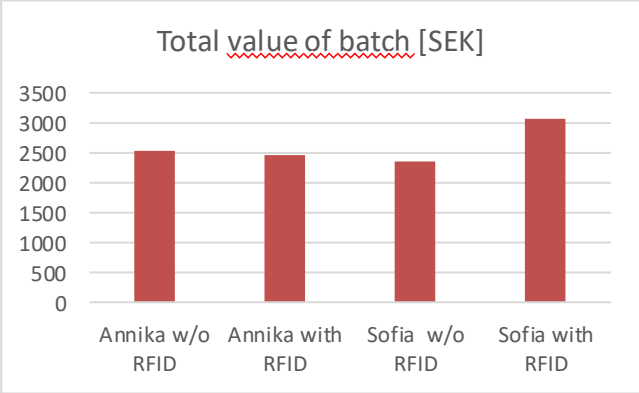

Figure 31: Value of the sorted batch, with and without RFID respectively, for both sorters.

Conclusions in the test and insights/wishes of the sorters were:

- Minor effect on value extraction with additional RFID information.
- Sorters wish to see a $, $$, $$$-system, where they get a "summarizing" data point which can complement their ocular inspection of the garment.
- Annika quote: "in the cases where the extra information mattered, I never felt that it was more important than my overall impression of the garment".

Finally, there are additional values of RFID/NFC which were not captured in this specific test. For example, the value of expanding into and being able to sort for new fractions/markets is somewhat hard to estimate for traditionally trained sorters and something that could be of interest in future studies.

11.3 Circular

Calculating ROI in terms of new circular business models is somewhat tricky. In a way, RFID/NFC could be a first step towards a more data driven retail business, with a higher degree of interaction with customers, building loyalty and MRR-models (Monthly Recurring Revenue). Moreover, one of the keys is to enable models which increases the utility rate of garments while generating an improved customer experience. there are several services that could be added, using an embedded and readable tag. In Figure 32 a few "low hanging

service-fruits" are illustrated, confirmed by project partners as ongoing pursuits to implement in a not too distant future.

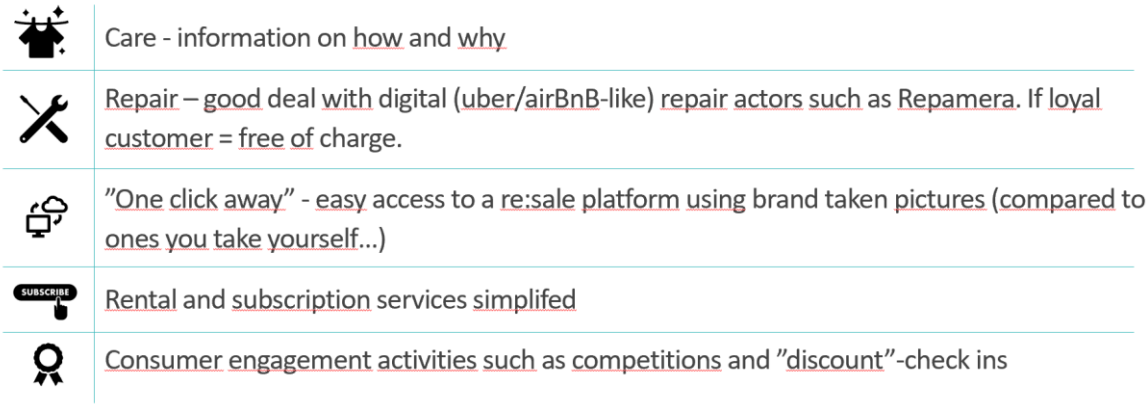

Figure 32: A variety of services enabled by an embedded tag.

To estimate what one could earn (ROI) by implementing above mentioned services has proven somewhat difficult, as many assumptions must be made in forward looking scenarios. In the project, a deeper analysis and a roadmap have been created by a project partner, but IPR restricts a more detailed description in this text. Instead, a calculation including a comparison with the effects of implementing customer loyalty programmes has been conducted. There is immense literature available on the subject. E.g. according to Marketing Metrics, the probability of selling to an existing customer is up to 14 times higher than the probability of selling to a new customer. Bain & Company and Harvard Business School report that "increasing customer retention rates by 5% increases profits by 25% to 95%." Another number from the same study is that existing customers spend 67% more than new customers.

Based on these KPIs, especially the increase of spent volume per customer, additional inbound data points are added to the case study in section 11.1:

- Total of 600 000 customers
- Spending approx. 1800 SEK per year & customer
- 50 000 (8%) of them are "loyal", averaging on 3000 SEK per year (67% increase)

If implementing RFID/NFC based business models and services could increase the number of "loyal" customers a good base for continuous investments is created. Figure 33 illustrates an example, including costs of tags, marketing, software and additional employees. There are of course many factors affecting the ROI-calculation, e.g. decreasing the additional "loyal" customers from +50k to +25k would mean a ROI of -7 MSEK. Nonetheless, as customer loyalty programmes is a well-researched topic and almost all brands have explicit goals to increase their member numbers, it could be a good way to initially measure the effects of implementation, as well as convincing sometimes short sighted market divisions that there are new and possibly improved ways of doing environmentally and circular business.

Assumptions/data	
Number of garments	3 140 000
Sales price per garment [SEK/unit]	340
Difference in spending between a "regular" and a "loyal" customer [SEK/customer]	1 200
Increased market cost per garment [%]	2%
Increased software cost per garment [%]	1%
Tag costs [kr/tag]	1
Additional need of employees per 1M garments	1
Yearly cost per employee [SEK/year]	900 000

	w/o RFID/NFC	w RFID/NFC	*Difference*
Revenue			
Number of "loyal" customers	50 000	100 000	50 000
Additional revenue from "loyal" customers [SEK/year]	60 000 000	120 000 000	60 000 000
TOTAL revenue increase			**60 000 000**
Costs			
Increased marketing costs [SEK/year]	-	21 352 000	21 352 000
Increased costs of tags (all garments) [SEK/year]		3 140 000	3 140 000
Increased cost of software structure [SEK/year]		10 676 000	10 676 000
Additional cost of employess [SEK/year]	-	2 826 000	2 826 000
TOTAL costs [SEK/year]	-		**37 994 000**

RESULT with +50 000 increase of "loyal" customers [SEK/year]	**22 006 000**
"Breakeven" of additional "loyal" customers	**31 662**

Figure 33: Illustrative calculation using customer loyalty program KPIs.

12 Discussion

When the Tex.IT project started a couple of other, similar initiatives based on transparency and traceability, commenced almost at the same time, i.e. the circularID™ by Eon Group (US) and circularity.id by circular.fashion (DE). Both initiatives, as well as the Tex.IT project, are roughly based on the same idea in terms of creating a digital information system for essential product related parameters and details, to be used at the end-of-life handling of textiles. Also, another digital information platform has been developed during the recent years by the company TrusTrace. Their platform does include information coupled to both fashion and textiles, as well as food products. However, there are some important differences between these initiatives, e.g. both TrusTrace and Eon Group business ideas, are to sign up clients to their platforms by means of license agreements, while circular.fashion aims, likewise one of the Tex.IT project objectives are, to investigate the possibilities for standardisation at ISO level. To standardise the required information into a certain harmonised terminology and possibly data format, will likely increase the global consensus of

how to categorise and handle textile products and materials at their "end-of-life", despite where in the world they end up for sorting.

Transparency and traceability are also two words that have been closely connected to textiles, e.g. when environmental and circular economy strategies at various political levels have been formulated during the recent couple of years. One example is the Swedish 'Expert Group in Strengthened Traceability', where TEKO, SIS and RISE, among other organisations and companies participated. This expert group has developed a report, published in January 2021 at the Delegation for Circular Economy webpage[11], which concludes the following (translated int English from the report summary):

Traceability of resources and the content of products is a prerequisite for achieving higher resource efficiency and circularity in society and for achieving the goals in Agenda 2030. The situation today does not meet this as traceability data is lacking or the data available with existing systems is not in a standardized format and is decentralized to a large variety of databases. This creates problems and counteracts reuse and recycling nationally as well as in international trade where traceability needs to be possible across borders. The situation is receiving international attention and within the EU there is a rapid development of policy initiatives with the aim of resolving this. Politically, Sweden should thus handle traceability as an important issue and drive development both nationally, within the EU and internationally. The expert group's view is that policy instruments are important for creating a system for traceability and for facilitating the administrative efforts that traceability entails for producers and buyers. Particular attention needs to be paid to a traceability system that can be handled by all relevant organizations, large and small. The system therefore needs to be simple and cost-effective and where the cost of the system is proportional for players of different sizes. The report is available (in Swedish only) as Appendix A10.

The role of such an expert group is, to prepare proposals that the Delegation can consider and, when appropriate, send them to the Government Offices. The proposals must contain a clear description of certain problems and concrete measures to solve them. It can be economic or regulatory instruments, that the government can decide on, to further accelerate the transition from a linear to a circular economy.[12]

Since terms such as transparency and traceability are central and essential words in the Tex.IT project, as well as the aim for circularity and circular textile material flows, it is very important to consider the environmental aspects in a wider perspective. Questions not to forget is: To what extent do the RFID tags production contribute to the overall environmental footprint? Are they possible to reuse or recycle? In fact, there will be, and already is, an environmental impact from the RFID tags produced for hangtags. Therefore, if most garments to be placed onto the future market will include this kind of digital information carrier, there will be significantly amounts of both metals and polymer materials consumed in the RFID tags production.

Possibly, the textile and fashion industry and their customers would need a total reset in the way of seeing the textile sector and what it has become over the recent years in terms of extremely cheap clothes and both mass production and mass consumption. Each textile

[11] https://delegationcirkularekonomi.se/
[12] https://delegationcirkularekonomi.se/om-oss/expertgrupper

product would deserve to be recognised as a nice piece of handicraft, since handicraft is what it is. There are no robots designing clothes or sewing shirts or jackets. Perhaps, just like Fletcher [20] states, "… – it is this shift in mindset that is essential to bring change beyond operational improvements to process or supply chain.", which refer to the current paradigms and accepted system models of the textile and fashion industry. If everyone, both producers and consumers, would start to recognise and value textile products more, it is likely to believe the textile waste streams considerably would be reduced.

13 Conclusion

The Tex.IT project has concluded it is possible to construct an RFID technology-based information system, which considerably would improve sorting textile materials by means of essential information, such as brand, fibre content, chemicals content, etc. A system like this would bring transparency to the textile value chains and more easily determine in what way a textile material or a textile product could be either reused or recycled. By knowing what brand and for example how old a garment is, an accurate second-hand value could be more easily set by the sorter. Or, if the fibre composition is defined down to every percentage, the correct recycling process could instantly be selected. Information like this would significantly increase circularity throughout the textile value chains and save materials from being wasted.

However, RFID technology as a single solution to facilitate handling of textiles at end-of-life, is unlikely to believe. Instead, there most likely will be a combination of different technologies, such as RFID, NFC, QR codes, NIR (near infrared spectroscopy), etc. This is based on the assumption that, despite smart integration of digital information carriers of one type or the other in garments, some of these tags will be missing and/or will not be readable for some reason (somehow damaged), hence the digital information is lost. Or perhaps more correctly, the connection to the information stored in a database will be lost. Then, technologies such as NIR or similar, that optically can read the various materials unique spectra will be a possible assisting technology to use.

To interact with customers in stores or at web shops, the RFID technology is not found to be the ideal solution, since customers in general do not have RFID scanning equipment at hand. Therefore, QR codes or similar techniques, that are available via a smart phone is more easily used for client interaction. Also, there is currently a significant obstacle to introduce RFID tags integrated in (textile) products, since the RoHS directive may imply CE-marking requirements.

Beside the various digital traceability technologies mentioned, which are available in varying maturity degree, from commercially (RFID in hangtags) to QR codes in circular.fashion's circularity.ID platform, the project has concluded that data security and privacy issues are solvable without the need for using block chain technology. Block chain is judged to be somewhat too complicated for use in the textile sector and is currently not recommended to further explore for this purpose. Instead, RFID tags have the possibility to be both encrypted at the point of sale. The required amount of information can then be un-locked and retrieved by the right actor further down along the value chain, e.g. at a sorting facility or a second-hand store, by means of using the correct type of RFID hardware set-up, equipped with the right set of encryption keys.

However, to construct the information system in the first place and gather the required information there is need for a standardised 'garment description file', where all relevant and essential data are gathered for each product. This file will be developed by means of data available in the brand companies PLM systems and there are two possible architectures for how to implement the file generator component in an as automated manner as possible. It could be implemented as a part of the PLM software by the vendor of the PLM software, or perhaps by a third party if the PLM software allows for custom software extensions. Another option is that it could be implemented as an external component, which safely accesses the information in the PLM software.

Further on, at a basic conceptual level, only two operations are needed, one function to store a garment description for a garment, which has been tagged by a specific id in an RIFD tag, and another function to look up the garment description corresponding to a given id retrieved from an RFID tag on a garment.

Also, there are two information models to consider, of which one is the Textile Material definition in the Global Data Synchronisation Network, GDSN [14], defined by GS1's global user community [15]. This model allows sharing product information through supply chains and is based on a subscription model, so parties can subscribe to updates to product data over the network. The GDSN could be an option to use instead of implementing a new system. The other information system to consider is the circular.fashion information model, Circularity.ID®, which is available on github [21]. This model is an open data source platform and is currently licensed under GPL 3, with intentions to make it an official standard.

Since the project objectives were to build knowledge and investigate the options for creating an information system, based on RFID technology, able to handle textile materials at end-of-life, it is concluded this is possible. Nevertheless, it might require that the existing information systems considered, will require expansion to incorporate all capabilities of such an information model in the future, instead of defining a new one. For example, details regarding chemical composition is not in place in the GDSN model, which will be needed to enable selection of suitable recycling technology.

To get the information in a format possible to use globally, the need for standardisation is rather clear. Conclusions from the investigation led and performed by SIS, within the frame of the project, are as follows (translated from the Swedish report in Appendix A5.): *There is a need for common ways to structure the data to be reported and to verify the security of the technology. Today, the necessary information about textiles is missing to be able to handle the products at "end-of-life" or "end-of-use". By standardising an information structure adapted to the textile industry, the foundation can be laid for an efficient circular system for textile handling. This in turn will facilitate the development of additional standards in the field, such as the current classification of textile raw materials.*

The market survey performed among textile and fashion brand companies, intended to investigate the awareness of digital information carriers and their potential for improved efficiency, as well the as the information availability in the company's own supply chains. In parallel, interviews were performed with the project textile and fashion brand companies. From the survey and interview results, it was obvious that many of the responding companies had good contacts with suppliers, at least down to the Tier 1 level, hence the information is credible to a very high or high level. Chemical use is restricted by means of restricted

substances lists (RSL), which comply with the REACH legislation. Further on, digital information carriers are rather well-known among the companies but are not considered to be the perfect solution for eliminating counterfeiting and IPR problems.

The return on investment (ROI) calculations shows that RFID technology significantly can save costs to textile and fashion brand companies. The main advantages obtained are reduced overproduction due to less losses and improved control of stock and inventory. In-store inventory procedure by means of a RFID technology system cuts inventory time to some working hours compared to several working days with manual inventory methods. Still, one main disadvantage is that installation and investment in hardware costs are rather high.

Since limited data is available regarding RFID tags manufacturing processes and related environmental footprints caused by them, the conclusion must be that further investigation is required prior to the "ready-to-go"-button is pushed for a digital information system based on RFID, for end-of-life handling of textiles. Associated and continuing work will be performed within the EU funded project HEREWEAR, which is an ongoing project where both RISE and circular.fashion have the possibility to transfer knowledge from this project and continue the important work regarding environmental aspects.

In addition, not to forget to get a textile waste handling system well-functioning, is the need to expand collection systems of both post- and pre-consumer textiles. Today (at least in Sweden), there is no solution available for the whole society, but since the politicians are about to implement the extended producer responsibility (at EU level), these kinds of systems must evolve to enable bringing textile products back to close the loop.

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Appendices list

A1. Survey for the Tex IT project – Survey questions

A2. Björkåfrihet – Paper regarding RFID

A3. Boer Group Recycling Solutions - Potential Use of RFID-Technology in Sorting Facilities for Post-Consumer Textiles

A4. Tex.IT – Fidra activities

A5. Utredning – Digitala informationsbärare i textil. Utvärdering av standardiseringsbehov.

A6. Excel file summary – Required information/data suggestion

A7. Use case XML documents

A8. The Importance of Harmonized Legislation

A9. Return On Investment (ROI) – How do one make money while implementing RFID/NFC technology

A10. Rapport – Expertgrupp Stärkt Spårbarhet Delegationen för Cirkulär Ekonomi