RFID and Counterfeiting: An Analysis of Current Trends in the Fashion Industry

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Abstract. The paper is aimed at providing an overview on Radio Frequency Identification (RFID) technology, focusing more specifically on RFID tags within the fashion industry. Starting with a comprehensive scenario on environmental concerns in the sector, the paper then moves on to focus on the uses of RFID in fashion, from the manufacturing processes up to commercialisation and post-consumption stages. The goal of this paper is to understand how RFID tags can contribute to contrast counterfeiting among other available technologies. In this context, to better understand the counterfeiting phenomenon, at the end of 2020 we submitted a survey questionnaire to a group of Millennials and Centennials. The aim was to explore and interpret consumers' attitudes on counterfeiting issues.

Results show that both Millennials and Centennials are not keen on purchasing fake fashion items. In the last section, the paper provides an overview on future technological perspectives in the fashion and apparel field and summarise the findings of the study.

Keywords: Radio Frequency Identification (RFID) · Fashion Industry · Counterfeiting

1 Introduction

1.1 RFID Technology and Fashion

Several years have passed since the very first creation of Radio Frequency Identification (RFID) tags in 1999, not to talk about RFID technology itself, which was firstly applied during World War II for the purpose of detecting enemy aircrafts [1]. Already since the early 2000s it was indeed possible to attest for a proliferation of academic articles often praising the advantages of RFID tags for a wide range of functions along the entire supply chain. Moreover, several researchers dared to predict the end of the barcode era due to the incredible edges demonstrated by the new applications of the technology. While the entire overhaul of the barcoding system has not occurred yet, after more than 20 years since the very first predictions, it is nonetheless necessary to remark that RFID tags can now claim an extensive variety of applications of which consumers themselves are often unconscious [2].

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Ranging from pharmaceuticals to virtual payments, from official documents to agri-food systems, RFID tags have been devoted high attention from researchers and managed to adapt to highly different sectors with overall benefits in terms of traceability and identification.

More specifically, RFID tags were soon experimented in the fashion industry, where they have proved their abilities to speed up the entire supply chain processes and improve the efficiency of all stages from production to distribution and consumption. Their positive impacts on management of value chains and sustainability in general are, indeed, widely attested. On the one hand, a wide array of scholars has focused on benefits and technological innovations brought about by RFID; on the other hand, others have highlighted the hindrances related to the implementation of the technology itself and consumers' concerns [3].

Against the versatility of RFID tags in general and within the fashion sector in particular, the present paper concentrates its focus on one of the most important applications of this technology, i.e. in the contrast against counterfeiting. Consequently, in the first section we will offer an overview of the fashion & apparel industry from a sustainability standpoint, thus considering the environmental impact of the sector in general. Then, we will move to generally consider RFID tags applications in fashion, thus restricting the scope to the description of the areas where they are used in the field. Among these, we will then focus on RFID tags against counterfeiting, which is a matter of utmost concern especially for luxury brands in general, but particularly in fashion. Consequently, in the third section we will consider a case study based on a questionnaire investigating attitudes and behaviours of Millennials and Centennials against counterfeiting. We will then conclude with a summary of the paper findings and an overview on the main technological novelties pertaining to RFID and the related Internet-of-Things (IoT).

1.2 Sustainability and the Fashion Industry: An Overview

It is common knowledge that the fashion industry is one of the most polluting sectors all over the world, ranging between the fourth and the second contributing most to environmental pollution worldwide. Some studies argument that the field is responsible for 10% of global worldwide emissions and that 73% of fashion products ends up incinerated or in landfills at the end of their life cycle [4].

The field has worsened its performances also due to the so-called 'fast fashion' phenomenon, which leads to higher amounts of textile products wasted beforehand than their expected lifetime.

The key point is that the entire textile value chain, from raw materials extraction to the production phases up to distribution, consumption and end-use, is unsustainable. Data confirm that not only production and distribution in fashion have an important impact on environment at worldwide level, but post-consumption raises important issues involving reuse opportunities, recycling possibilities, end-users' knowledge and technological development.

The fashion industry raises environmental concerns starting from production processes. First of all, they imply massive energy consumption which often comes from non-renewable sources (especially fossil fuels), since manufacturing is mostly performed

abroad in under-developed countries where much less attention is devoted to sustainable practices. Adding to this, textile factories make extensive use of water and natural resources, starting from the cultivation of cotton and natural fibres up to their use during production steps [5].

Procedures such as printing or dyeing also make use of chemical substances whose use has been limited over time, but that still impact on soil, atmosphere and waters due to the release of polluting gases [6].

Not only is environmental sustainability involved, but also social and economic concerns enter the game in the sector. Manufacturing phases are mostly conducted in countries where labour rights are neglected, unsustainable energy sources are implied and the balance between environmental benefits and economic advantages is often unclear to define. Moreover, several supply chain stages are not transparent, thus providing incentives to illicit trafficking and unfair labour conditions in scattered parts of the world, not only during production and distribution but also in after-use stages.

Apart from the amount of waste produced along the supply chain, the post-consumption component needs to be more closely examined. As a matter of fact, the fast fashion trend has changed consumers' habits by shortening retail products life, while at the same time favouring greater chances to reuse, lending and exchange opportunities. For instance, in Italy post-consumption by itself accounted for more than 146 tons of waste in 2019, mainly exiting in storage and material recovery (around 60 tons overall) while 4% ended up incinerated [7].

It is also a matter of concern the lack of knowledge shown by consumers in relation to the different collection modes, reuse and recycle possibilities and final destinations of discarded fashion products, which reveals the need for sensitisation on post-consumption phases [8]. Nonetheless, some studies demonstrate that consumers buying greater amounts of retail items are those also more aware of post-consumption channels to enhance products reuse, reselling and exchange opportunities [9].

Given these premises, it is not surprising that legislative authorities at national and supranational level are striving for regulating the field in direction of circular practices [10]. Particularly, the EU has recently introduced its Strategy for Sustainable and Circular Textiles in order to achieve recyclable, safe, environment-friendly and respectful of labour rights products, so as to allow consumers to benefit from higher-quality items together with repair and reverse logistics services [6]. Extended Producer Responsibility (EPR) is one of the main policies EU authorities will implement in the next few years in this respect, in order to redesign the fashion industry and enhance more sustainable consumption choices.

In this context, the first companies leading the circular transformation of the sector are luxury brands, striving for meeting calls for a more sustainable fashion industry (sometimes even due to emerging scandals on production and labour conditions in the field) as well as consumers' trends towards more sustainable purchases. It is indeed a fact that sustainable labels and targets benefit brand visibility in front of consumers and with respect to competitors.

It is in this scenario that RFID enters the game through its multiple usage possibilities at different stages of the fashion industry, as we will consider in the next section.

1.3 The RFID Technology in the Fashion Industry

The Radio-Frequency Identification (RFID) technology is a non-contact automatic identification technology, whose birth for detection purposes dates back to World War II [11].

However, due to recent technological developments in the fields of information security and network communication, it has been widely applied in several fields ranging from health to agriculture, from housing to mobility in the turn of some decades. As a matter of fact, RFID is one of the components of Internet-of-Things as a new technological model based on interaction and responsiveness between machines and the human world [12].

RFID tags basically consist of small wireless chips with radio circuits where data is encoded. A complete RFID system is made up by three main components: the transponder (or tag), the antenna to communicate with the tag, and the receiver or controller, which controls the antenna, reads the tag and can write the code on it [2]. The main distinction is between active or passive tags (depending on whether they have independent energy sources or not) and the frequency at which they work, ranging from low to very high frequencies. Passive tags are the most common ones in retail and do not possess inner energy, but they respond when interrogated from the antenna and can be read at a limited distance. Another key component is the power of the antenna and, most importantly, of the controller, which affects the reading distance, the identification and writing possibilities with respect to the tag [13].

The implementation of RFID in retail started already in the early 2000s, with some big companies as the retail giant Walmart deciding to revolutionise its supply chain management [14].

RFID tags brought indeed several advantages at all stages of fashion industry, in a context distinguished by simultaneous increase in competitiveness, growth in global demand and complex worldwide supply chains. As a matter of fact, multiple functions can be made more efficient thanks to the uses of RFID in the field, as the technology can benefit all stages of the supply chain from manufacturing to transportation up to distribution and retailing [13].

First of all, the technology can improve efficiency of the production line and enhance 'smart manufacturing' by means of constant monitoring of movement and product aggregation. This can help to free up resources and streamline processes, thus ensuring the accuracy and reliability of inventory and shipping in the production sites as well as tracking equipment maintenance [15].

Moreover, RFID tags can easily fasten logistics processes and ensure reduction of human errors, consequently reducing the risk of lost items, improving reverse logistics and return policies after consumption, which may also be beneficial in light of the future introduction of the Passport for products and EPR policies at EU level [6].

As far as retail is concerned, RFID serves shop operations by favouring inventory management and stock counting, saving or redirecting labour force or improving the visibility and traceability of products. An RFID important contribution in retail consists in improving the purchasing experience by making it faster, easier and potentially customised. Many new applications of RFID technologies in retail imply, for instance, the use of 'smart dressing rooms' providing advice to customers together with 'smart

mirrors', 'smart shelves' that ease restocking and reordering of depleting products, as well as anti-theft systems for salespersons [16].

It is possible to selectively adopt RFID only for some stages of the supply chain, although benefits from the technology are enhanced when it is implemented and integrated along the entire process [17].

As a matter of fact, the reduction in human mistakes, the improved efficiency throughout all processes in the supply chain management and better customer services overall ultimately lead to benefits in revenue terms. In particular, this has been the case also for very big retailers as Decathlon, which since RFID implementation has assisted to a reduction in lost resources, increased efficiency in restocking and inventory management and revenues growth. Indeed, the company has already planned not to fire but to redirect personnel to advise and customer services [18].

However, one of the most important uses of the RFID technology is in the contrast against counterfeiting, which is of utmost interest especially for luxury brands. This will indeed be the focus of the next section, which concentrates on the possibilities offered by RFID to prevent and fight against falsification and frauds.

2 Material and Method

2.1 RFID Against Counterfeiting: Possibilities and Applications

In 2016, the Organisation for Economic Cooperation and Development (OECD) estimated the counterfeiting market value to be around 12 billion euros, equal to 4% of Italian import of authenticated items. Moreover, over the same year the global trade market of counterfeited items and imitations of Italian brands reached 32 billion euros, i.e. 3.6% of the value of products sold by the national manufacturing sector [19].

In this context, new technologies are fundamental against counterfeiting as they can help in tracing and contrasting illicit practices. Nonetheless, three key issues are worth remarking in the current fight against counterfeiting through technology [20]:

- Technical problems, as tools and procedures are costly and difficult to spread rapidly on a large scale, while also turning difficult to understand for common consumers;
- Awareness issues, as not many customers understand the importance of not buying fake products and are not aware of actually committing a crime;
- Size factors, given the lack of incentives in the implementation of costly technological anti-counterfeiting devices not only by luxury brands but also by smaller fashion companies.

In this context, actual technologies against counterfeiting can be categorised in four main ways [21]:

- Overt or visible features (manifest);
- Covert or hidden markers;
- Forensic techniques, i.e. legal ones as those making use of chemicals;
- Serialisation or track-and-trace systems.

Similarly, other scholars divide types of anti-counterfeiting systems according to the means of use and their effects, that is to say distinguishing the manifest ones (e.g.

holograms and filigrees), hidden methods such as safety inks and invisible printing, use of chemicals and, in the end, barcodes and RFIDs [17].

In retail, anti-counterfeiting methods can additionally be split according to whether they are fixed to internal supports of the product, attached to the item itself or even inserted in the product or the packaging.

In 2003 the U.S. Food and Drug Administration was the first to propose track-and-trace anti-counterfeiting through RFID in pharmaceutics [22]. RFID tags are, indeed, unique to the associated garments, thanks to the use of PID/UID (Product Identifier or Unique Identifier). Consequently, the tag becomes an identification system that stores the entire history of a product and is able to trace it through the entire value chain [20].

More specifically, some scholars divide anti-counterfeiting systems using RFID into 4 categories, which we will explore in depth [23]:

a) **PUF Based 'Unclonable' RFID ICs and chipless RFID tags for anti-counterfeiting;**
b) **Track and trace anti-counterfeiting;**
c) **Distance-bound control protocols;**
d) **Other types of anti-counterfeiting protocols.**

a) *PUF Based 'Unclonable' RFID ICs and chipless RFID tags for anti-counterfeiting*

Physical Unclonable Functions (PUFs) exploit the physical features of the Integrated Circuits (ICs) manufacturing process, which are distinguishable for every tag, so that copying, cloning or controlling one of them becomes highly difficult [24].

PUFs react to external signals embodied in a physical object through random variables with a different probability distribution which depend on whether the object is a fake or not. Moreover, PUF systems can be further distinguished in:

– Integrated Physical Unclonable Function (I-PUF), i.e. the PUF is connected to a chip preventing communications issues between the anti-counterfeiting system and the product;
– PUF tags, where the technology is directly incorporated into products and the tag acts as a key whereas the inside pattern is the lock.

An alternative way is to use chipless RFID tags, which are not as fully unclonable like the PUF-based unclonable ones due to their manufacturing process but are more low cost, adaptable and more resistant [25].

b) *Track and trace anti-counterfeiting*

This approach has attracted the attention of researchers due to its reliability. This system typically involves an electronic pedigree (e-pedigree) guaranteeing the product visibility and constantly transmits diverse types of data according to the state of the product, so the database is stored in the back-end and forms the pedigree background [21].

Three main steps are involved while using pedigree-generated data:

- Pedigree Data Formatting, which is important for collecting and handling data that facilitate ID generation, item tracking, authentication and monitoring;
- Pedigree Data Processing, which keeps the e-pedigree updated and ensures its integrity;

- Pedigree Transmission Mechanism, which provides access control to the pedigree data, e.g. in the case of internal or external controls.

This anti-counterfeiting system is suitable for supply chain operations where manufacturers, distributors, and retailers are connected in production, selling and transportation of items. Moreover, improvements in imprecise features of the technology have been made, thanks to ultra-high frequency (UHF) tags of 2nd generation which solve critical issues of e-pedigree in diverse stages [22].

c) *Distance-bound control protocols*

This process exploits broadcast and collision techniques to identify RFID cloned tags. As a matter of fact, cloning attacks on RFID tags constitute a non-irrelevant risk in RFID applications [25]. Thus, in this method, each tag is assigned a unique ID and random number which is then stored on a back-end server, the so-called synchronised secret. Tags are interrogated by readers present in the same environment and, in case multiple responses are returned, this means we have at least a cloned tag in addition to the original one.

Consequently, this type of protocols can effectively identify clones and more cheaply than sophisticated cryptographic techniques. Although it is a quick and adaptable method, the adoption of these protocols brings about space limitations, since synchronisation always needs to occur in the same environment.

d) *Other types of anti-counterfeiting protocols*

This category includes different cryptographic protocols. This type of protocols ensures that information retrieved by unauthorised readers is of no interest to attackers, unless they are able to decipher it [11].

Different cryptographic technologies exist, for instance common encryption methods (cheaper, but also more vulnerable) and probabilistic ones. The latter are more complex to decipher as an anonymous ID is provided each time upon interrogation, but are more expensive and difficult to implement on a large scale.

Consequently, some authors proposed a new model composed by two protocols with a unique function. The tag authentication protocol allows the customer to read information stored in the tag, then the database correction protocol corrects it when the status of the read items need to be changed (from unsold to sold) [26].

Although cryptographic protocols involve several computational processes and back-and-forth communications, they result as more flexible and adaptable.

As these techniques show advantages in terms of traceability, effective sorting and circular economy in general, researchers have developed new protocols, i.e. the one exploiting the positive advantages of the combination between QR codes and PUF [1].

While luxury brands were among the first to implement RFID for sustainable and anti-counterfeiting purposes, less well-known fashion companies already successfully adopted this technology several years ago [17].

For instance, this has been the case of an Italian fashion company which has adopted, since 2012, the RFID system using a 22-character alphanumeric code (unique and not reproducible) for each generated tag. This has allowed it to protect its brand and its made-in-Italy production, while ensuring better SCM, distribution and customers' satisfaction

overall. Moreover, this has improved relations with customers as the technology allows to check for product authenticity thanks to a mobile app that permits reading of all information stored in the RFID tag. The fact that RFID systems have turned cheaper over time, easing returns on initial investment, has made the adoption of the RFID technology more appealing all along the supply chain and across sectors.

Scholars have contributed to advancing the field by promoting new advancements of this technology, e.g. chipless tags having longer interrogation range that can be used against counterfeiting also for banknotes [27] or active tags that can work in combination with other technologies to ensure higher protection against fraudulent practices [1].

Lastly, additional methods to contrast counterfeiting have been elaborated by researchers, by also taking into account technologies different from RFID. Considering that several companies in the fashion industry have adopted RFID tags for anti-counterfeiting purposes, in the next section we will focus on consumers' behaviour and consumption habits with respect to counterfeited products.

3 Survey on Consumers' Attitudes on Counterfeited Products

In order to deepen the counterfeiting phenomenon in fashion, we conducted a quantitative analysis on a survey concerning behaviour and perceptions of consumers. The survey was realised and administered between September and November 2020 to a selected target of Millennials and Centennials, also named as Generations Y and Z. The former constitutes a group of consumers aged between 24 and 39, while the latter includes people between 18 and 23 years old. The two groups were chosen because of their involvement and proactivity in the fashion field.

The questionnaire aimed at investigating the effective consumption propension of consumers on counterfeited products of 16 luxury brands in fashion. The selected brands were: Luois Vuitton, Gucci, Chanel, Dior, Dolce & Gabbana, Hermès, Rolex, Cartier, Burberry, Yves Saint Laurent, Prada, Lancôme, Faoma, Moët e Chandon Versace and Tiffany & Co. They were chosen due to their popularity among luxury brands and, while some of them concentrate on one field only of the fashion system, others diversify their offer in different fashion sectors.

Thus, we collected a sample of 352 Italian Millennials (24–39, 49% of interviewees) and Centennials (18–23, 51% of the total). These are, indeed, the two main categories of people involved in fashion consumption habits and particularly keen on luxury brands. As for the geographical areas involved, most of the sample was collected in the Southern regions of Italy (56%), while only 3% were abroad at the time of the survey.

Concerning the income, most people presented an average annual income between 0–18,000.00 euro (27% of respondents). This highlights the low purchase power of interviewees (Fig. 1).

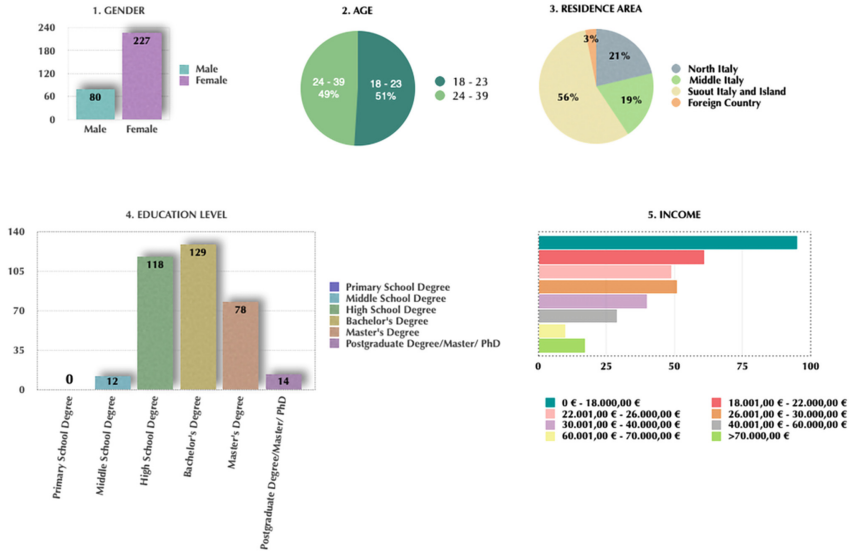

Fig. 1. Socio-demographic area (Author: Sinatra F., 2023)

As a first step, interviewees were asked about the importance they are used to assigning to factors as authenticity, quality, made in and brand. They were demanded whether they ensured about the presence of these factors in the purchase phase. From collected data, it is evident that they assign high importance to the analysed attributes with a particular attention devoted to quality and authenticity. It also emerges the attention devoted to the purchase of luxury products by younger consumers, rather than older generations [28]. Moreover, younger generations assign higher value to the presence of the above-mentioned features in products before making a purchase decision (Fig. 2).

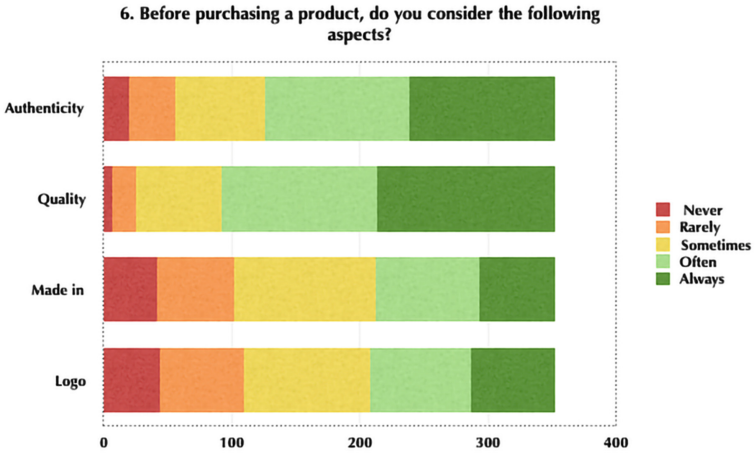

Fig. 2. Factors considered in purchase of luxury items (Author: Sinatra F., 2023)

After that, the survey requested whether they had ever purchased counterfeited products. The label 'counterfeited' does not indeed have negative connotations and simply stands for the copy or unauthorised imitation of luxury products containing similar symbols to the original brands, such as logos or tags. In addition, consumers can be more or less aware of buying counterfeited products. Data show that most of the sampled people had never bought counterfeited products (52%), which led us to think that consumers nowadays are more attracted by ethical practices and understand side backs deriving from the purchase of counterfeited products. 34% of the interviewees declared having purchased counterfeited products at least once and an additional 14% of having done that without awareness of their fake character. Among the latter group, the majority belonged to the Centennials category, which seems to be in line with their lower purchase power and trend not to buy luxury items (Fig. 3).

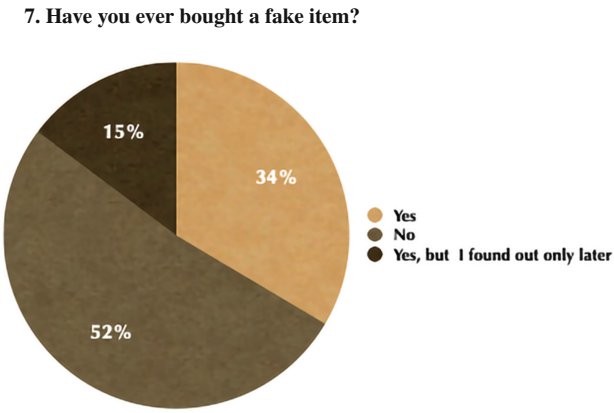

Fig. 3. Purchase frequency of fake items (Author: Sinatra F., 2023)

In case of positive answer to having bought fake items at least once (170 interviewees of the overall sample), the survey proceeded with more specific questions concerning consumers' attitudes on purchase of counterfeited products. The questionnaire went on with questions related to the purchase frequency of counterfeited fashion products of the 16 luxury brands.

Collected answers reveal that most people of both the generations considered in the study never bought counterfeited items of the 16 luxury brands taken into account, mostly because they do not know about their existence (Fig. 4).

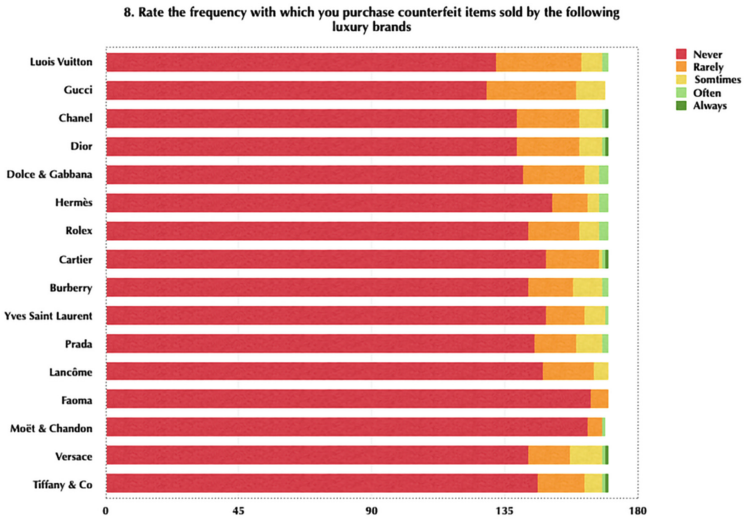

Fig. 4. Purchase frequency of counterfeited items belonging to 16 luxury brands (Author: Sinatra F., 2023)

The survey ends with two additional questions related to the purchase channels of fake products (retail or online) and the reasons conducive to buying counterfeited items.

As for the frequency according to which counterfeited products are bought through the two main channels, retail and e-commerce, there is an overall low propensity to buy fake products according to both. Nevertheless, a wider use of online platforms is attested in the purchase of fake products, probably due to the lower degree of control and chances to check for authenticity than when buying in presence. Lastly, the last question addresses the motivations leading to purchase of counterfeited items and tries to provide an exhaustive answer [29]. Five relevant variables have been taken into account, that is to say low price of fake products, high cost of branded items, social acceptance, personal interest and custom (in the meaning of lower effort required to get fake products). Collected answers reveal that cost-related reasons are the most important ones in purchase choices, particularly for Centennials (Fig. 5).

What overall emerges is a low purchase frequency in relation to counterfeited products of the selected luxury brands, and that consumers (younger ones, too) prefer to buy real items with authenticity features and higher qualitative standards rather than fake ones. The analysis also highlights significant differences on consumption habits of counterfeited products. Consequently, it seems important to try to adapt and diversify strategies to discourage counterfeiting in order to appeal to different consumers' categories.

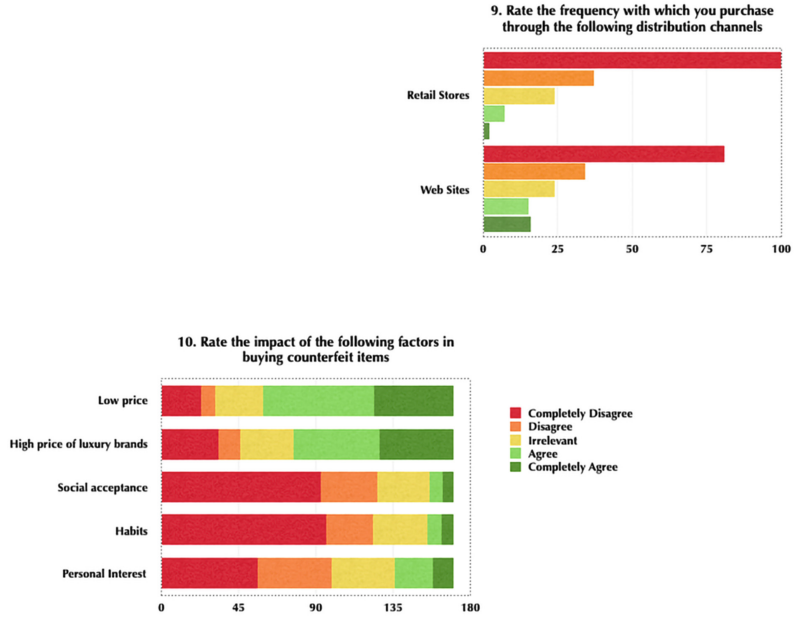

Fig. 5. Purchase channels and influential factors in buying counterfeited items (Author: Sinatra F., 2023)

4 Conclusions

To sum up, the paper focused on RFID tags in the fashion and apparel industry, by providing first an overview of the field to then move to consider the general RFID use. After that, we concentrated the analysis on the technologies against counterfeiting and restricted the scope to RFID use for this purpose. Lastly, we explored consumers' attitudes with respect to counterfeiting in the fashion sector. Results showed that consumers (both Millennials and Centennials) are not used to buying counterfeited products of the 16 selected luxury brands. Moreover, they tend to pay attention to authenticity and quality. What also emerges is that consumption patterns change according to different generations and their purchase power.

Technological development concerning RFID tags has been speeding up a lot since the very birth of IoT, which was initially meant to connect machines with other machines. Nowadays, challenges lie more in perfectioning RFID tags performances, such as making the technology less visible and more adaptable to track people through on- and off-body links [30], for instance through wearable chipless RFID sensors [27] or improving washability in harsh environments [31, 32].

As for the use of RFID tags against counterfeiting, instead, researchers currently focus more on new and safer technologies for data encryption and authentication [11]. However, we need to take stock of the fact that RFID is not anymore a novelty in the fashion sector and that new technologies show promising applications, too. Differently from the early 2000s, researchers now speak more generally of IoT applications and concentrate on the new possibilities it offers [12, 33]. Moreover, other different technologies

such as blockchain empowered by Big Data seem to show advantages in supply chain management with respect to RFID and may ensure more safety against counterfeiting, too [34].

The present paper is not without weaknesses. First, the survey is focused on specific age ranges and, as all field research, has inner geographical, time and design limits that must be taken into account in case of further generalisation of the study. Moreover, despite trying to provide as a complete technological overview as possible, it may be that more recent developments have been inadvertently neglected. Thus, for future research we suggest dealing with the weaknesses we could not adequately tackle, by providing a more specific and technological-oriented analysis of RFID tags against counterfeiting and by extending -geographically, over time and in scope- the survey on consumers' perceptions about this illegal practice.

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Author Contribution. Conceptualization, methodology, formal analysis, materials and resources, data curation and validation: all authors. In particular: Marinelli wrote Sect. 1, Sect. 1.1, Sect. 1.2, Sect. 1.3, Sect. 2; Sect. 2.1; Sinatra wrote Sect. 3; Marinelli and Sinatra wrote Sect. 4

References

1. Agrawal, T. K., Koehl, L., Campagne, C.: Cryptographic tracking tags for traceability in textiles and clothing supply chain. In: Zeng, X., Lu, J., E Kerre, E., Martinez, L., Koehl, L. (Eds.), World Scientific Proceedings Series on Computer Engineering and Information Science: Volume 10 - Conference on Uncertainty Modelling in Knowledge Engineering and Decision Making (FLINS 2016), pp. 800–805. World Scientific (2016)
2. Nayak, R., Singh, A., Padhye, R., Wang, L.: RFID in textile and clothing manufacturing: technology and challenges. Fashion Text. **2**(1), 1–16 (2015). https://doi.org/10.1186/s40691-015-0034-9
3. Pramatari, K., Theotokis, A.: Consumer acceptance of RFID-enabled services: a model of multiple attitudes, perceived system characteristics and individual traits. Euro. J. Inf. Syst. **18**, 541–552 (2009)
4. Economia circolare applicata. https://circularity.com/economia-circolare-applicata/tessile/. Accessed 07 Mar 2023
5. Denuwara, N., Maijala, J., Hakovirta, M.: Sustainability benefits of RFID technology in the apparel industry. Sustainability **11**(6477) (2019)
6. Textiles in Europe's Circular Economy. https://www.eea.europa.eu/publications/textiles-in-europes-circular-economy/textiles-in-europe-s-circular-economy. Accessed 07 Mar 2023
7. Fondazione per lo Sviluppo Sostenibile, FISE UNICIRCULAR: L'Italia del Riciclo 2021. Italia (2021)

8. Istituto Nazionale di Statistica: Raccolta differenziata dei rifiuti: comportamenti e soddisfazione dei cittadini e politiche nelle città | Anni 2020–2021. Istat, Italia (2022)
9. Woolridge, A.C., Ward, G.D., Phillips, P.S., Collins, M., Gandy, S.: Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: an UK energy saving perspective. Resour. Conserv. Recycl. **46**(1), 94–103 (2006)
10. ReSet the Trend: EU calls on young people to promote circular and sustainable fashion. https://environment.ec.europa.eu/news/reset-trend-2023-01-26_en. Accessed 07 Mar 2023
11. Oyarhossein, S.: Cryptography and authentication processing framework on RFID active tags for carpet products. In: Proceedings of ICCTA, pp. 26–31. Institute of Electrical and Electronics Engineers (IEEE), Beijing (2009)
12. Prajapati, D., Felix, T.S. Chan, F.T.S., Chelladurai, H., Lakshay, L., Pratap S.: An Internet of Things embedded sustainable supply chain management of B2B E-Commerce. Sustainability **14**(9), 5066 (2022)
13. Sushila, S.D., Singh, S.S.J.: RFID technology in apparel manufacturing. Pharma Innov. J. **8**(2), 669–672 (2019)
14. Stafford, J.: How marks & spencer is using RFID to improve customer service and business efficiency: a case study. In: Kerry J., Butler P. (eds.) Smart Packaging Technologies for Fast Moving Consumer Goods, pp. 197–210. Wiley Online Library (2008)
15. O'Dubhthaigh, D., Borchers, M., Jin, Y., Maropoulos, P.: Implementing smart manufacturing technology into the textile industry. Adv. Manufact. Technol. **35**, 37–44 (2022)
16. Bayraktar, A., Ylmaz, E., Erdem, S.: Using RFID technology for simplification of retail processes. In: Turcu, C. (ed.), Designing and Deploying RFID Applications. IntechOpen, London (2011)
17. Varese, E., Pellicelli, A.C.: The RFID technology for monitoring the supply chain and for fighting against counterfeiting: a fashion company case study. In: Beltramo, R., Romani, A., Cantore, P. (eds.) Fashion Industry - An Itinerary Between Feelings and Technology. InTechOpen, London (2019)
18. Decathlon, come utilizzare al meglio la tecnologia RFID. https://www.alfacod.it/blog-decathlon-come-utilizzare-tecnologia-rfid. Accessed 08 Mar 2023
19. OECD: II commercio di beni contraffatti e l'economia Italiana: Tutelare la proprietà intellettuale dell'Italia. OECD Publishing, Paris (2018)
20. Meraviglia, L.: Technology and counterfeiting in the fashion industry: friends or foes? Bus. Horiz. **61**, 467–475 (2018)
21. Choi, S.H., Yang, B., Cheung, H.H., Yang, Y.X.: Data management of RFID-based track-and-trace anti-counterfeiting in apparel supply chain. In: The 8th International Conference for Internet Technology and Secured Transactions (ICITST-2013), pp. 265–269. Institute of Electrical and Electronics Engineers (IEEE) (2013)
22. Choi, S.H., Yang, B., Cheung, H.H., Yang, Y.X.: RFID tag data processing in manufacturing for track-and-trace anti-counterfeiting. Comput. Ind. **68**, 148–161 (2015)
23. Khalil, G., Doss, R., Chowdhury, M.: A comparison survey study on RFID based anti-counterfeiting systems. J. Sens. Actuator Netw. **8**(3), 37 (2019)
24. Agrawal, T., Campagne, C., Koehl, L.: Development and characterisation of secured traceability tag for textile products by printing process. Int. J. Adv. Manufact. Technol. **101**(9–12), 2907–2922 (2018). https://doi.org/10.1007/s00170-018-3134-z
25. Bu, K., Liu, X., Xiao, B.: Approaching the time lower bound on cloned-tag identification for large RFID systems. Ad Hoc Netw. **13**, 271–281 (2014)
26. Tran, D.-T., Hong, S.J.: RFID Anti-counterfeiting for retailing systems. J. Appl. Math. Phys. **3**, 1–9 (2015)
27. Behera, S.K.: Chipless RFID sensors for wearable applications: a review. IEEE Sens. J. **22**(2), 11015–11120 (2022)

28. Grossman, G.M., Shapiro, C.: Counterfeit-product trade. Am. Econ. Rev. **78**, 59–75 (1988)
29. Huang, W., Schrank, H., Dubinsky, A.J.: Effect of brand name on consumers' risk perceptions of online shopping. J. Cons. Behav. **4**, 40–50 (2006)
30. Manzari, S., Occhiuzzi, C., Marrocco, G.: Reading range of wearable textile RFID tags in real configurations. In: Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP), pp. 433–436. Institute of Electrical and Electronics Engineers (IEEE) (2011)
31. Moraru, A., Helerea, E., Ursachi, C.: Passive RFID tags for textile items – requirements and solutions. In: International Symposium on Fundamentals of Electrical Engineering (ISFEE), pp. 1–6. Institute of Electrical and Electronics Engineers (IEEE) (2018)
32. Pei, J., Fan, J., Zheng, R.: Protecting wearable UHF RFID tags with electro-textile antenna. IEEE Antennas Propag. Mag. **63**(4), 43–50 (2021)
33. Lemey, S., Agneessens, S., Van Torre, P., Baes, K., Rogier, H. Vanfleteren, J.: Autonomous wearable RFID-based sensing platform for the Internet-of-Things. In: 2017 International Applied Computational Electromagnetics Society Symposium - Italy (ACES), pp. 1–2. Institute of Electrical and Electronics Engineers (IEEE) (2017)
34. Hader, M., Tchoffa, D., El Mhamedi, A., Ghodous, P., Dolgui, A., Abouabdellah, A.: Applying integrated Blockchain and Big Data technologies to improve supply chain traceability and information sharing in the textile sector. J. Ind. Inf. Integr. **28,** 100345 (2022)