C.A.R.L

final whitepaper

by S.A.G.E

CONTENTS

EXECUTIVE SUMMARY

Fast fashion has transformed the clothing industry by making trendy apparel rapidly and cheaply accessible to consumers. However, this convenience comes at a significant cost to the environment, society, and the economy.

This whitepaper examines the detrimental impacts of fast fashion and proposes solutions to mitigate these effects. The fashion industry has doubled production in the last two decades, leading to severe environmental consequences.

Unsustainable production practices and the widespread use of non-biodegradable materials contribute to pollution, waste, and resource depletion. Fast fashion often relies on exploitative labor practices, including poor working conditions and unfair wages, highlighting severe ethical concerns within the industry.

The rapid turnover of fashion trends encourages overconsumption, resulting in excessive waste and a disposable culture that undermines sustainable living.

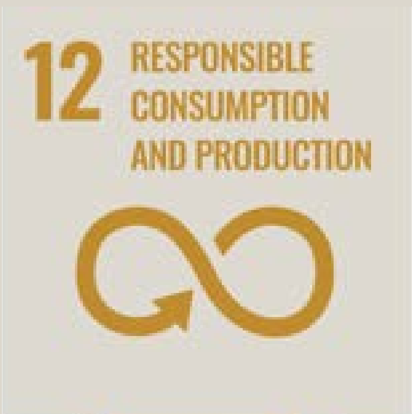
To address these issues, the report emphasizes the importance of aligning with the United Nations Sustainable Development Goal (SDG) 12, which advocates for responsible consumption and production. Achieving this goal involves reevaluating consumer habits, fostering sustainable production, advocating ethical labor practices, and reimagining fashion.

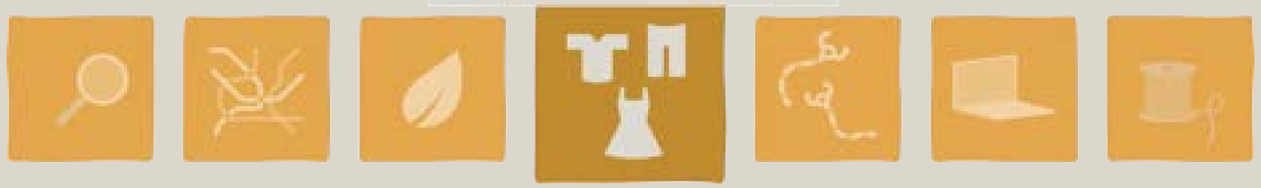
The following whitepaper provides details about C.A.R.L (the Cool Automated Recycling Loop), a user-based machine designed to bridge the gap between consumers and producers.

C.A.R.L is intended to harvest materials, tailor, customize, and recycle textiles, promoting a circular economic solution for the fashion industry. It also focuses on consumer education and awareness. The main focus currently is on consumer education and policy advocacy to support the development of the first C.A.R.L. Additionally, collaboration between fast fashion brands, governments, and NGOs is crucial for funding and promoting the C.A.R.L movement and investing in its innovative technologies.

To combat the fast fashion, crisis requires a comprehensive approach involving changes in consumer behavior, industry practices, and technological innovation.

By fostering collaboration and emphasizing sustainability, the fashion industry can significantly reduce its negative impacts and contribute to achieving SDG 12's objectives.





PROBLEM SPACE AND KEY INSIGHTS

PROBLEM SPACE

Fast fashion refers to inexpensive clothing produced rapidly by mass-market retailers to keep up with the latest fashion trends. The primary issue with fast fashion is the enormous amount of textile waste it generates. Large quantities of clothing end up in landfills, awaiting incineration or left to decompose, contributing significantly to environmental pollution.

Globally, textile production results in the creation of 100 to 150 billion pieces of clothing annually, equating to about 18 times the world's population [1], [2]. However, only 80 billion of these items make it into consumers' homes [3], [4]. This leads to a staggering 92 million tonnes of clothing-related waste each year, including unwanted and discarded garments [3].

Alarmingly, only 1 to 2 percent of this waste is recycled circularly, leaving up to **91 million tonnes of textile waste** annually that is either downcycled, landfilled, or incinerated [5].

Beyond waste, the environmental impact of fast fashion includes extensive water usage, chemical pollution from dyes and treatments, and high carbon emissions from production and transportation [6]. Socially, fast fashion often relies on exploitative labor practices, with workers in developing countries facing poor working conditions and inadequate wages .

A significant driver of these issues is overconsumption. The fast fashion business model thrives on consumers constantly buying new clothes to keep up with rapidly changing trends [7], [8].

This constant demand leads to overproduction and excessive resource use, as brands aim to supply an ever-increasing variety of styles at low prices [6], [9]. As a result, consumers purchase far more clothing than they need, with many items worn only a few times before being discarded [10], [11]. This disposable culture worsens the cycle of waste and accumulates environmental degradation.

Another critical issue is the inefficiency and challenges associated with clothing and textile recycling. Current recycling processes are limited by several factors such as quality degradation, blended fabrics, lack of infrastructure, economic viability, and consumer participation.

Most recycled textiles are downcycled, meaning that the most common route is to be downcycled into lower-quality materials that cannot be used to produce new clothing. This reduces the value and usability of recycled fibers. Along with this, many garments are made from blended materials (e.g. cotton-polyester mixes), which are difficult to separate and recycle efficiently [12], [13]. The recycling process for these mixed fabrics is often complex and costly [12].

There is an **insufficient infrastructure** for collecting, sorting, and processing textile waste on a large scale [14], [15].

GLOBAL MATERIAL FLOWS FOR CLOTHING IN 2015

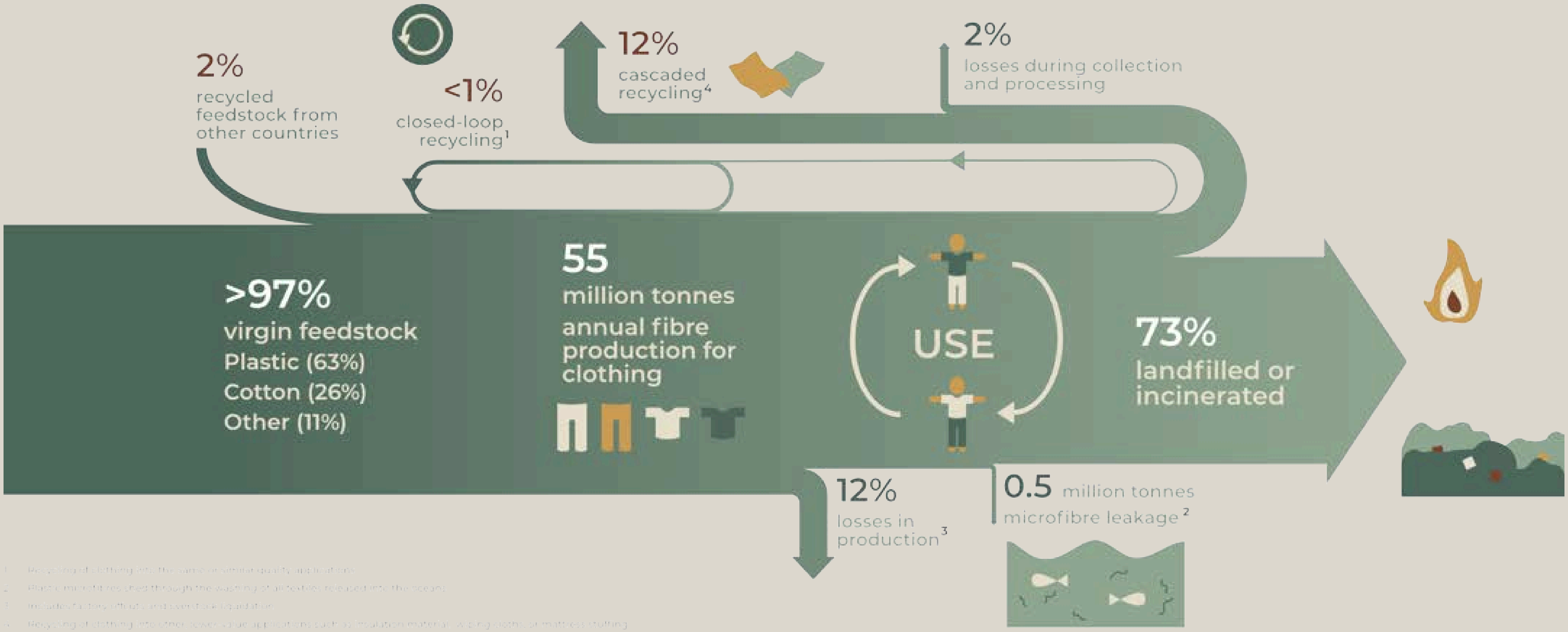


Fig. 1 | Global material flows for clothing in 2015 - Ellen Macarthur Foundation.

https://archive.ellenmacarthurfoundation.org/assets/downloads/A-New-Textiles-Economy.pdf

Many regions lack the facilities and systems needed to handle the volume of discarded clothing. Furthermore, recycling textiles can be less economically viable compared to producing new materials [16].

The cost of recycling processes, combined with the lower quality of recycled fibers, can make it less attractive for businesses. Lastly, effective recycling relies on consumer participation in returning and properly disposing of used garments [17]. Lack of awareness and convenient recycling options can hinder the effectiveness of recycling programs [18].

Addressing these issues requires a multi-faceted approach. First, educating consumers on the environmental and social impacts of fast fashion can encourage more sustainable purchasing decisions and reduce overconsumption. Brands also need to adopt more sustainable materials and production methods to reduce resource usage and pollution.

Enhancing textile recycling and promoting a circular economy can significantly reduce waste; innovations like C.A.R.L. (Cool Automated Recycling Loop) can help bridge the gap between consumers and producers by facilitating material harvesting, tailoring, and recycling. Additionally, governments and international bodies can enforce regulations to ensure ethical labor practices and environmental standards in the fashion industry.

By implementing these strategies, the fashion industry can mitigate its negative impacts and contribute to more sustainable and ethical consumption and production patterns.

KEY INSIGHTS

REDUCING OVERCONSUMPTION

Promoting sustainable consumer behavior is fundamental to reducing overconsumption. Educating consumers about the environmental and social impacts of overconsumption in fashion can help to promote responsible purchasing decisions. Emphasizing the importance of buying less, choosing quality over quantity, and opting for sustainable choices can shift consumer behavior.

Alternative business models can also contribute to reducing overconsumption. Supporting business models that focus on longevity, repairability, and reuse of clothing is essential. Brands can offer repair services, resale of pre-owned items, and rental options to extend the lifecycle of garments.

Designing for longevity is another key strategy.

Encouraging fashion brands to design **durable and timeless pieces** that are made to last can ensure longer garment lifespans.

Using high-quality materials and craftsmanship can contribute to the durability of clothing. Additionally, designing versatile and modular clothing that can be easily updated or modified to keep up with trends without needing to buy entirely new items can make fashion more sustainable. Modular fashion allows consumers to adapt their wardrobes in an environmentally friendly way.

Policy and regulation can play a significant role in reducing overconsumption. Implementing policies, which the EU Parliament is set to establish in the near future [19] that discourage overconsumption, such as higher taxes on fast fashion items and incentives for purchasing sustainable products, avoiding greenwashing [20], [21], [22], can help shift consumer behavior towards more sustainable choices.

Mandating **transparency** in supply chains, so consumers can make informed decisions based on the environmental and social practices of brands, can also guide consumers toward more sustainable options.

Finally, fostering community and cultural shifts is crucial for promoting sustainability. Encouraging a cultural shift that values sustainability and ethical consumption through influencers, media, and educational institutions can drive a broader societal change. Supporting community initiatives like clothing swaps, second-hand markets, and repair cafes can reduce waste and promote a culture of reuse and sustainability.

These community-driven efforts can complement broader industry and policy initiatives, leading to a more consumer-lead, sustainable and ethical fashion industry.

IMPROVING TEXTILE RECYCLING

Enhancing recycling technologies is crucial for maintaining or improving the quality of recycled fibers.

Innovations in chemical recycling, which can break down textiles to their original fibers without degrading quality [14], are promising; however, can be costly and still require further innovation. Furthermore, investing in technologies capable of efficiently separating and recycling blended fabrics, such as cotton-polyester mixes, is essential for effective recycling. These advancements can help overcome the current limitations and make textile recycling more viable.

Developing robust infrastructure can be established for handling the large volumes of discarded clothing. Providing places for textile collection and sorting systems, such as accessible drop-off points and curbside collection, can significantly increase consumer participation in recycling efforts. Expanding the number and capacity of recycling facilities, including those equipped for both mechanical and chemical recycling processes, will ensure that the collected textiles are effectively processed and repurposed.

Economic incentives can play a significant role in encouraging sustainable practices within the textile industry. Providing subsidies, tax breaks, and grants to companies that invest in recycling infrastructure and technologies can make these investments more attractive.

Additionally, creating markets for recycled textiles by promoting their use in new products can support the financial viability of recycling initiatives. Research and development in applications for recycled fibers beyond clothing, such as in construction materials or automotive interiors, can further expand the market.

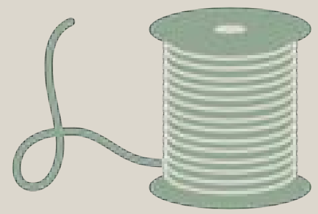
Engaging consumers is critical to the success of textile recycling.

Launching educational campaigns to raise awareness about the importance of textile recycling and providing information on how consumers can participate is essential.

Emphasizing the environmental benefits and the processes involved in recycling textiles can motivate consumers to take part. This is complementary to encouraging consumers to not overconsume fast fashion. Therefore, offering convenient and user-friendly recycling options, such as easily accessible drop-off points, take-back programs, and partnerships with retailers, will also encourage greater consumer participation and awareness.

Regulation and standards can drive improvements in textile recycling. Implementing Extended Producer Responsibility (EPR) policies [23], which hold manufacturers accountable for the entire lifecycle of their products, including end-of-life disposal, can incentivize producers to design more recyclable products and manage waste more effectively.

Developing and enforcing standards and certifications for recycled textiles, such as the Global Recycled Standard (GRS) [24], can ensure quality and build consumer trust, promoting the use of recycled materials.



DETAILED DESIGN SOLUTION

INTRODUCTION

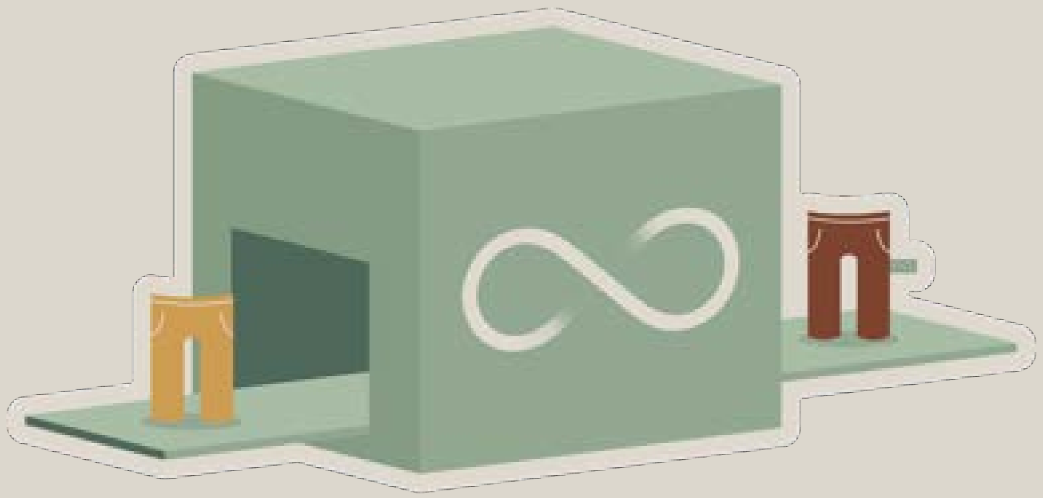
C.A.R.L, the Cool Automated Recycling Loop, is a system designed with the goal of making fashion more sustainable by directly linking textile production and recycling. The term loop "loop" highlights the pursuit of more circularity in the fashion industry.

C.A.R.L is a machine made up of a series of components that work together to take in old clothes, recycle them, and **produce new clothes from the recycled materials** - all in one.

The process is local and fully automated, with materials moving seamlessly from one stage of the recycling- and production process to the next without any human help or intervention.

Clothing is produced by C.A.R.L on demand; customers request single, customized pieces of clothing that are then produced specifically for them and tailored exactly to their measurements.

Instead of having to search through different sizes and styles to find the right fit, customers can have clothes made to their specific preferences by C.A.R.L.



With this, the system takes a novel approach to combat overproduction and highlight more individuality in fashion, compared to players in the fast fashion industry producing large amounts of clothing, much of which does not reach consumer homes [25].

By offering a more affordable and sustainable alternative to fast fashion, C.A.R.L aims to provide people with durable, custom-made clothing that is made to be worn and kept for longer periods of time as opposed to a lot of contemporary fashion [26].

C.A.R.L aims to change the way people think about fashion production and consumption, and gives them an opportunity to enjoy custom made, individual and affordable clothes without harming the environment.

THE GOAL

If the fashion industry continues producing and discarding large amounts of cheap clothing as it does today [27], this will lead to excessive waste and environmental degradation to a point at which humanity is no longer capable of mitigating its effects on planet earth and making it habitable for future generations [28]. As such, the main goal of C.A.R.L is to shift the course of the fashion industry towards a path that will lead to a future in which humanity will be able to coexist peacefully and sustainably with nature.

This goal consists of two main initiatives:

The first of these aims to **lower clothing production and consumption**. This has to be done indirectly, by raising awareness in consumers about the poor working conditions associated with the current fast fashion industry [29], which should inspire people to be more conscious about the clothes they buy and be less likely to discard clothing quickly. Ideally, this would also put more scrutiny on brands that currently support these working conditions and help advance regulations across the world, limiting the imports of unethically produced clothing. Additionally, as a direct contribution, C.A.R.L replaces the traditional model of overproduction with on-demand production, so clothes are made only when requested by customers.

Second, C.A.R.L focuses on **scaling up textile recycling**. The textile recycling industry currently struggles to keep pace with the large volumes of clothing produced, as the recycling process requires a lot of manual labour for sorting clothes, removing accessories, and processing materials [30]. By fully automating textile recycling and linking all steps of the process directly without the need for transportation, C.A.R.L can recycle clothes at much higher rates, making it more capable of handling the growing challenge of textile waste.

The following chapters will delve deeper into what C.A.R.L (the machine) is, how it looks and works, as well as the components beyond the machine itself that make up the system C.A.R.L and help achieve the goal of shifting the trajectory of the fashion industry.

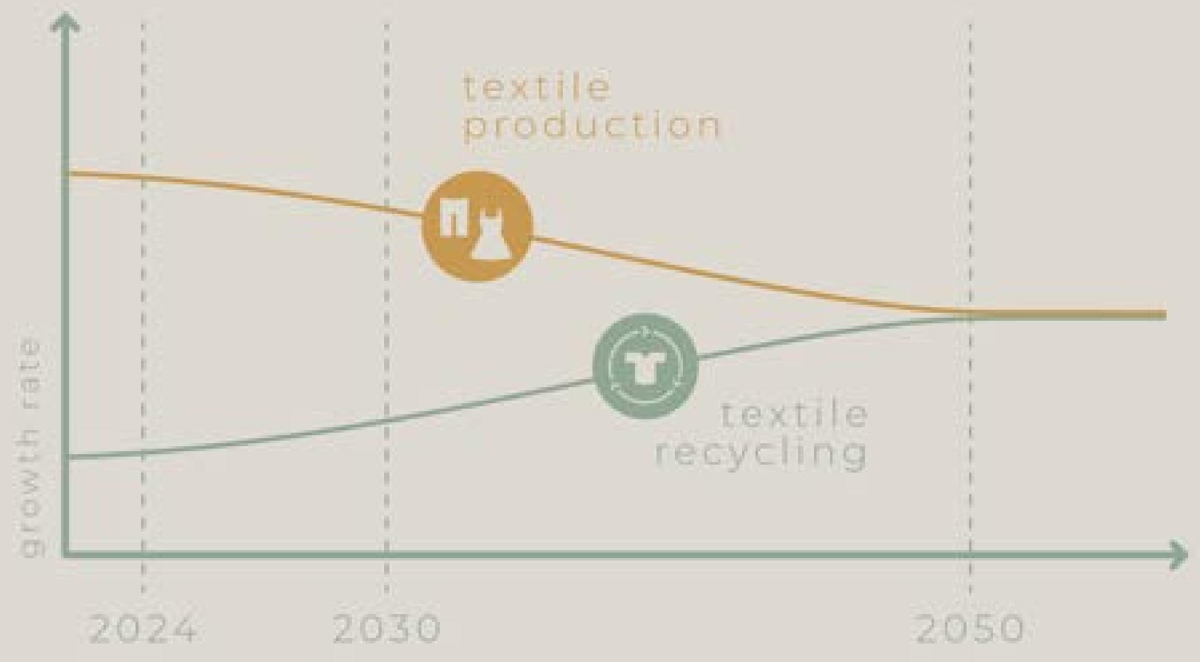


Fig. 2 | The goal of C.A.R.L is to change the current trajectory of both fashion production and -recycling

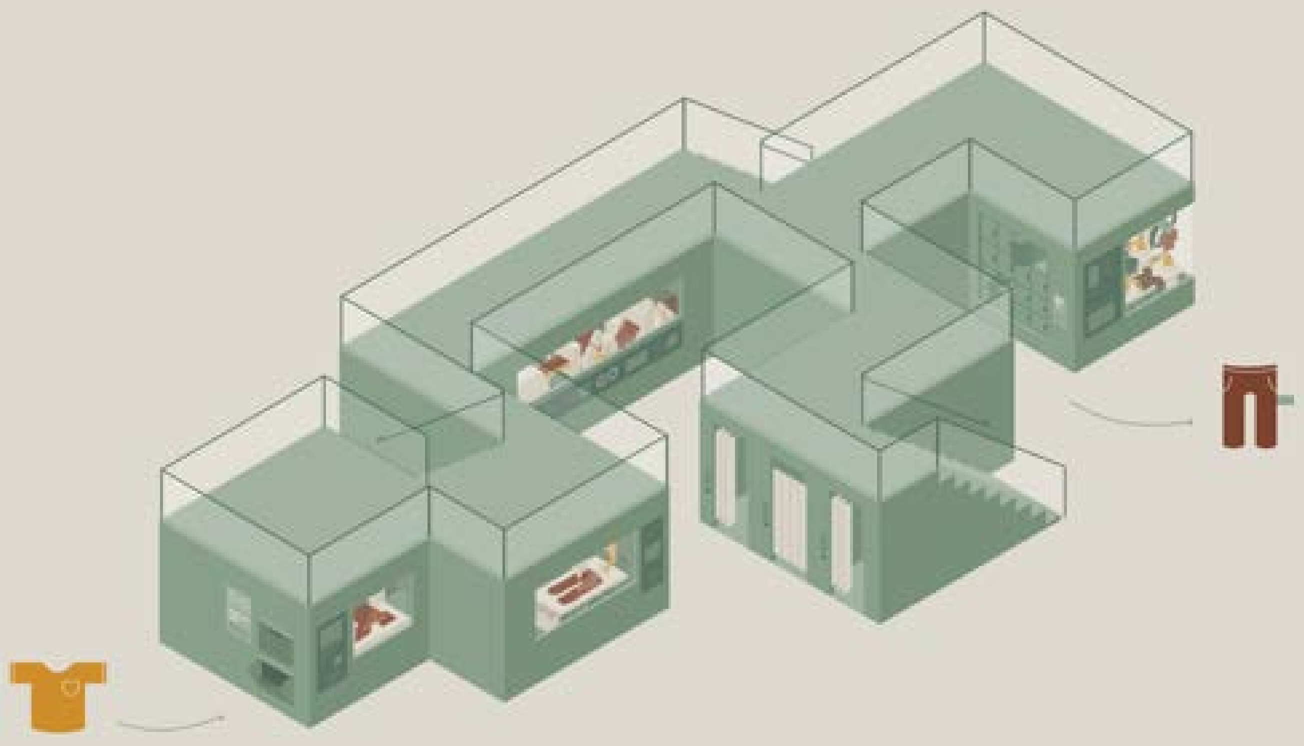


Fig. 3 | Basic C.A.R.L construction, clothes travel through the machine as they are recycled

C.A.R.L - THE CENTREPIECE

SIZE & POSITION

At the center of the C.A.R.L concept stands the machine itself, as shown in figure 3 which takes clothing, recycles it and produces new clothing.

The machine itself is designed with the aim of radically scaling down contemporary textile recycling and production structures [30], in order to bring these processes closer to where consumers live and shop. Its modular structure allows for easy construction, deconstruction, and replacement of different components, making the system highly adaptable.

This modularity also makes for easier transport, as its components can fit into standard shipping containers and can then be assembled on site. Additionally, components can be added or run in parallel to speed up recycling- and production processes, allowing the size and structure of C.A.R.L to vary depending on available space and other requirements. This flexibility ensures that C.A.R.L can be integrated into a variety of environments, enhancing accessibility and efficiency in textile recycling and production.

A standard C.A.R.L,with no parallel components aims to fit into **a single shipping container.**

A slightly larger, parallelized C.A.R.L can be distributed into 2 to 3 shipping containers and will need a larger space to fit. Depending on the available space, components can be arranged and stacked differently.

C.A.R.L will be positioned as close to customers as possible, because availability and convenience enables more people to use the machine's services. To attract new customers in the initial phases of the project, C.A.R.L will be located in high-traffic areas such as shopping malls, where many people visit and spend their time, potentially exploring the machine and its offers.

As the project progresses and more and more C.A.R.Ls spread in cities and all over the world, C.A.R.L will be situated where people can benefit most from the affordability of the sustainable fashion it provides. This means placing C.A.R.L where people with low income can easily access and use it. By positioning C.A.R.L in these locations, it aims to be accessible to a wide range of people, promoting widespread use and contributing to a more sustainable fashion industry.

USER JOURNEY

Customers approach C.A.R.L, preferably with old clothing that they either can not or do not want to wear anymore.

At the input for old clothing, customers are greeted by a screen informing them about the procedure of using C.A.R.L. The screen instructs customers to place their clothing into the input one by one. Each piece of clothing is analyzed to gain insights about weight and material composition. I f a piece of clothing is not fit to be recycled by C.A.R.L, it is returned to the customer.

Information about the weight and rough material composition of all clothes that are fit for further processing is displayed to the customer. From this data, a C.A.R.L makes a calculation of how many credits the customer will receive depending on which materials and how much clothing in terms of weight has been provided.

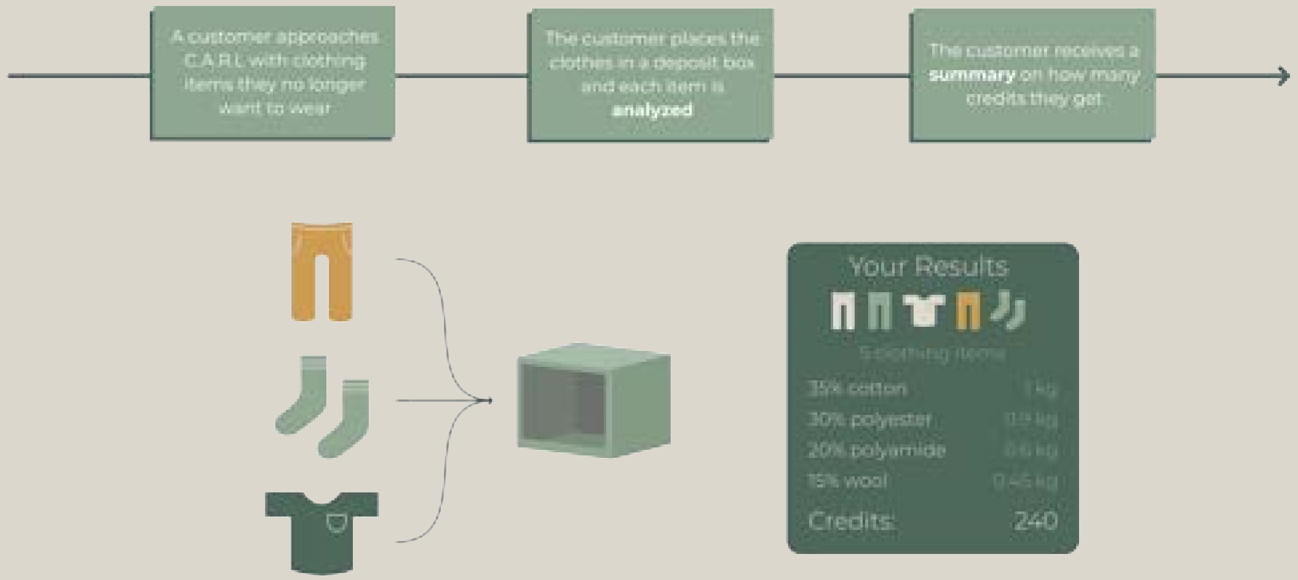


Fig. 4 | Short visualization of the clothing intake and analysis

These credits can then be used to discount the purchases that customers make from C.A.R.L or donate to charity, which will be addressed later in more detail.

If the customer is happy with their choice of providing their clothing and receiving credits, they can confirm the exchange. Then, they will receive their credits, either via a code which they can later use or, if they have a C.A.R.L account, directly into their account. In the background, the provided clothes are further analyzed, taken apart and processed into new yarn for clothing production. This process, as well as the technologies used by C.A.R.L will be explained in more detail later on.

After this, customers can either save their credits for another time or directly order clothing. Before they can do this, they first need their measurements to be taken.

> C.A.R.L is supplied with measuring booths, where **depth sensors will scan people** for their measurements, so they do not have to measure themselves.

Returning customers can save their measurements to be used for their future purchases as well.

Once a customer has had their measurements taken, they can either use one of the tablets provided around C.A.R.L, or their own mobile devices to access the C.A.R.L customization interface, which will also be addressed in more detail later on. There, they can choose which piece of clothing they want to be produced and customize aspects like shape, color and accessories.

After configuration, they can apply any credits they have, pay and confirm their purchase. Customers then receive a code with which they can later retrieve their order.

C.A.R.L then receives the order and assigns it to one of its production components. There, the order is queued until all previous orders have been processed. Customers are notified of these waiting times in advance, so they can plan accordingly.

Once the ordered piece of clothing has been produced, it is moved to a storage box, where the customer can retrieve it with the code they have been provided. Then, they can take the piece home with them and hopefully return for future purchases.

THE TECHNOLOGY OF C.A.R.L

ANALYSIS

Clothing is analyzed using VIS- and NIR sensors to gain insights on material composition. Only clothing with a mono-material composition is taken for further processing, other clothes are rejected and returned.

DISINFECTION

Clothing that has been accepted by analysis is then collected into ozone chambers, where it is thoroughly disinfected to eradicate any potential sources of decontamination.

ACCESSORY REMOVAL

After disinfection, any accessories are removed so the clothing material can be shredded and recycled properly. Particle beams are used to recognize accessories, and lasers are used to cut them out.

SHREDDING

Once only the textile remains, it travels into a three-step process to separate and prepare the fibers for production. In the first step, the textiles are shredded to separate the fibers.

CARDING

In the second step of fiber preparation, the separated fibers are carded. This disentangles the fibers, positions them parallel to each other, and removes impurities, which results in a so-called "sliver".

COMBING

In the third step of fiber preparation, the separated fibers are combed. This prepares the sliver for being spun into yarn. Combing is optional, but makes the yarn smoother and stronger.

SPINNING & COLORING

After preparation, the fibers are spun into new mono-material yarn. The yarn is then discolored using redox decoloring agents and recolored with sustainable color pigments.

KNITTING

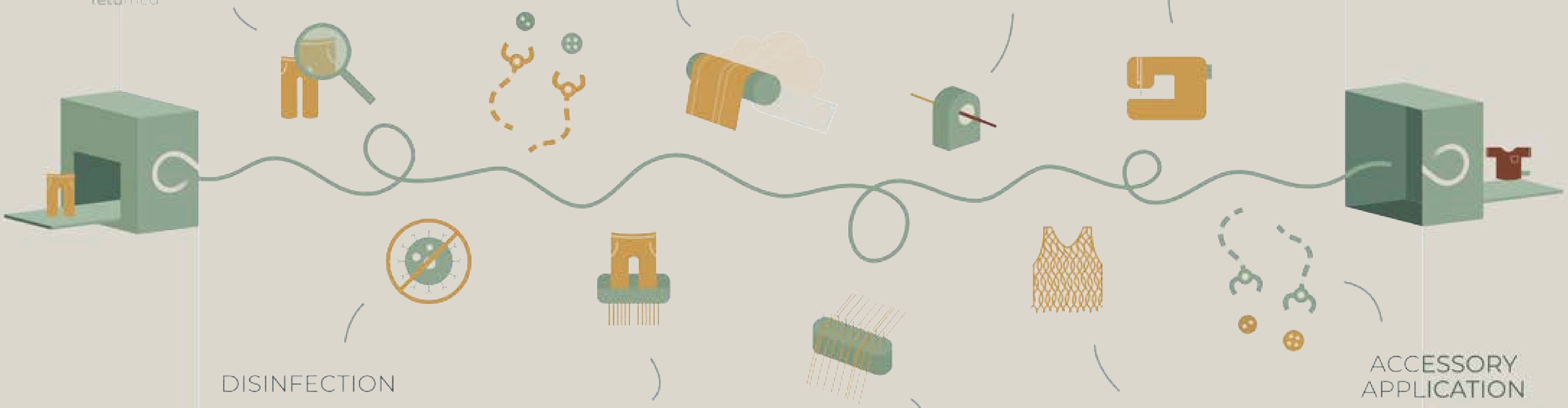
Once the yarn is spun and colored, it can be used to knit fabric patterns for the clothes that are going to be produced. Knitting the patterns eliminates losses that occur when the pattern is cut from fabric.

SEWING

The knit patterns are then passed on to be sewn together into complete garments. This is fully automated via highly dexterous, AI-powered robotic arms capable of handling textiles.

ACCESSORY APPLICATION

Finally, the same robotic arms then apply any accessories like buttons and zippers to the clothing. Additionally, a C.A.R.L tag is added to inform about the clothes' origin and material composition.



The textile industry faces increasing pressure to adopt sustainable practices, and recycling technology is at the forefront of these efforts. This chapter provides an in-depth look at the advanced technologies employed in a state-of-the-art clothing recycling facility. These technologies include:

- Body scanning - for **measurement**
- VIS/NIR spectroscopy - for material **analysis** and rejection of mixed-material garments
- A miniature particle accelerator - for scanning and **detection** of accessories, and automatic removal of accessories
- Ozone and UV Radiation - for **disinfection**
- Automation - for fiber shredding, carding, combing, spinning, decolorization, dyeing, **knitting** into new garments
- The Da Vinci surgical assistance robot - for automated **sewing**

BODY SCANNING FOR MEASUREMENTS

At the beginning of the recycling process, body scanners are used to capture the precise measurements of individuals. This information is crucial for creating new garments that fit well and meet consumer demands. Advanced body scanners use 3D imaging technology to obtain accurate and comprehensive measurements quickly and efficiently.

KEY COMPONENTS

The primary tool used in this process is the 3D body scanner. This device captures detailed three-dimensional images of the human body. By using multiple cameras and sensors, the scanner constructs a highly accurate digital model of the person, capturing the full contour and dimensions of the body. This allows for precise measurements that are far more accurate than traditional methods.

Once the 3D image is captured, specialized measurement software analyzes the image to extract key measurements. The software uses advanced algorithms to identify and calculate critical dimensions such as chest, waist, hips, inseam, arm length, and more. This analysis is performed rapidly and accurately, providing a comprehensive set of measurements that are essential for garment production.

After the measurements are extracted, they are stored in a secure database.

This data storage system is designed to handle large volumes of measurement data, ensuring that it is easily accessible for use in the garment production process. The storage system is also integrated with other production systems in the facility, allowing for seamless data transfer and utilization. [31]

PROCESS

The first step in the body scanning process involves individuals stepping into the 3D body scanner. The scanner, equipped with multiple cameras and sensors, captures a 3D image of the individual's body. This process is quick and non-intrusive, typically taking only a few seconds to complete. The individual stands still while the scanner records the necessary data from multiple angles. Once the 3D image is captured, the measurement software begins its analysis.

The software identifies key landmarks on the body and calculates various measurements based on these points. For example, it can measure the circumference of the chest, waist, hips, the length of the legs and arms, and other critical dimensions. This extraction process is automated and highly accurate, ensuring that the measurements are precise and reliable. [32]

After the measurements have been extracted, they are stored in a centralized database. This database is designed to securely hold all measurement data, making it easily accessible for use in the subsequent stages of garment production. The stored data includes all the necessary measurements and can be retrieved by production systems to create custom-fitted garments. The integration of this data storage with other production systems ensures that the measurements are used efficiently and accurately in the creation of new clothing items. [33]

In conclusion, the body scanning process in C.A.R.L is an essential component that ensures the production of well-fitting garments. By utilizing advanced 3D body scanners, sophisticated measurement software, secure data storage systems, the facility can capture, analyze, and store precise body measurements efficiently. This process not only improves the fit and comfort of the recycled garments but also enhances the overall efficiency and sustainability of the clothing recycling process.

MATERIAL ANALYSIS USING VIS/NIR SPECTROSCOPY

The recycling process begins with the identification and sorting of incoming textiles.

Material analysis is a crucial step in the recycling process, ensuring that only suitable textiles are processed further. This facility employs Visible/Near-Infrared (VIS/NIR) spectroscopy to analyze and identify the composition of incoming textiles.

VIS/NIR spectroscopy is a powerful analytical tool that provides precise material composition data, distinguishing between various fiber types such as cotton, polyester, wool, and blends by analyzing the light absorption patterns of the materials.

Only garments made from a single type of material are accepted for further processing; mixed-material garments are rejected to ensure the quality and efficiency of the subsequent recycling processes. [34]

KEY COMPONENTS

The spectrometer is the core device in the VIS/NIR spectroscopy system. The specific type could be a VISIR2-Sensor. It combines the VIS- and NIR spectroscopy in one chip. [35] It measures the light absorption of textiles at different wavelengths.

By shining light on the textile sample and measuring how much light is absorbed at various wavelengths, the spectrometer generates a spectral signature unique to each type of material. The spectrometer's precision and sensitivity are crucial for accurate material identification, making it an indispensable tool in the recycling process. Calibration models are sophisticated algorithms used to interpret the spectral data collected by the spectrometer. These models correlate the spectral data with specific materials.

Developed through extensive testing and calibration using known samples, the calibration models ensure that the system can accurately identify different materials. They are continually updated and refined to improve accuracy and adapt to new textile compositions.

This system automatically sorts textiles based on the spectrometer's analysis. Once the fiber composition is identified, the sorting mechanism directs monomaterial textiles to further processing and rejects mixed-material garments. The automated sorting mechanism enhances efficiency and accuracy, reducing the risk of human error and ensuring consistent quality control. [36]

PROCESS

The spectrometer shines light on the sample and measures the absorption at various wavelengths. This process generates a spectral signature that reflects the material composition of the textile. The spectrometer captures detailed data on how the textile interacts with light across the visible and near-infrared spectrum, providing a comprehensive profile of the material's properties.

The spectral data collected by the spectrometer is then processed using the calibration models. These models interpret the data to identify the fiber composition of each sample. The algorithms compare the spectral signature to known patterns for different fibers, determining the type of material. This step involves sophisticated data analysis techniques to ensure accurate identification, taking into account the subtle differences in light absorption characteristics between various fibers.

The automated sorting mechanism categorizes textiles based on fiber composition. Single-fiber textiles are accepted for further processing, while mixed-material garments, which could compromise recycled fiber quality, are rejected. Designed to handle high volumes efficiently, the system ensures accurate recycling at scale. Sorted textiles are then directed to the appropriate processing streams.

VIS/NIR spectroscopy in material analysis offers significant advantages for C.A.R.L. By processing only monomaterial textiles, the facility maintains high-quality recycled fibers, improving durability and consumer appeal. The automated analysis and sorting reduce labor costs and human error, enhancing efficiency and cost-effectiveness. Accurately identifying and rejecting mixed-material garments prevents contamination, maintaining the integrity of the recycled fibers. Additionally, VIS/NIR spectroscopy allows the facility to adapt to new textile compositions, keeping the recycling process effective as the industry evolves.

In summary, the integration of VIS/NIR spectroscopy into the material analysis process is a critical component of C.A.R.L. By leveraging advanced spectral measurement, sophisticated calibration models, and automated sorting mechanisms, the facility can accurately and efficiently identify suitable textiles for recycling. This not only enhances the quality and sustainability of the recycled garments but also contributes to the overall efficiency and cost-effectiveness of the recycling process, supporting the broader goals of environmental sustainability and resource conservation. [36]

SCANNING & DETECTION OF ACCESSORIES

After the initial material analysis, garments undergo scanning to detect accessories such as buttons, zippers, and embellishments. This step is crucial as these accessories can interfere with the recycling machinery, contaminate the recycled fibers and damage the machinery.

A miniature particle accelerator is used to create high-resolution scans of the clothing. In C.A.R.L, one of the critical processes involves the detailed scanning and removal of accessories such as buttons, zippers, and tags from garments.

This is achieved using a miniature particle accelerator, which provides a highly detailed and efficient scanning method, ensuring that all accessories are accurately identified and removed before the garments proceed to the shredding and fiber processing stages.

This innovative approach enhances the precision and efficiency of accessory removal, ensuring the quality and purity of the recycled fibers.

KEY COMPONENTS

The core of this advanced scanning system is the miniature particle accelerator. This device generates high-energy particles that penetrate the garments, providing detailed scans of their internal structures. The high-resolution data obtained through this method allows for the precise identification of accessories embedded in the garments.

Detection sensors are used to capture the detailed images produced by the particle accelerator. These sensors are highly sensitive and capable of detecting minute differences in the material composition, enabling them to identify various accessories regardless of their size or placement within the garment.

Once the detection sensors capture the images, these are processed using advanced image processing systems. These systems employ sophisticated algorithms to analyze the images, identify accessories, and map their exact locations on each garment. This ensures that the removal process can be carried out with high accuracy.

PROCESS

The process begins with the garments being fed into the scanning system. This is done in a controlled and automated manner, ensuring that each garment is properly positioned for optimal scanning. The feeding system is designed to handle a wide variety of garment types and sizes, ensuring versatility and efficiency. As the garments pass through the scanning system, the miniature particle accelerator generates high-energy particles that are directed at the garments. These particles penetrate the fabric, providing detailed internal images. The high-energy particles interact with the materials in the garments, producing signals that are captured by the detection sensors. Detection sensors positioned around the scanning area capture high-resolution images of the garments. These images reveal the internal structure of the garments, including the presence and position of accessories such as buttons, zippers, and other non-fabric components. The sensors are capable of capturing images in real-time, allowing for continuous and efficient scanning. The captured images are then analyzed by advanced image processing systems. These systems use sophisticated algorithms to process the data, identifying the accessories based on their distinct material properties and shapes. The image processing systems can distinguish between different types of accessories, ensuring comprehensive identification.

After the accessories are identified, the system creates a detailed map of their locations on each garment. This map is used to guide the removal process, ensuring that all accessories are accurately and efficiently extracted. The mapping system provides precise coordinates for each accessory, allowing for targeted removal.

The use of a miniature particle accelerator for scanning and accessory removal offers several significant advantages. Firstly, it ensures that all accessories are accurately identified and removed, preventing contamination of the recycled fibers. This is crucial for maintaining the quality and purity of the final recycled products.

Secondly, the high-resolution scanning capability of the particle accelerator allows for the detection of even the smallest accessories, which might otherwise be missed by conventional scanning methods. Moreover, the automated and precise nature of this system enhances the overall efficiency of the recycling process.

By ensuring that accessories are removed quickly and accurately, the system reduces the time and labour required for manual inspection and removal. This not only speeds up the recycling process but also reduces operational costs.

In conclusion, the integration of a miniature particle accelerator for detailed scanning and accessory removal represents a significant advancement in textile recycling technology. By combining high-energy particle scanning with advanced image processing and mapping, the facility can ensure the thorough and efficient removal of accessories from garments.

This technology not only improves the quality and purity of recycled fibers but also enhances the overall efficiency and cost-effectiveness of the recycling process, supporting the broader goals of sustainability and resource conservation in the textile industry. [37]

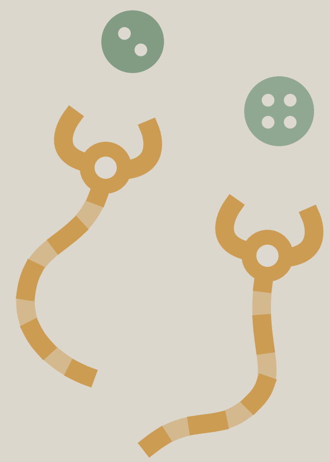
AUTOMATIC REMOVAL OF ACCESSORIES

Once accessories are detected, the next step involves their automatic removal. Robotic systems equipped with precision tools and AI algorithms carefully extract buttons, zippers, and other accessories without damaging the fabric.

In C.A.R.L, the automated removal of accessories from garments is a critical step to ensure the purity and quality of the recycled fibers.

This process is facilitated by robotic arms equipped with specialized tools, guided by advanced AI algorithms. These robotic systems efficiently and accurately remove accessories and other embellishments, ensuring that only clean and pure fabric is further processed.

Here's an in-depth look at the key components and the process involved in automated accessory removal.



KEY COMPONENTS

The robotic arms serve as the primary mechanism for accessory removal. These arms are equipped with specialized tools designed to handle various types of accessories. Each robotic arm is capable of precise and dexterous movements, allowing for targeted removal without removing too much fiber material of the garment.

AI algorithms play a crucial role in guiding the robotic arms during the removal process. These algorithms analyze the data generated by the scanning systems to identify the type and location of accessories on each garment.

Based on this information, the AI algorithms instruct the robotic arms on the optimal approach for removing each accessory, ensuring efficiency and accuracy. Control systems oversee the coordination and synchronization of the robotic removal process. These systems ensure that multiple robotic arms work together seamlessly, positioning the garment for accessory removal and coordinating the movements of each arm to avoid collisions. Control systems also monitor the progress of the removal process and intervene if any issues arise.

PROCESS

The process begins with the robotic system positioning the garment for accessory removal. This may involve adjusting the orientation of the garment to ensure optimal access to the targeted accessories. The positioning process is guided by the data provided by the scanning systems, which accurately map the location of each accessory on the garment.

Once the garment is properly positioned, the robotic arms proceed to extract the detected accessories. Precision tools attached to the robotic arms are used to carefully remove each accessory based on the mapped locations provided by the scanning systems. After the accessories are removed, the system conducts a quality check to verify the successful removal and ensure that no contaminants remain. This may involve visual inspections or additional scanning to confirm that all targeted accessories have been extracted. Any remaining contaminants are identified and addressed before the garment proceeds to the next stage of processing. [31], [38]

Automated accessory removal with robotic arms offers several significant benefits for C.A.R.L. Firstly, it enhances the efficiency and accuracy of the removal process, significantly reducing the time and labour required compared to manual removal methods. This increases overall productivity and throughput, allowing the facility to process garments at a faster rate. Moreover, automated removal ensures consistency and uniformity in the removal process, minimizing the risk of errors or oversights.

The precise control provided by the robotic arms, guided by AI algorithms, ensures that accessories are removed with minimal disruption to the fabric of the garment, preserving the integrity of the recycled fibers. Furthermore, automated accessory removal improves workplace safety by reducing the need for manual labour in potentially hazardous conditions. Robotic systems can handle repetitive and physically demanding tasks with ease, reducing the risk of injuries to human workers. In conclusion, the integration of robotic arms for automated accessory removal represents a significant advancement in textile recycling technology.

By leveraging AI-guided robotics, the facility can achieve efficient and accurate removal of accessories from garments, ensuring the purity and quality of the recycled fibers. This technology not only improves the efficiency and productivity of the recycling process but also enhances workplace safety and sustainability in the textile industry. [31], [38]

DISINFECTION USING OZONE & UV RADIATION

Disinfection is a critical step in ensuring that recycled textiles are hygienic and safe for reuse. The facility employs a dual-method approach using ozone and ultraviolet (UV) radiation. Ozone is a powerful oxidizing agent that eliminates bacteria, viruses, and other pathogens, while UV radiation disrupts the DNA of microorganisms, rendering them harmless.

Together, these methods provide a thorough and environmentally friendly disinfection process. In C.A.R.L, maintaining a high level of hygiene and sanitation is crucial to ensure the quality and safety of the recycled textiles. To achieve this, the facility utilizes an advanced disinfection process that combines ozone treatment and UV-C radiation.

Here's a comprehensive overview of the key components and the detailed process involved in the disinfection procedure.

KEY COMPONENTS

Ozone generators are essential components of the disinfection system. These devices produce ozone, a powerful oxidizing agent that is highly effective at neutralizing a wide range of pathogens, including bacteria, viruses, and fungi.

Ozone is generated on-site and introduced into the disinfection chambers where it interacts with contaminants on the textiles, breaking them down and rendering them harmless. UV lamps emit UV-C radiation, a type of ultraviolet light known for its germicidal properties. UV-C radiation damages the DNA and RNA of microorganisms, effectively deactivating them and preventing their replication. UV lamps are strategically positioned within the disinfection chambers to ensure thorough exposure of the textiles to UV-C radiation, further enhancing the disinfection process.

Disinfection chambers are enclosed spaces specifically designed for the disinfection of

textiles. These chambers are equipped with ozone generators and UV lamps, creating an environment where textiles can be effectively treated to eliminate pathogens. The chambers are sealed during the disinfection process to prevent ozone leakage and ensure maximum efficiency. [39]

PROCESS

The disinfection process begins with the loading of textiles into the disinfection chambers. Textiles are carefully arranged to ensure uniform exposure to ozone and UV radiation. The loading process is carried out in a controlled manner to optimise the efficiency of the disinfection process. Once the textiles are loaded into the chambers, ozone is introduced into the chamber. Ozone molecules react with contaminants on the textiles, oxidizing and neutralizing pathogens present on the surface and within the fibers. Following ozone treatment, the textiles are exposed to UV-C radiation emitted by the UV lamps. UV-C radiation penetrates the textiles, reaching the surface and interior fibers, where it deactivates any remaining microorganisms. UV exposure provides an additional layer of disinfection, ensuring that the textiles are free from pathogens and contaminants. After the disinfection process is complete, the chambers are ventilated to remove any residual ozone. Ventilation systems circulate fresh air through the chambers, rapidly dissipating the ozone and ensuring that the textiles are safe to handle. Once the residual ozone levels are below the specified safety thresholds, the chambers are opened, and the disinfected textiles are unloaded.

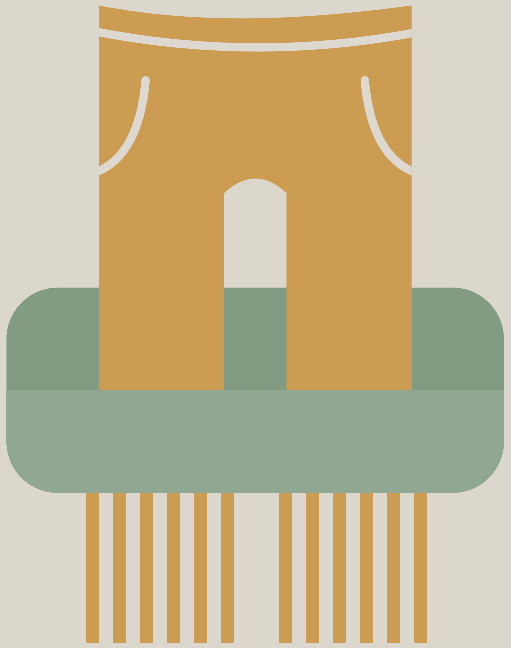
The advanced disinfection process with ozone and UV-C radiation offers several significant benefits for C.A.R.L. Firstly, it provides a highly effective method for disinfecting textiles, ensuring that they meet stringent quality and safety standards. Ozone treatment and UV exposure work synergistically to neutralize a wide range of pathogens, leaving the textiles clean and sanitised. Moreover, the disinfection process is environmentally friendly and water-free, minimizing the use of harmful substances and reducing the facility's environmental footprint. Ozone is a naturally occurring gas that breaks down into oxygen after use, leaving no harmful residues or by-products. In high concentration it can be harmful for humans, thus a strict safety protocol is needed to ensure humans and animals are not in direct contact with the ozone. UV-C radiation is a clean and sustainable disinfection method that does not produce any chemical residues or pollutants. Furthermore, the automated nature of the disinfection process ensures consistency and reliability, minimizing the risk of human error and ensuring uniform disinfection of all textiles processed in the facility. This improves the overall quality and safety of the recycled textiles, enhancing customer satisfaction and confidence in the recycled products. [39]

In conclusion, the integration of ozone treatment and UV-C radiation in the disinfection process represents a significant advancement in textile recycling technology. By harnessing the power of these disinfection methods, the facility can effectively neutralize pathogens and ensure the cleanliness and safety of the recycled textiles. This not only enhances the quality and value of the recycled products but also promotes sustainability and environmental stewardship in the textile industry.

TEXTILE SHREDDING

Following disinfection, the textiles are shredded into small fiber pieces. This mechanical process breaks down the fabric structure, converting it into loose fibers. The shredding machinery is designed to handle various types of textiles, ensuring uniformity in the fiber output. This stage is crucial for preparing the fibers for carding and combing.

In C.A.R.L, the fiber shredding, and collection process is a crucial stage where disinfected textiles are transformed into small, manageable fiber pieces ready for further processing. This process is facilitated by specialized equipment and machinery designed to efficiently shred textiles while ensuring minimal waste. Here's a detailed overview of the key components and the step-by-step process involved in fiber shredding and collection.



KEY COMPONENTS

The heart of the shredding process lies in the shredding unit. The blades are designed to be durable and robust, capable of cutting through various types of textiles with ease and shredding of the textiles into small, uniform fiber pieces.

Conveyors play a vital role in transporting shredded fibers from the shredding machine to the next stage of processing. These conveyor systems are designed to handle large volumes of shredded material efficiently, ensuring continuous operation and minimizing downtime.

Conveyors are equipped with features such as adjustable speed and direction control to accommodate different processing requirements. Dust collectors are essential for maintaining a clean and safe working environment during the shredding process. These systems are designed to remove dust and fine particles generated during shredding, preventing them from dispersing into the air and causing respiratory hazards. [40]

PROCESS

The process begins with disinfected textiles being fed into the shredding machine. Textiles are carefully loaded onto the feeding mechanism, ensuring uniform distribution and optimal shredding efficiency. The feeding mechanism controls the rate at which textiles are introduced into the shredding unit, preventing overloading, and ensuring consistent performance.

As textiles enter the shredding unit, the shredder rapidly cuts through the textiles, transforming them into small, manageable fiber pieces. The shredding process is carefully controlled to achieve the desired fiber size and consistency, ensuring that the resulting fibers are suitable for further processing.

Once shredded, the fibers are collected and transported for further processing. Conveyors carry the shredded fibers away from the shredding machine, depositing them into designated collection bins or storage containers. Dust collectors are employed to remove any dust or fine particles generated during shredding, the dislodged fibers are reintroduced into the process to mitigate waste.

The fiber shredding and collection process play a crucial role in C.A.R.L, enabling the transformation of disinfected textiles into small, uniform fiber pieces ready for reuse. By efficiently shredding textiles, the facility can maximize the yield of recycled fibers while minimizing waste and environmental impact.

Additionally, the use of dust collectors helps maintain a clean and safe working environment and reducing waste. Furthermore, the automated nature of the shredding process improves efficiency and productivity, allowing the facility to process large volumes of textiles quickly and cost-effectively. This enhances overall operational efficiency and throughput, enabling the facility to meet the growing demand for recycled fibers in a sustainable and environmentally responsible manner. [40]

In conclusion, the fiber shredding, and collection process is a critical component of C.A.R.L, enabling the efficient transformation of disinfected textiles into high-quality recycled fibers. By utilizing specialized equipment and machinery, the facility can achieve consistent and reliable shredding performance, ensuring the production of clean and uniform fiber pieces ready for further processing and reuse.

CARDING & COMBING FIBERS

The shredded fibers undergo carding and combing to align them and remove any remaining impurities. Carding involves passing the fibers through fine-toothed rollers that disentangle and blend them into a continuous web. Combing further refines this web by removing short fibers and ensuring that only the longest, strongest fibers are retained. The result is a smooth, uniform fiber mass ready for spinning.

In C.A.R.L, the fiber preparation process plays a vital role in transforming shredded fibers into high-quality material ready for spinning and weaving. This process involves the use of specialized machinery, including carding and combing machines, to disentangle, align, and refine the fibers, ensuring uniformity and quality in the final product.

KEY COMPONENTS

Carding machines are equipped with fine-toothed rollers that work to disentangle and align the fibers into a continuous web. As the fibers pass through the carding machine, they undergo a series of mechanical actions that separate and straighten them, ensuring that they are evenly distributed and oriented in the same direction.

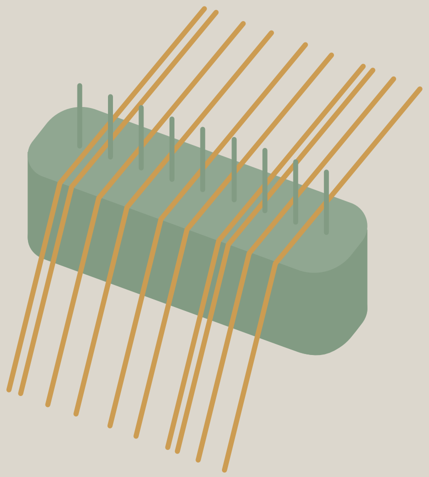
This process helps to improve the quality and consistency of the fibers, preparing them for further processing. Combing machines further refine the fiber web by removing short fibers and impurities. Fiber collectors gather the cleaned and aligned fibers after they have been processed through the carding and combing machines. These collectors are equipped with mechanisms to ensure the even distribution and accumulation of fibers, ready for the next stage of the spinning process. Fiber collectors play a crucial role in maintaining the efficiency and continuity of the fiber preparation process.

PROCESS

The fiber preparation process begins with the feeding of shredded fibers into the carding machines. Inside the carding machines, the fibers undergo a series of carding actions, where fine-toothed rollers work to disentangle and align them into a continuous web. This process helps to remove any remaining tangles and irregularities in the fibers, ensuring that they are evenly distributed and oriented for further processing.

After carding, the delicate fiber web is transferred to combing machines for further refinement. Combing machines work to remove short fibers and impurities from the fiber web, leaving behind only the longest and highest-quality fibers. This process helps to increase the uniformity and strength of the fibers, resulting in a smoother and more consistent yarn.

Combing ensures that the fibers are of the highest quality, ready to be spun into yarn. Once the fibers have been carded and combed, they are collected in fiber collectors for the next stage of the spinning process. Fiber collectors gather the cleaned and aligned fibers, ensuring their even distribution and accumulation. The collected fibers are then ready to be fed into spinning machines, where they will be spun into yarn for use in textile production. [40], [41]



The fiber preparation process is a critical step in C.A.R.L, ensuring that shredded fibers are transformed into high-quality material ready for spinning and weaving. This process helps to maximize the value and usability of recycled fibers, contributing to the sustainability and efficiency of the textile recycling process. Furthermore, the use of advanced machinery and automation in the fiber preparation process improves efficiency and productivity, allowing the facility to process large volumes of fibers quickly and cost-effectively. This enhances overall operational efficiency and throughput, enabling the facility to meet the growing demand for recycled fibers. [25]

In conclusion, the fiber preparation process is a crucial component of C.A.R.L, ensuring that shredded fibers are transformed into high-quality material ready for spinning and weaving. By utilizing specialised machinery and advanced techniques, the facility can achieve consistent and reliable results, contributing to the sustainability and efficiency of the textile recycling process.

SPINNING FIBERS INTO YARN

The aligned and cleaned fibers are then spun into yarn. Spinning involves drawing out and twisting the fibers to form a cohesive thread. The facility uses advanced spinning machines that can adjust the thickness and strength of the yarn according to the desired end product specifications. This process transforms the loose fibers into durable, high-quality yarn.

In C.A.R.L, the yarn production process is a crucial stage where aligned fibers are transformed into yarn ready for dyeing and knitting. This process involves the use of specialized machinery, including spinning machines and bobbin winders, to draw, twist, and wind the fibers into yarns of desired specifications.

Additionally, quality control systems are employed to ensure that the yarn meets the required standards for strength, consistency, and uniformity. Here's a detailed overview of the key components and the step-by-step process involved in yarn production.

KEY COMPONENTS

Spinning machines are the core components of the yarn production process. These machines draw out and twist the aligned fibers to form yarns of desired thickness and strength. Spinning machines come in various configurations, including ring spinning, rotor spinning, and air-jet spinning, each offering unique advantages in terms of yarn quality and production efficiency.

Bobbin winders are used to wind the spun yarn onto bobbins for storage and further processing. These machines ensure that the yarn is wound evenly and securely onto the bobbins, ready for subsequent dyeing and knitting processes. Bobbin winders come with features such as adjustable winding speed and tension control to accommodate different types of yarn and production requirements. Quality control systems play a crucial role in ensuring that the yarn meets the required specifications for strength, consistency, and uniformity.

These systems employ various techniques such as tension monitoring, yarn diameter measurement, and defect detection to identify and rectify any deviations from the desired quality standards. Quality control systems help to maintain the integrity and reliability of the yarn production process, ensuring that the final product meets the expectations of customers and end-users. [42], [43]

PROCESS

The yarn production process begins with aligned fibers being fed into the spinning machines. These fibers are sourced from the fiber preparation process, where they have been carded and combed to ensure uniformity and quality.

The feeding mechanism controls the rate at which fibers are introduced into the spinning machines, ensuring optimal spinning performance and yarn quality. Inside the spinning machines, the aligned fibers undergo drawing and twisting to form yarns of desired thickness and strength. Drawing involves stretching the fibers to align them in the direction of yarn formation, while twisting imparts twist to the fibers, providing cohesion and strength to the yarn.

The spinning machines adjust parameters such as drafting tension, twist level, and spindle speed to achieve the desired yarn characteristics. Once spun, the yarn is wound onto bobbins using winders. These machines wind the yarn evenly and securely onto the bobbins, ensuring uniform tension and winding density. The wound bobbins are then ready for further processing, including dyeing and knitting. Bobbin winders may incorporate features such as automatic bobbin changing and yarn break detection to maximize efficiency and minimize downtime.

The yarn production process is a critical stage in C.A.R.L, enabling the transformation of aligned fibers into high-quality yarns ready for use in textile production. By utilizing specialized machinery such as spinning machines and bobbin winders, the facility can produce yarns of desired specifications with consistency and reliability. This process helps to maximize the value and usability of recycled fibers, contributing to the sustainability and efficiency of the textile recycling process.

Furthermore, the use of quality control systems ensures that the yarn meets the required standards for strength, consistency, and uniformity. This helps to maintain the integrity and reliability of the yarn production process, ensuring that the final product meets the expectations of customers. Additionally, the automation and efficiency of the yarn production process enable the facility to produce large volumes of yarn quickly and cost-effectively, meeting the growing demand for recycled fibers in a sustainable and environmentally responsible manner. [42], [43]

In conclusion, the yarn production process is a crucial component of C.A.R.L, enabling the transformation of aligned fibers into high-quality yarns ready for use in textile production. By utilizing specialized machinery and quality control systems, the facility can achieve consistent and reliable results, contributing to the sustainability and efficiency of the textile recycling process.

DECOLORIZATION & DYEING

To expand the usability of the recycled fibers, decolorization and dyeing processes are employed.

Decolorization removes existing dyes from the fibers, providing a neutral base for new coloration. This is typically achieved through chemical treatments that break down dye molecules. The fibers are then dyed using environmentally friendly dyes that comply with industry standards for safety and sustainability. This step allows for the production of textiles in a wide range of colours.

In C.A.R.L, the decolorization, dyeing, and finishing process is a critical stage where recycled fibers are treated to remove existing dyes, apply new colours, and prepare them for use in downstream production. This process involves the use of specialized equipment, including decolorization tanks, dyeing machines, rinsing, and drying systems, to achieve the desired colour and finish on the fibers. Here's a detailed overview of the key components and the step-by-step process involved in fiber decolorization, dyeing, and finishing.

KEY COMPONENTS

Decolorization tanks contain chemical solutions designed to remove existing dyes from the recycled fibers. These tanks provide an environment where the fibers can be treated to break down the dye molecules, ensuring that they are effectively removed from the fibers. Continuous decolorization systems are used offering unique advantages in terms of efficiency and effectiveness. [44], [45]

Dyeing machines are used to apply new colours to the neutral coloured fibers after the decolorization process. Dyeing machines come in various types, including jet dyeing machines, beam dyeing machines, and garment dyeing machines, each tailored to specific dyeing requirements and production volumes. Rinse and dry systems are employed to remove excess dye from the dyed fibers and prepare them for further processing.

These systems typically include rinse tanks or baths where the fibers are thoroughly rinsed to remove any residual dye particles. After rinsing, the fibers are passed through conveyor dryers. Rinse and dry systems ensure that the dyed fibers are clean, dry, and ready for use in textile production. [46]

PROCESS

The decolorization process begins with the feeding of recycled fibers into the decolorization tanks. Inside the tanks, the fibers are treated with chemical solutions that break down the existing dyes. The decolorization tanks provide agitation and mixing to ensure thorough treatment of the fibers, effectively removing the dyes, and restoring them to a neutral state.

Once decolorized, the fibers are transferred to dyeing machines for the application of new colours. The dyeing machines are loaded with the desired dye solutions, and the fibers are immersed or passed through the dye baths. These machines provide precise control over the dyeing parameters, including temperature and dye concentration, to achieve the desired colour intensity and uniformity. [28], [29]

After dyeing, the dyed fibers are subjected to rinse and dry systems to remove excess dye and prepare them for further processing. The fibers are first rinsed in rinse tanks or baths to remove any residual dye particles, ensuring that the dyed fibers are clean and free from excess dye. Once rinsed, the fibers are passed through drying systems, where they are dried to the desired moisture content. The dried fibers are then ready for use in textile production. [30]

The decolorization, dyeing, and finishing process play a crucial role in C.A.R.L, enabling the transformation of recycled fibers into dyed materials ready for use in textile production. By utilizing specialized equipment and chemical solutions, the facility can effectively remove existing dyes, apply new colours, and prepare the fibers for further processing. This process helps to maximize the value and usability of recycled fibers, allowing them to be used in a wide range of textile applications.

Furthermore, the use of rinse and dry systems ensures that the dyed fibers are clean, dry, and ready for use in textile production. This helps to maintain the integrity and quality of the dyed fibers, ensuring that they meet the expectations of customers. Additionally, the controlled and precise nature of the dyeing process enables the facility to achieve consistent and reliable results, ensuring uniformity and quality in the final product.

KNITTING NEW GARMENTS

The newly spun and dyed yarn is knitted into fabric using automated knitting machines. These machines can produce various types of knit fabrics, suitable for different clothing items. The knitting process is highly customizable, enabling the creation of fabrics with specific patterns, textures, and properties.

In C.A.R.L, the fabric knitting process is a pivotal stage where dyed yarn is transformed into knit fabrics ready for use in various textile applications. This process relies on specialized equipment such as knitting machines, advanced patterning software, and quality control systems to automate the creation of fabrics with desired patterns and textures while

ensuring consistent quality. Here's a comprehensive overview of the key components and the step-by-step process involved in fabric knitting.

KEY COMPONENTS

Knitting machines are the backbone of the fabric knitting process, automating the creation of knit fabrics from dyed yarn.

Knitting machines use needles or loops to interlock yarns, forming fabric structures according to specified patterns and textures. Patterning software plays a crucial role in controlling the knitting machines to produce desired patterns and textures on the fabrics. This software allows designers to create intricate designs and patterns, which are then translated into machine-readable instructions for the knitting machines.

Patterning software offers features such as stitch manipulation, colour management, and pattern simulation, enabling precise control over the knitting process to achieve the desired fabric aesthetics. Quality control systems monitor the fabric throughout the knitting process to ensure consistency and detect any defects or irregularities. These systems employ various techniques such as visual inspection, dimensional analysis, and defect detection algorithms to assess the quality of the fabric in real-time.

Quality control systems help to identify and rectify issues promptly, ensuring that only high-quality fabrics are produced.

PROCESS

The fabric knitting process begins with dyed yarn being fed into the knitting machines. The yarn is loaded onto the machine's yarn carriers or feeders, where it is carefully tensioned and guided into the knitting zone. Yarn feeding mechanisms ensure smooth and consistent yarn delivery to the knitting needles, ensuring uniform fabric formation.

Once yarn feeding is complete, the knitting machines begin the fabric knitting process. The machines use programmed instructions from the patterning software, inputs from the measuring booth and the customer individualization to knit the yarn into fabric according to specified patterns and textures. Knitting machines employ various techniques such as warp knitting, weft knitting, and circular knitting to create different fabric structures and designs. The knitting process is automated and highly efficient, allowing for rapid production of knit fabrics with precise control over quality and consistency.

Throughout the knitting process, the fabric is subjected to inspection by quality control systems to ensure that it meets the required standards for consistency and quality. These systems employ sensors, cameras, and algorithms to detect any defects or irregularities in the fabric, such as dropped stitches, yarn tension variations, or pattern deviations. Inspections are carried out continuously during the knitting process, allowing for prompt identification and correction of any issues. [32]

The fabric knitting process is a critical stage in C.A.R.L, enabling the transformation of dyed yarn into knit fabrics with desired patterns and textures.

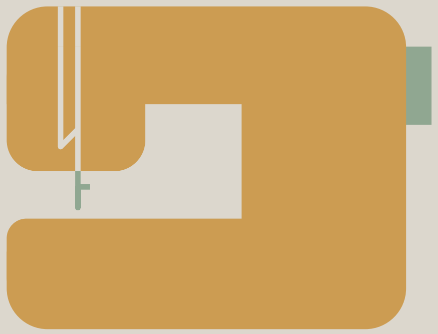
By utilising specialized equipment such as knitting machines, advanced patterning software, and quality control systems, the facility can automate the fabric knitting process while ensuring consistent quality and efficiency. This process helps to maximize the value and usability of recycled yarn, allowing it to be used in various textile applications ranging from apparel to home textiles.

Furthermore, the automation and precision of the fabric knitting process enable the facility to achieve high levels of productivity and throughput, meeting the demands of customers and end-users in a timely and cost-effective manner. Quality control systems ensure that only high-quality fabrics are produced, enhancing customer satisfaction and confidence in the recycled products. Additionally, the flexibility and versatility of the fabric knitting process allow for customization and innovation, enabling the creation of unique and marketable fabric designs.[33]

In conclusion, the fabric knitting process is a crucial component of C.A.R.L, enabling the automated creation of knit fabrics with desired patterns and textures. By leveraging advanced technology and quality control measures, the facility can achieve consistent quality and efficiency in fabric production, contributing to the sustainability and competitiveness of the textile recycling industry.

AUTOMATED SEWING

The final stage in the recycling process involves transforming the knitted fabric into finished garments. This is accomplished using robotic sewing systems inspired by the Da Vinci surgical assistance robot. In C.A.R.L, the automated sewing process represents a cutting-edge advancement, leveraging robotics and advanced programming to stitch garments with unparalleled precision and efficiency.



Inspired by the Da Vinci surgical robot, robotic sewing arms are equipped with sophisticated technology to provide precision and dexterity, while programmable sewing patterns guide the robots in stitching garments according to desired specifications.

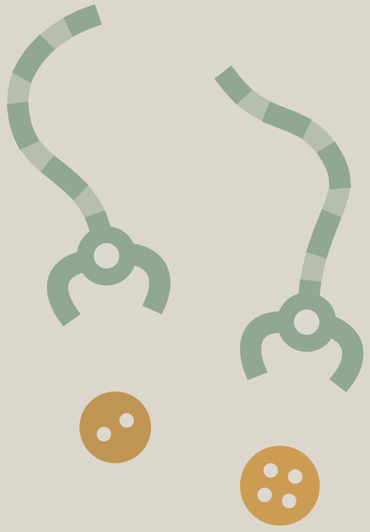
Additionally, quality assurance systems ensure that the sewn garments meet rigorous standards for consistency and quality. Here's a detailed overview of the key components and the step-by-step process involved in automated sewing.

KEY COMPONENTS

Robotic sewing arms, inspired by the Da Vinci surgical robot, are the cornerstone of the automated sewing process. These arms are equipped with advanced sensors, actuators, and end-effectors that provide unparalleled precision and dexterity in stitching garments. Robotic sewing arms can mimic the movements of human hands with remarkable accuracy, allowing for intricate and complex stitching patterns. [49]

Programmable sewing patterns play a crucial role in guiding the robotic sewing arms in stitching garments. These patterns are programmed into the system using specialized software, specifying the sequence of stitches, seam allowances, and other sewing parameters. Programmable sewing patterns allow for customization and flexibility, enabling the production of a wide range of garment styles and designs. [50]

Quality assurance systems are employed to inspect the sewn garments for consistency and defects. These systems utilize advanced sensors, cameras, and algorithms to assess the quality of stitching, seam strength, and overall garment construction. Quality assurance systems ensure that only high-quality garments are produced, enhancing customer satisfaction and confidence in the recycled products. [48]



PROCESS

The automated sewing process begins with knitted fabric being loaded onto the robotic sewing station. The fabric is carefully positioned and secured to ensure smooth and consistent stitching. Fabric loading is carried out manually or with the assistance of automated fabric handling systems, depending on the production requirements. Once the fabric is loaded, the desired sewing patterns are programmed into the system. Pattern programming involves specifying the sequence of stitches, seam allowances, and other sewing parameters using specialized software. Programmers collaborate with designers to ensure that the programmed patterns accurately reflect the desired garment design and style. With the sewing patterns programmed into the system, robotic sewing arms perform the sewing tasks with high precision and accuracy. The robotic arms follow the programmed patterns, stitching the fabric according to the specified sequence of stitches and seam allowances. Advanced motion control algorithms ensure smooth and consistent stitching, even on complex garment shapes and contours. Once the sewing process is complete, finished garments are subjected to quality inspection. Quality assurance systems inspect the sewn garments for consistency and defects, using sensors, cameras, and algorithms to assess the quality of stitching and garment construction. Any defects or irregularities are identified and addressed promptly to ensure that only high-quality garments are released to the market. [51], [52]

The automated sewing process represents a significant advancement in textile manufacturing, offering precision, efficiency, and consistency in garment production. By leveraging robotics and advanced programming, the facility can achieve unparalleled levels of precision and quality in stitching garments, enhancing the value and competitiveness of the recycled products. Additionally, automated sewing reduces labour costs and increases production throughput, allowing the facility to meet the demands of customers and end-users in a timely and cost-effective manner. Quality assurance systems ensure that only high-quality garments are produced, further enhancing customer satisfaction and confidence in the recycled products. [31]

In conclusion, the automated sewing process revolutionises garment production in C.A.R.L, offering precision, efficiency, and quality assurance in stitching garments. By combining robotic sewing arms, programmable sewing patterns, and quality assurance systems, the facility can achieve consistent and reliable results, contributing to the sustainability and competitiveness of the textile recycling industry.

CONCLUSION

The integration of these advanced technologies in a clothing recycling facility ensures efficient and high-quality recycling of textiles. By leveraging body scanning for measurements, VIS/NIR spectroscopy, miniature particle accelerators, robotic systems for accessory removal and sewing, and comprehensive disinfection and processing methods, the facility can produce high-quality recycled garments.

This not only supports sustainability in the textile industry but also contributes to reducing waste and promoting the circular economy.

OUTSIDE THE MACHINE

The concept of C.A.R.L extends beyond the machine itself, and includes a range of additional offers and features that aim to create an experience for customers, where they can feel comfortable, educate themselves and express their individuality. The following chapters expand upon the additional offers provided by C.A.R.L, some of which have briefly been addressed in previous chapters.

THE C.A.R.L CUSTOMIZATION INTERFACE

The C.A.R.L customization interface is directly tied to the machine itself and is a user interface that allows people to fully customize the clothes they want C.A.R.L to produce. It can be accessed on tablets located around C.A.R.L, as well as on mobile devices like phones and laptops. It is possible to use the interface remotely and order clothing from home to retrieve it at a later date. For this, a map of available C.A.R.Ls near the customer is provided, from which they can choose their desired location.

The goal of the customization interface is to allow for full expression of individuality, thus attracting customers regardless of their style preferences. Additionally, the interface educates users about sustainable choices in clothing production throughout the customization process. This combination of personalization and sustainability information ensures that the C.A.R.L interface not only meets diverse fashion needs but also promotes environmentally conscious decisions.

Figures 5 to 8 highlight key parts of the clothing customization journey.

Right at the beginning, customers can view current collaborations, in the initial phases of the project with larger brands, then moving towards smaller, local brands, artists and designers, who can make their designs available to be put on clothing pieces and be compensated whenever people order clothing with them. Collaborations can also offer ready-made designs of full clothing items, in case customers may not want to spend the time to customize their own clothing.

After having chosen a piece of clothing, customers can choose which material the piece will be produced from. Along with this choice, information about the different materials, the purposes they are most fit for, and how sustainable they are, is provided to educate customers and help them make more conscious choices. Next, depending on which piece of clothing people have chosen, they can customize colors or patterns, as well as the shape and size of different aspects like sleeves or pockets to fit their individual preferences.

After the customization of the desired clothing item is complete, customers get an overview over all charities that are supported by C.A.R.L, and can choose to donate either the credits they have or money directly to them. If not, they can apply the credits they have to their purchase to receive a discount.

After the order has been submitted, people receive a code with which to retrieve it as well as an estimated time at which the piece will be finished.

Fig. 5 | Ready-made designs can be chosen from collaborations with brands and designers

Fig. 7 | An overview of charities gives customers an opportunity to donate their credits

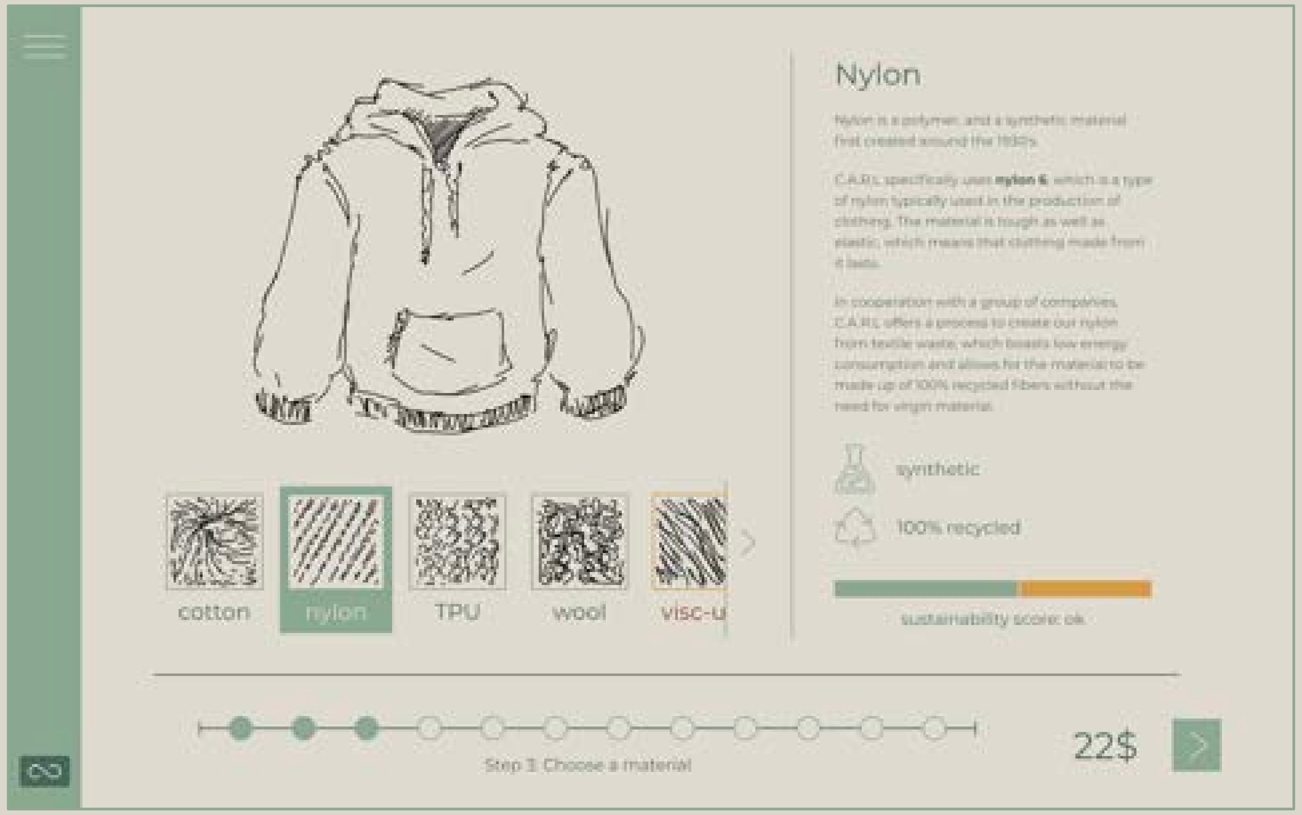


Fig. 6 | The choice of material is accompanied by information about source and sustainability

Fig. 8 | After ordering, customers can see when their clothes will be produced

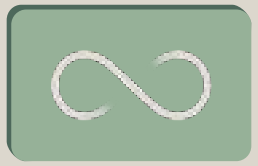
C.A.R.L ACCOUNTS & CREDITS

To make using C.A.R.L as comfortable as possible, especially for returning customers, accounts allow for the storage of measurements, credits, purchases and other information. Accounts are available from all mobile devices, and people can manage their data whenever they please.

The credits given to people for the clothes they donate provide incentive to encourage more clothing donations, and also serve to allow people to buy clothes at a lower price if they use their credits. This allows C.A.R.L to be more adept for challenging the prices currently offered by fast fashion brands, and thus provide a viable alternative for people with low income.

Because some people may want to provide more clothing than what they want to order, which can lead to an excess in credits, collaborations with other sustainable brands in the clothing industry can allow customers to use their credits outside of C.A.R.L, or donate them to charities of their choice.

Along with an account, people can receive something akin to a credit card, which stores their information and is C.A.R.L readable. When providing clothing to C.A.R.L or ordering clothing from one of the tablets provided, people can simply insert the card and then receive the credits or provide their measurements directly from their account without needing to log in.



THE C.A.R.L HUMANE FASHION INITIATIVE

The C.A.R.L Humane Fashion Initiative aims to transform not only consumer mindsets but also their behavior regarding fashion, as well as support the people that are being negatively impacted by the fashion industry. Its purpose extends beyond the clothes C.A.R.L produces and recycles, striving to make a broader impact on the fashion industry.

The initiative's goal is to support charities, local art, and designers, raise awareness about working conditions and global issues, and educate people about sustainability.

Supporting local art and designers is important, because we are aware that the automation of clothing production plays a big role in robbing fashion of its potential as a medium through which people can express themselves, and can potentially cost designers their jobs. This is why we want to directly integrate them into C.A.R.L to maintain personal expression and creativity in fashion.

As previously mentioned, the awareness that is raised about the unethical and unsustainable practices supporting the fast fashion industry optimally contributes to consumers being less willing to purchase fast fashion and instead opting for more sustainable alternatives.

To mitigate the effect this has on sweatshop workers, charities aim to support these workers all over the world and improve working conditions in general, because localizing and automating production with C.A.R.L puts them at risk of losing their jobs.

Lastly, the C.A.R.L Humane Fashion Initiative adheres to a set of principles that we aim to follow to make sure that the project has as positive of an impact as possible:

1. Embrace individuality and human expression whenever possible.
2. Maintain affordability at all costs.
3. Donate excess funds to good causes, ensuring traceability of the donations and their effects.
4. Maintain transparency in all aspects of C.A.R.L's operations, including electricity usage, donation amounts, clothing production metrics, and data confidentiality.

Following these principles ensures that we can have a meaningful impact on sustainability in fashion, without losing sight of the people that may be negatively impacted by the advancements we make.

THE C.A.R.L EXPERIENCE

All of the concepts, mentioned above and including the machine itself, come together into the C.A.R.L experience, as shown in figure 9.

This culminates into **one location** with the recycling- and production machine at the center, around which the other aspects of the C.A.R.L project can be found.

We want people to feel comfortable around this experience and encourage them to stay a while with different seating opportunities and amenities like cafés and restaurants. All around C.A.R.L, customers can find plants and other greenery, which helps us convey our focus on prioritizing nature and sustainability with all that we do.

To educate people about sustainability and how C.A.R.L works, each step of the recycling- and production process can be viewed through windows, and is supplied with posters informing about how the technologies we use and how they work.

Additionally, we want to use the space to display different aspects of the C.A.R.L Humane Fashion Initiative. To achieve this, informational posters and donation boxes are placed to collect for charities which directly support sweatshop workers and other people affected negatively by the fast fashion industry.

Lastly, we want to provide local artists and designers with a platform to display their art, not only through design options in the C.A.R.L customization interface, but also through art exhibitions and displays, which aim to further the reach of these artists.

Fig. 9 | The C.A.R.L experience, which combines the machine itself with all previously mentioned aspects

A WORLD MADE FOR C.A.R.L

In order to create an environment where C.A.R.L can reach its full potential, not only the project itself but the world around it will have to grow and develop to be fit for sustainability.

One of these changes could be the widespread adoption of machine-readable tags on clothing. These tags, which detail the material composition of clothes, will enable machines to quickly and automatically process them, streamlining the recycling process. In addition, the production of monomaterial clothing will simplify recycling by eliminating the need for material separation, one of the most challenging steps in the current recycling process.

Local governments will also play a crucial role in supporting the growth and spread of C.A.R.L.

By endorsing the C.A.R.L project, governments can promote the sustainable and local production of fashion, which in turn boosts the local economy.

Legislative support could include passing laws that discourage the import of fast fashion, creating a regulatory environment that prioritizes sustainability. This could help build a more sustainable economy, where local production and recycling of fashion become the norm.

For C.A.R.L to thrive, society must also shift its mindset towards valuing sustainability and ethical consumption. Education and awareness campaigns, like those mentioned in the C.A.R.L Humane Fashion initiative but extending beyond just C.A.R.L will be key to changing consumer behavior, encouraging people to make more sustainable fashion choices.

Overall, a future that is most suitable for C.A.R.L is one that makes recycling as easy as possible, supports local and sustainable production through legislative measures, and helps shift society towards sustainable consumption. This approach will enable C.A.R.L to achieve its goal of making fashion circular and sustainable.

STAKEHOLDERS

ALLIES

In order to support the buildup and implementation of the C.A.R.L project, cooperations with locations, companies and other people are required to help build the brand and support the efforts.

Shopping Malls and Other Gathering Spaces: Shopping malls are ideal locations for C.A.R.L because they offer a variety of shops, cafés, and restaurants nearby, which customers can visit while waiting for their clothes to be made. The benefit may also be mutual, because malls may gain additional visitors with C.A.R.L as an attraction and gathering space.

Fashion Designers: Cooperation with designers and artists in general brings about new designs for C.A.R.L clothing, both as ready-made pieces, complete with accessories, as well as bases for further customization. Simultaneously, this also helps the designers' brands grow and earn them revenue for their designs.

Waste Management: By sourcing discarded clothes directly from waste management companies, C.A.R.L can ensure a steady supply of materials for recycling and production, even when donations from customers may not always be plenty.

Local Brands: While C.A.R.L might compete with local brands by offering a more affordable sustainable alternative, we can also collaborate with them. By producing their clothing through C.A.R.L, local brands can reduce costs and prices. Additionally, joint marketing efforts, fashion shows, and other collaborations can benefit both parties.

Influencers: Influencers can play a significant role in promoting C.A.R.L. Many influencers currently promote fast fashion brands, but those seeking sustainable alternatives could partner with us to reach a broader audience and attract more customers.

Technology Brands: Collaborations with technology companies will help us continuously enhance C.A.R.L's capabilities. These partnerships can improve the efficiency of our processes and reduce the energy and resources required.

Local Government: Cooperation with local governments can help integrate C.A.R.L into different parts of the infrastructure and secure financial support for our sustainability efforts. Government backing can also facilitate broader acceptance and implementation of C.A.R.L in various communities.

TARGET GROUPS

The goal of C.A.R.L is to appeal to as many target groups as possible, independent of their style preferences, to garner as much support for sustainable clothing production as possible. The primary target group for C.A.R.L is individuals with lower incomes. To effectively combat and replace fast fashion, it's crucial to maintain low prices, providing a viable alternative for those who depend on affordable clothing options.

Families with children can also benefit from C.A.R.L. As the children grow, their clothes can be given to C.A.R.L to discount the purchase of new clothing that fits their size. This helps families manage the constant need for new clothes without excessive spending.

In general, C.A.R.L also aims to appeal to those who are environmentally conscious by enabling them to minimize their environmental impact while still expressing their individuality through custom clothing options. Ultimately, C.A.R.L aims to serve everyone by providing clothing that is more durable, individual, and sustainable than contemporary fashion.

THE IMPACT OF C.A.R.L

This chapter summarizes all that C.A.R.L aims to achieve, which has been brought up across the previous chapters. The main goal is aligning clothing production and recycling to bring circularity to the fashion industry. Without this circularity, we face a future where our planet can no longer support our excess, and future generations will suffer as a consequence [6]. C.A.R.L aims to lower production and consumption by raising awareness and creating transparency about the poor working conditions in producing countries. By making clothing more durable and turning sustainability into a trend, C.A.R.L encourages consumers to buy less and choose better-quality clothing items. It also seeks to upscale recycling by eliminating human intervention, lowering costs, and fully automating the process to make it faster and more efficient. Additionally, it makes recycling more lucrative for consumers by offering credits for their discarded clothes, and can tackle existing clothing landfills across the world by tapping into them for recycling material.

To make fashion more sustainable, C.A.R.L reduces transport efforts to virtually zero by localizing the entire recycling and production process, addressing a significant environmental issue since transportation contributes heavily to carbon emissions . The components within C.A.R.L aim to not use any water, be as efficient as possible, and produce monomaterial clothing, which is easier to recycle. By making recycled fashion more affordable, C.A.R.L ensures that sustainable choices are accessible to more people.

In summary, C.A.R.L is a valuable tool for advancing sustainability in fashion and can significantly impact the clothing choices of future generations. Through its innovative approach, C.A.R.L promotes a more sustainable, ethical, and environmentally friendly fashion industry.

CALCULATING THE IMPACT

C.A.R.L is designed to produce roughly 800 pieces of clothing per day, accounting for production time and breaks. This translates to approximately 280,000 pieces of clothing per year per C.A.R.L unit (800 pieces/day * 350 operational days/year). [53]

To contextualize this, consider that the average person buys about 36 pieces of clothing annually, with studies indicating that 40% of these items are rarely worn. If consumers only purchased garments they wore regularly, their annual consumption would decrease to about 36 pieces (60 pieces * 60%). [54]

Given Germany's population of roughly 83 million people, the total number of clothing pieces consumed annually (if only regularly worn items were bought) would be:

80.000.00036 = 2.888.000.000

A single C.A.R.L unit can produce 280,000 pieces per year. If 500 C.A.R.L units were operational, they could collectively produce:

500 280.000=140.000.000

This production volume would cover approximately 5% of the German clothing market.

2.888.000.000/140.000.000=5%

By localising production and automating the recycling process, C.A.R.L significantly reduces the environmental footprint of the fashion industry. Key environmental benefits include:

1. Reduced Transportation Emissions: By producing clothing locally, transportation emissions are minimised.

> The fashion industry's transportation contributes significantly to carbon emissions—about 10% globally. **Localizing production could reduce these emissions by up to 70%.** [55]

2. Lower Production Emissions: Automated, efficient production processes can cut emissions by reducing energy use and eliminating waste. Traditional textile production is highly energy-intensive, contributing to significant CO_2 emissions.

3. Water Use Reduction: C.A.R.L units are designed to use no water, addressing the substantial water consumption in traditional textile manufacturing

In summary, C.A.R.L could be a pioneering initiative in advancing sustainability within the fashion industry. By promoting circularity, transparency, and efficiency, C.A.R.L can substantially impact future clothing choices and reduce Germany's greenhouse gas emissions by up to 6 million metric tons of CO_2 annually. Through its innovative approach, C.A.R.L paves the way for a more sustainable, ethical, and environmentally friendly fashion industry, ensuring that future generations inherit a healthier planet.

NEXT STEPS

The roadmap for C.A.R.L displayed on the following two pages outlines a comprehensive strategy to revolutionize the fashion industry by addressing critical issues related to sustainability, automation, and community engagement. The document provides a detailed vision for the development and implementation of C.A.R.L systems from initial stages to future integrations.

ENHANCING AUTOMATION & AI INTEGRATION

To further advance C.A.R.L, the integration of more sophisticated automation and artificial intelligence (AI) is essential. This includes developing advanced robotic systems capable of handling the complex and flexible nature of fabrics with greater precision. AI algorithms can be improved to enhance the sorting process, distinguishing between various types of textiles more accurately and efficiently. The goal is to reduce the need for human intervention in sorting, cutting, and sewing, achieving full automation across all stages of the recycling process.

EXPANDING MATERIAL COMPATIBILITY

Another crucial step is expanding C.A.R.L's ability to handle a wider range of materials. Currently, certain fabrics or mixed-material garments may pose challenges.

Research and development should focus on creating versatile processing techniques and machines capable of dealing with various textiles, including blends, technical fabrics, and materials with embedded accessories. This expansion will ensure that C.A.R.L can recycle all types of clothing, minimizing waste and increasing the overall recycling rate.

A WORLD WITHOUT C.A.R.L

In our current era of fast fashion, the exploitation of laborers and environmental degradation are significant obstacles to achieving sustainability. While strides are being made in automated clothing production, the flexibility of fabric presents a formidable **challenge for robots** to handle and understand visually.

It's clear that the world urgently requires a sustainable solution to address these pressing issues.

THE FIRST C.A.R.L

...but immediate action is essential, even while clothing production still strives for full automation. Enter **C.A.R.L No1**, a hub where individuals can recycle old clothing, transforming it into new garments. Visitors select from a curated collection of designs and customizations, while learning about fashion and sustainability through informative displays and refreshments.

While some tasks like sorting and sewing still require human assistance, automation aids in other aspects of recycling and production.

ACHIEVING THE VISION

Just a decade later, C.A.R.L achieves its initial goal: a compact, **fully automated** machine that recycles old clothing into new, locally produced, ethical garments on demand. Within the span of under an hour, C.A.R.L can make the clothing that people create with an interactive customization interface.

C.A.R.L can now be placed almost anywhere, allowing for a transition of C.A.R.L's purpose from education to the production of large amounts of clothing, which has a significant positive impact on sustainability in the fashion industry.

BEYOND C.A.R.L

In the distant future, C.A.R.L transitions from an independent project to a **vital component of humanity's sustainability initiatives**. It could be situated in community centers, where it coexists with agricultural endeavors and shared living spaces.
Alternatively, C.A.R.L might employ an efficient underground tunnel system to deliver and recycle clothing directly to people's homes. This evolution leads to a fully circular fashion industry, promoting creativity and benefiting everyone. With boundless potential, the future holds exciting prospects.

2024 | 2030 | 2040 | 2050

OUTSIDE ENVIRONMENT

SCIENCE AND TECHNOLOGY

2024: Available technology can be used to prepare automation of the first components: analysis (NIR/VIS), measuring (depth sensors), disinfection (UV/ozone), shredding, carding & combing, spinning, knitting (round/flat)

Great progress is made in: automated sewing, material separation

2040: Improved dexterity and AI allow for fully automated clothing production

In-depth analysis is performed via multiple sensors and small particle accelerators

2050: C.A.R.L processes are integrated into: underground transportation, resource monitoring, textile handling

SOCIAL ENVIRONMENT

2024:
being environmentally conscious with fashion is reserved to smaller subcultures and social movements

fast fashion is on the rise, with clothing production and sales continuously increasing

EU laws on fast fashion imports and exports of disposed clothing are set to be put into effect

2030:
Showing that clothes are produced sustainably becomes a common fashion statement

Brands that produce unsustainably are put under public scrutiny. Closer investigations start into the production of fast fashion

Laws start to restrict the imports of fast fashion into Europe

2040:
Machine readable tags are mandated that inform about clothing materials and recycling instructions

The import of unethically and unsustainably produced garments into Europe is fully outlawed

2050:
The EU achieves full climate neutrality in society and economy

All members of society are not only obliged but also willed to live sustainably

C.A.R.L

C.A.R.L COMPONENTS

2024:
website with information about the project and contact forms

promotional and informational speeches at conventions about sustainability in the industry

promotional posters to garner attention and establish customers

2030:
C.A.R.L accounts & loyalty programs to retain measurement-, order- and payment-information

educational posters & charities to raise awareness about working conditions and sustainable clothing production

automated components for measuring, disinfection, shredding, carding, combing, spinning, coloring and knitting

work space & employees who help with sorting and sewing

area with seating, cafés, an indoor garden and other opportunities for people to relax and educate themselves

2040:
fully automated C.A.R.L recycling and production machines

C.A.R.L AI to continuously learn from and improve production

C.A.R.L IT for collecting and sharing data about production, environmental impact, clothing choices and other information

user interface for choosing and fully customizing pieces of clothing on different devices

2050:
C.A.R.L, fully integrated into a circular economy

PARTNERS AND MARKETING

2024: Direct outreach to potential **investors** and tech firms secures project funding. Pre-release marketing begins to raise awareness, and target group interviews refine additional goals. Contact with major fashion industry players initiates future collaboration planning.

Recycling Companies who can take the clothes that C.A.R.L can't handle yet

Large Brands who want to be more sustainable and **known Designers** to boost awareness

2040: Cooperations with larger brands are slowly phased out and cooperations with small local businesses and artists take their place.
These cooperations vary from location to location and help make different C.A.R.Ls more individual by integrating them into the cultures whose fashion they contribute to.

2050: Beyond its vision, C.A.R.L may find itself in a future where it is so deeply integrated into society's **circular economy** that there is no longer need for investors.

Only local community members remain as partners, utilizing C.A.R.L to express their art, culture, and individuality through fashion.

Investors (includes players in the **fashion industry**, **tech companies** whos technologies we want to use and any other people or **governments** that want to support a path towards sustainability)

Small, **local clothing brands and artists/designers** in an effort to support local art and culture and emphasize individuality, even in the realm of automation

IMPACT

2030: While the clothing produced by C.A.R.L No1 only has minimal impact on fashion industry metrics and the environment, its widespread awareness efforts wield significant global influence. **Education** on unethical production practices abroad spurs support for workers and prompts companies to revise their policies.
This catalyzes a societal **shift towards sustainable clothing choices**, redirecting the fashion industry's focus towards greater sustainability.

2040: C.A.R.L produces durable, sustainable clothing tailored to individual preferences, shaping global consumption habits. In Europe and beyond, it prompts significant changes: People now buy **half as much clothing** as they did 20 years ago and keep them for over five years, compared to just over two years previously.

With C.A.R.L's influence and sustainable practices, the fashion industry's **environmental impact decreases from 10%** of global carbon emissions two decades ago to just 5%.

DEVELOPING ECO-FRIENDLY CHEMICALS & PROCESSES

To support the decolorization and dyeing processes, the development and use of eco-friendly chemicals and sustainable practices are paramount.

Innovations in green chemistry can provide safer and more efficient ways to remove dyes and re-dye fibers without harming the environment. Additionally, investing in waterless dyeing technologies or closed-loop water systems will help minimize water usage and reduce the ecological footprint of the recycling facility.

IMPROVING ENERGY EFFICIENCY

Energy efficiency is a critical factor in making C.A.R.L truly sustainable. Implementing renewable energy sources, such as solar panels or wind turbines, can power the facility and reduce reliance on fossil fuels. Additionally, optimizing the energy consumption of each stage of the recycling process through smart grid technology and energy-efficient machinery will further decrease the environmental impact and operational costs.

SCALING UP PRODUCTION CAPABILITIES

For C.A.R.L to make a significant impact on the fashion industry, scaling up production capabilities is essential. This involves designing modular systems that can be easily replicated and installed in various locations, from urban centers to rural communities. Developing compact, mobile versions of C.A.R.L can also facilitate the establishment of recycling hubs in remote or underserved areas, promoting local recycling and garment production.

ENHANCING USER INTERACTION & CUSTOMIZATION

Improving the interactive customization interface will enhance user experience and satisfaction. Incorporating virtual and augmented reality (VR/AR) technologies can allow users to visualize and customize their garments in real-time, making the recycling process more engaging and personalized. Additionally, expanding the range of customization options, including styles, colors, and patterns, will attract a broader audience and encourage more people to recycle their old clothing.

STRENGTHENING EDUCATIONAL OUTREACH & COMMUNITY ENGAGEMENT

While automation is a key goal, continuing to educate the public about the importance of sustainable fashion and recycling remains necessary. C.A.R.L facilities can serve as educational hubs, offering workshops, tours, and interactive displays that teach visitors about the environmental impact of fast fashion and the benefits of recycling. Collaborating with schools, universities, and community organizations can further spread awareness and foster a culture of sustainability.

ESTABLISHING STRATEGIC PARTNERSHIPS

Forming strategic partnerships with fashion brands, retailers, and government agencies can accelerate the adoption and expansion of C.A.R.L. By working together, stakeholders can support research and development, invest in infrastructure, and create incentives for consumers to recycle their clothing. These partnerships can also help integrate C.A.R.L into existing supply chains, promoting a circular economy in the fashion industry.

ENSURING ROBUST QUALITY CONTROL & STANDARDISATION

To maintain high standards, robust quality control measures must be implemented. Developing standardized protocols for every stage of the recycling process, from sorting to sewing, will ensure consistent output quality. Regular audits and updates to these protocols will address any emerging challenges and incorporate new technological advancements, keeping C.A.R.L at the forefront of sustainable fashion innovation.

FOSTERING GLOBAL EXPANSION & ACCESSIBILITY

Ultimately, the vision for C.A.R.L extends beyond local implementation to global accessibility. By creating scalable and adaptable models, C.A.R.L can be introduced in diverse geographic and economic contexts, ensuring that the benefits of clothing recycling are accessible to all. International collaborations and knowledge-sharing can help tailor C.A.R.L systems to meet regional needs, driving global progress towards a sustainable and circular fashion industry.

CONCLUSION

The fast fashion industry is at a juncture.

The environmental degradation, excessive waste, and labor exploitation associated with this model underscore the need for urgent and comprehensive action. With the introduction of C.A.R.L the consumer is the main focus and driver to bringing change to this industry, all while having the experience support and raise awareness.

The challenges appear to be significant; however, are not insurmountable. C.A.R.L. represents a groundbreaking advancement in textile recycling technology, offering an efficient system for material harvesting, tailoring, and recycling with an emphasis on customization and the consumer experience.

By facilitating a circular economy within the fashion industry, C.A.R.L. bridges the gap between consumers and producers, enabling the sustainable management of textile resources. C.A.R.L can drastically reduce textile waste, transforming discarded garments into valuable resources for new garment production.

Furthermore, the deployment of C.A.R.L. can enhance existing recycling infrastructure, making large-scale textile recycling more feasible and economically viable.

This technological advancement is complemented by promoting sustainable consumer behavior and endorsing business models that prioritize durability, quality, and reusability. Together, these approaches can significantly mitigate the environmental and social impacts of overconsumption.

Policymaking and regulatory frameworks also play a crucial role in directing industry practices and consumer choices towards sustainability. Implementing policies that support the integration of technologies like C.A.R.L. and incentivize sustainable practices are essential steps toward achieving a more responsible fashion industry.

Ultimately, realizing a sustainable fashion industry requires an enormous effort from all stakeholders. Consumers, fashion brands, policymakers, and communities must collaborate to drive the necessary changes.

Through education, technological innovation, and collaboration, the fashion industry can become more sustainable and ethical, aligning with the United Nations' Sustainable Development Goal 12 on responsible consumption and production.

By committing to these strategies and integrating C.A.R.L. into communities, a future can be envisioned, where fashion serves not only as a medium for personal expression but also as a testament to our dedication to environmental awareness and ethical responsibility. It is imperative to take decisive action now to ensure that the fashion industry of tomorrow is sustainable, equitable, and resilient.

C.A.R.L

S.A.G.E

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to our teaching team at inno.space for their guidance and support throughout this project, with special thanks to Clara Dieing, Kirsten Kohler, and Christian Müller.

Our appreciation also goes to our partner team, Susta.Inno, within our design factory for the friendly banter, valuable feedback, and fun over the past seven months. Additionally, our heartfelt thanks go to the IdeaSquare team, our overseas partner CBIA3 teams, and their teaching teams for the diverse perspectives, unwavering support, and encouragement from Geneva to the finish line.

Special thanks also to the ATTRACT Academy for providing the resources and platform that made this work possible, and for all the experts, colleagues and friends who lended us their time and their knowledge to help us develop our ideas to the best of our abilities.

We all received licenses to dream in November; this whole project proved that dreams can become reality, one just needs orders of magnitudes, future thinking, and a lot of ideation to become (potentially) true, one day.

REFLECTIONS

HNUDEE ESPEDAL

Process engineering

Joining this project was truly life-changing. Not only was the task something that I had a profound interest in but the connections I made with my Design Factory and team members have been engraved in my heart and brain that I am truly grateful for.

One of the biggest challenges we had was trying to think out of the box with design thinking methods, however, we all come from an engineering background, and it was difficult to think too radically within the boundaries of the tech. We felt we needed to be limited by this, but we overcame it with the approach of thinking into the far future, where technology has evolved and has reached our expectations.

As engineers, when we work with data and numbers, we always like to quantify them into values that make sense within the scale we are working with. Similarly, we had to do that while defining our problem space, but in a way that was more visual with qualitative attributes such as city sizes or populations.

KASJEN SAATHOFF

Process Engineering

Participating in this project has been a significant experience for me. One major challenge was adapting to a multidisciplinary approach. As an engineer, I usually deal with numbers and machines, but this project required a more human-centered approach, focusing on user experience and community impact. This shift was challenging but rewarding, as it helped me understand the broader implications of our work. This project required more creative thinking, which was difficult at first. We had to think beyond current technology and imagine future possibilities. This helped us find innovative solutions despite our technical constraints. Presenting in English was another hurdle. Explaining complex concepts in a second language was tough, but I managed to improve my communication skills. This experience taught me the importance of clear and effective communication. Visiting CERN and IDEAsquare and interacting with experts was truly inspiring. The lessons learned and experiences gained with the CBI A3 project will stay with me. I'm grateful for this opportunity and look forward to applying these insights in the future.

KATHARINA SALEWSKI

Computer science

Visiting CERN and interacting with the brilliant people from idea square was one of the most inspiring moments of this project for me, because it showed me that there's so much value in wanting to think big and change the world for the better.

The biggest challenge during the project was refining our idea of C.A.R.L, because it was hard to continue to branch out and explore new ideas for a concept of which we already had a pretty steady image in our heads, but everything was well worth the effort.

During the work on C.A.R.L and the whole of CBI, I learned that combining optimism for what future technologies might hold with the realism of grasping today's most pressing issues can help foster the most impactful ideas and concepts. I am beyond grateful for this experience and will keep the memories and all that I have learned in my heart and mind for as long as I possibly can.

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