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The true cost of denim, Making jeans sustainable

Abstract

The fashion industry is one of the most polluting industries that exists on our planet having 2.1 (billions of tonnes) annual GHG emissions according to Our World in Data. With fast fashion being on rampage in this industry characterized by the production and massive consumption of clothing items, overconsumption is at its peak.

Denim is one of the most iconic and widely worn fabrics in the world but very few consumers are aware of the environmental and social impact behind their favourite pair of jeans. This seminar explores the full lifecycle of jeans going from raw material extraction to post consumer waste.

In this seminar we will cover the anatomy of denim, the complex supply chain behind its production and the significant water, chemical and carbon footprint it leaves behind.

We will also introduce innovative materials, cleaner production technologies and circular business models aimed at reducing the industry's environmental impact.

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1. Introduction

1.1. Jeans global popularity and cultural relevance

Jeans are one of the most significant statement pieces of clothing created, and most people wear them at least once at some point in their lives. The word ‘denim’ originally comes from a type of twill fabric called ‘Serges de Nimes’ from France that weavers first used to create their type of jeans. This comes with their first use of natural indigo on the pants to produce the vibrant blue color we know today.

Eventually, Levi Strauss introduced the pants to the U.S., and their changes were incorporated into the product.Jeans were initially designed as hard-wearing clothes for prospectors during the California Gold Rush by a tailor called Jacob Davis. Davis was using a brown canvas fabric reinforced with rivets so that prospectors could fill their pockets with rocks and stones.

Davis knew his virtually indestructible pants were a winner but didn't have the money to take a patent out. He turned to the man who was supplying the fabric he was using, dry goods salesman Levi Strauss, whose name would become synonymous with the garment.

From the 1880s to the Second World War, jeans became a universal workwear item. After the war, jeans became a ubiquitous symbol of Western youth culture, popularised by, among others, James Dean in Rebel Without a Cause and Marilyn Monroe in The Misfits.

As jeans have been part of the fashion industry for the past decades, various denim brands have come around within the sector, and their prices vary depending on the craftsmanship dedicated to each work put into the product. One of the most prominent examples of this is the rise in demand for selvedge denims. Selvedge, meaning that they are self-edged creations, is denim that is traditionally made by hand and uses shuttle machines for the loom. Created differently than the mass-produced counterparts, these denim are often customizable and sometimes dyed with natural indigos (which is way more expensive), just like the original way they were made instead of the synthetic indigos used most often on jeans. Japan has one of the biggest audiences regarding the denim phenomenon. With their own set of standards for their quality denim, Japanese selvedge denim is most famously known to be heavier and technical when it comes to developing the jeans, making them a durable piece to own for a high price. Companies such as Momotaro Jeans and Japan Blue Jeans established the standard Japanese selvedge denim is known for.

The fashion industry produces over 97 million tons of waste annually, including textiles, chemicals, and packaging materials. Jeans have been no different to this during the production cycle. They use tons of water along with various chemicals to create them. As more customers and companies are being more cautious to be more environmentally sustainable, people are finding new and innovative ways to sell jeans.

1.2.Objectives of the seminar

- **Raise awareness of the environmental and social impact of jeans**

  Educate participants on the hidden costs of denim production from cotton farming to consumer use and disposal. Highlighting issues such as water overuse, chemical

pollution, carbon emissions and labor exploitation.

- **Introduce sustainable alternatives and innovations**

  Showcase technologies, materials, and processes that can reduce the environmental footprint of jeans. Explore circular fashion models, eco-certifications, and ethical labor practices.

- **Empower consumers, designers and industry professionals**

  Provide practical tools and tips to make more sustainable choices whether as a buyer, brand, or policymaker. Encourage critical thinking about fashion consumption habits and the role of design in sustainability.

2. Anatomy of a pair of jeans

2.1. Material usage

Cotton is the primary raw material used in denim production. Denim fabric is typically made from cotton fibers, although blends with other fibers like polyester or elastane are also common. Cotton provides the characteristic durability and comfort associated with denim.

Indigo dye is crucial for creating the classic blue color of denim. It's a natural dye derived from the indigo plant or produced synthetically. Indigo dye is applied to cotton yarn or fabric during the dyeing process, giving denim its signature look.

High-quality thread, often made from cotton or polyester, is used for sewing and constructing denim garments. Thread strength is essential to ensure the durability of the final product.

Denim jeans typically feature metal rivets and buttons for reinforcement and fastening. These hardware components are an integral part of denim garment construction.

Labels and patches made from leather or synthetic materials are used for branding and adding style elements to denim garments.

Denim pants often feature zippers for closures. These zippers are typically made from metal or plastic.

Pocketing fabric is used to create the pockets on denim jeans. It's usually a lightweight and durable cotton or polyester-cotton blend.

In stretch denim, elastane or spandex fibers are blended with cotton to provide flexibility and comfort. These fibers give stretch and recovery properties to the fabric.

Some denim garments, especially jackets and vests, may have lining materials for added warmth or comfort. Linings can be made from various materials, including cotton or polyester.

Interfacing materials, often made from fusible fabric, are used in denim garments to provide structure and support in specific areas like collars and cuffs.

2.2. Components

A pair of jeans has many different components to it starting with the denim fabric. Denim is a type of woven twill fabric, usually made from cotton. It consists of two yarns woven together. The yarn that runs across (weft) is threaded over and under the yarn that runs downwards (warp):

- **Belt loops**: Strips of fabric that hold a belt into place.
- **Felled seams**: A durable seams construction that folds one fabric into another.
- **Jacron**: A rectangle patch found on the back right side of the waistband.
- **J-stitch**: The j-shaped stitch along the crotch seam that hides the zipper and creates a more flattering fit.
- **Pocket Stitching**: Decorative topstitching commonly in a contrasting color and ornate design. Notable brands often stick with the same stitching as another way to gain brand recognition.
- **Rise**: The length between the waistband and the crotch.
- **Rivets**: Small metal pins placed on areas of pants that are susceptible to tears.
- **Tack buttons**: A raised metal button that attaches to a back fastener to secure it into place.
- **Topstitch**: Stitching visible on the outside of the jeans, usually in a contrasting color. Serves both functional and decorative purposes.
- **Twill Fabric**: A durable weaving technique that creates a consistent diagonal pattern and texture to the fabric.
- **Waistband**: Stripes of fabric with interfacing between them that wraps around the top of the jeans. The added interfacing reinforces the waistband's durability and keeps pants from rolling down.
- **Wash**: The amount of distressing a fabric has undergone to add texture, sporadic color patterns, and soften it to the touch.
- **Whiskers**: Fading technique that creates faded horizontal lines that are often placed between the front pockets of the jeans.
- **Yoke**: A piece of V-shaped fabric or panel of fabrics located below the back of the waistband that adds a curved shape to the construction.
- **Zipper**: Placed at the crotch seam to make it easy to take jeans on and off. Many modern styles swapped out zippers for buttons.

2.3.Production workflow

Cotton Preparation:
Cotton is one of the most important ingredients for making denim fabrics, so the quality of cotton plays a key role in denim fabrics.

After the cotton plants are planted, it takes about two months for each cotton plant to develop flower buds. After about three weeks, the flowers open. Wait for the petals to wilt and fall off, leaving behind green pods called “cotton bolls”. Cotton fibers grow in bolls, and as the fibers grow and swell, the bolls mature and open, eventually forming fluffy clumps of cotton. These little cotton balls on plants can be picked by hand or machine.

After the cotton is picked, it goes through the ginning process. The collected raw cotton fibers are fed into the cotton gin. This is a mechanical cleaning process where the machine separates other impurities such as leaves and twigs from the raw cotton fiber itself. Finally, it is dried and compressed into bales called lint.

Typically, about 33 percent of a harvested crop ends up as usable cotton. The rest of the cotton plant isn’t wasted. The seeds are pressed into cooking oil, the husks and meal are made into animal feed, and the stems are used to make paper.

To improve strength, prevent wrinkles and increase durability, some manufacturers add synthetic fibers to cotton fabrics. Combining various grades or different types of fiber to yield the desired properties. Blending is the process of mixing different fibers (natural or synthetic) to produce fabrics with specific properties. As we all know, cotton is the main fiber used to make denim. So blending is mixing cotton with synthetic fibers such as polyester, spandex, modal, tencel, and acrylic. Depending on the desired properties of the denim fabric, the blending process can be done at high or low ratios.

Spinning:
The earliest forms of denim spinning were done using spinning wheels and spindles, which were slow and labor-intensive. This process was later replaced by mechanized methods of spinning, such as water mills, which led to increased production of denim textiles.
Ring spinning and open-end spinning are two traditional techniques used in denim spinning. New denim spinning technologies have emerged in recent years, improving efficiency, sustainability, and quality. These techniques include compact spinning, siro spinning, and core spinning:

- Compact spinning: Compact spinning involves compressing the fibers before twisting them onto a bobbin. This method produces a more uniform yarn with higher tenacity and less hairiness.

- Siro spinning: It involves twisting fibers using special machines, resulting in extra strength and sturdiness of yarns. This approach results in stronger, more durable, and sustainable premium denim fabrics.

- Core spinning: During this process, the core yarn is fed into the spinning rotor where the cotton fibers are twisted around the core. This process increases the strength of the yarn and reduces hairiness, resulting in a high-quality denim fabric.

While traditional techniques such as ring spinning are still the technology of choice for producing premium denim fabrics, new technologies are emerging to make the process more efficient, sustainable, and of higher quality. For example, open-end spinning is a faster and less expensive way to produce yarn, but it results in a yarn that is flawed and less smooth. Compact spinning, siro spinning, and core spinning provide more uniform, stronger and durable yarns, making them the preferred technologies for producing top-quality denim fabrics.

Warping:
Warping is the process of placing multiple threads (called warp ends) parallel to each other and in a specific order to form continuous lengths for weaving. Warping aims to provide the weaver with consistent, even yarn tension during the weaving process. The uniformity of the warp ensures that the denim is free from defects such as knots, irregularities, or unevenness:

- Preparation: The yarn quality and stiffness are checked first, then the spindles are placed on the drawing-in frame, ready for warping.

- Yarn weaving :After the two yarns pass through the loose tube, they are carded along the warping machine to the warp beam, and the yarns form a whole string, called the warp yarn.

- Shaft winding: Wind the whole string of warp yarns on the long axis, wind them with a winch, and adjust the tension and position through corresponding devices.

- Go to the machine: Install the yarn shaft on the warping machine, thread the warp yarn on the hook according to the hook number and pattern requirements, and comb the warp yarn after finishing and calibrating the machine head to ensure that the yarn is neat, smooth, and tight.

Dyeing:
The dyeing characteristics of indigo are unique because the dye is insoluble in water but requires a reducing agent to release dye particles. When the dye is released, it oxidizes and turns blue. Indigo dye is used to obtain the iconic blue color of denim fabric. Its unique dyeing properties make it an ideal choice for dyeing cotton fiber, which is used as the base of denim. Indigo dyes are highly valued for their color fastness, which means that even after repeated washing, the dye can maintain its color. This characteristic is crucial for denim because it will go through a severe washing cycle, and fading is a matter of concern.
There are two primary dyeing methods used in denim production: rope dyeing and slasher dyeing:

- Rope Dyeing: Rope dyeing is a highly technical and labor-intensive traditional dyeing method. Rope dyeing is carried out by twisting 12 to 16 cotton threads into a rope-like structure. The dyeing process is completed by threading the rope through a series of indigo dyeing vats. The first barrel contains a weak solution of indigo dye, and as the rope passes through the subsequent barrel, the dyeing strength will increase. This process can maintain the unique color changes unique to denim fabrics. The color of denim fabric obtained by this dyeing technology will be darker and more beautiful.

- Slasher Dyeing: Slasher dyeing is a modern automatic dyeing method, which is usually used in the production of denim. In oblique cutting dyeing, the fabric flows

continuously through a series of rollers. Then denim is soaked in indigo dye, and the desired color is obtained by controlling the number of dips and dye speed. The more times dipping and the slower the dyeing speed, the darker the color of the final denim fabric.

Overall, both slasher dyeing and rope dyeing have their advantages and disadvantages.

Slasher dyeing: the cost is cheap, and the output is higher, which is suitable for denim fabrics with low volume. Disadvantages: Color difference and color fastness are not well dyed with ropes.

Rope dyeing: the cost is more expensive than sheet dyeing because of its long process and low output. At the same time, it has the advantage of small color differences and high color fastness. It is mostly used in high-grade denim fabrics.

Weaving:
Denim fabrics are produced using four main weaving technologies: shuttle looms, projectile looms, rapier looms and air-jet looms:

- Shuttle looms: The shuttle loom is the oldest traditional method of producing dense, durable fabrics. However, this method is time-consuming and laborious, and cannot keep up with the speed of modern production.

- Projectile looms: Projectile looms, introduced in the 1950s, use a shuttleless system that uses small metal bullets or projectiles to pass the weft yarn through the warp yarn. This method is faster than a shuttle loom and produces a smoother surface.

- Rapier looms: Rapier looms use flexible rods to thread the weft through the warp. This method results in minimal yarn breakage and produces a uniform fabric.

- Air-jet looms: Most efficient in terms of speed and efficiency, air jet looms use compressed air for weft insertion. It produces fabrics of the highest quality with the fewest imperfections.

Finishing:
Most denim, including raw denim, undergoes finishing. It's the last stage of denim production and is an important factor in the fabric's performance, appearance, and value.

The finishing process involves several techniques that can change and improve the look and feel of denim fabrics.

- Sanforization (Pre-shrinking): Eliminates shrinkage: Solves a key problem of unfinished denim, and keeps its shape and size stable.

- Pre-skewing: Eliminates leg twist: Prevents denim from skewing in the direction of the twill line due to washing and shrinking.

- Heat Setting: Controls stretch: Controls the elasticity and dimensional stability of stretch denim made with thermoplastic fibers such as polyester or elastane.

- Singeing: Removes fluff from the fabric's surface: Burns away loose, hairy cotton fibers on the surface of denim, for a smoother feel.

- Mercerization: Increases smoothness and luster: The fabric is soaked in a chemical solution that swells the cell walls of the fibers for a more even look and smoother hand feel.

Quality Check:
Before finished denim products are released to the market, they undergo several quality control tests to ensure that they comply with the required standards and regulations.

Quality control standards are set by denim manufacturing regulators and include physical properties such as color fastness, wash resistance, and dimensional stability. Inspection and testing methods used during the finishing and packaging process include visual inspections and performance tests such as wash and dry cycles.

Common defects in denim products include shrinkage, stretching, bleeding, and damaged seams. Precautions include maintaining a steady wash cycle and using high-quality materials.

3. Life Cycle of jeans

3.1. Raw material sourcing

The types of cotton currently available in the market are Upland(Gossypium hirsutum), Egyptian(Gossypium barbadense), Indian(Gossypium arboreum), Levantine(Gossypium herbaceum) and Xinjiang cotton.

Upland Cotton (Gossypium hirsutum)
Upland cotton (Gossypium hirsutum) is the most common type of cotton because it is high yielding and easy to grow. It accounts for 90% of the world's cotton production.

For upland cotton, the common origin countries are America, Mexico, the Caribbean, and southern Florida.

Egyptian Cotton (Gossypium barbadense)
Egyptian cotton (Gossypium barbadense) is known as extra-long staple cotton, meaning longer and silkier than most types of cotton. It is characterized by softness, delicateness, and durability. But it is more difficult to produce in large quantities than upland cotton, so it accounts for only 8 percent of world production.

Gossypium barbadense, although it is often called Egyptian cotton, has its origin in South America, such as Brazil and other countries.

Indian Cotton(Gossypium arboreum)
Indian cotton(Gossypium arboreum), commonly known as tree cotton. It can be spun into a single thread and maintain its tensile strength at a higher count than any other cotton variety. Indian cotton is a type of cotton native to India, Pakistan, and Bangladesh.

Levantine Cotton(Gossypium herbaceum)

Levantine cotton(Gossypium herbaceum), is commonly known as Grass cotton. It is cotton extracted from cotton bushes that grow wild in semi-arid regions of sub-Saharan Africa and the Arabian Peninsula.

Xinjiang Cotton
Xinjiang cotton is called Xinjiang long-staple cotton. The main characteristics of this cotton are long cashmere, good quality, and high yield.

Due to the different soil and climatic conditions in Xinjiang, China, it can achieve more than 18 hours of light at most. So Xinjiang is especially suitable for growing cotton, Xinjiang produces more than 20 percent of the world's cotton.

3.2. Manufacturing

The manufacturing process of denim involves several key stages that transform raw materials into finished garments. Each stage requires specific techniques and equipment to ensure quality and efficiency.

Cutting
The manufacturing process starts with cutting. This step slices large rolls of denim fabric into precise shapes and sizes based on the pattern.

Computer-Aided Design (CAD) software often guides automated cutting machines to ensure accuracy and minimize waste. These machines use lasers or sharp blades to cut multiple layers of fabric simultaneously, optimizing production speed and consistency.

Sewing

Once the fabric is cut, sewing begins. This stage involves joining pieces of fabric together using various types of stitching. Chain stitching is common in denim because it provides flexibility and strength.

Lock stitching creates strong, permanent seams. Industrial sewing machines, made for heavy fabric, make sure the seams are durable. Specialized machines like overlock and serger machines finish the edges and stop fraying, helping the garment last longer.

Assembly
During assembly, workers attach components and hardware, such as zippers, buttons, rivets, and belt loops. This step requires precision and care, as these elements add both functionality and aesthetic value to the denim. Automated machinery usually does these tasks. However, skilled workers might check and adjust parts by hand to ensure high quality.

Washing and Finishing
The washing and finishing process gives denim its characteristic look and feel. Various washing techniques help achieve different styles and textures:

- Stone Washing: This method involves tumbling denim with pumice stones to soften the fabric and create a worn-in look. It reduces the rigidity of the fabric, enhancing comfort and style with a faded appearance.
- Acid Washing: This technique uses chlorine and pumice stones to create dramatic contrasts and a marbled effect. It gives the denim a distinctive, high-contrast look favored in vintage and retro styles.
- Enzyme Washing: This eco-friendly process uses enzymes to break down the cellulose in the fabric, creating a softer feel and subtle fade. Enzyme washing offers a more sustainable alternative to traditional methods, reducing the environmental impact of denim finishing.

3.3. Distribution and retail

Jeans are shipped worldwide contributing to greenhouse gas emissions through air and sea. In every continent there are different leading denim manufacturers but countries like China, India, and Bangladesh are key manufacturers and exporters of denim products.

Once the product reaches the stores they are sold, retail often encourages overconsumption through fast fashion business models.

3.4. Consumer use

Jeans typically have a really long lifespan. On average, a well-maintained pair of jeans can last anywhere from 2 to 10 years or even longer. However, this estimate can vary widely based on the factors mentioned above. High-quality jeans, like raw selvedge denim, can last much longer with proper care and infrequent washing. But frequent washing adds to water and energy use.

3.5. End of life

Most jeans and other clothing items end up in landfills or incinerators. Every year a massive 2.16 million metric tons of denim jeans is globally wasted and mostly goes into landfill. Though denim is highly rich in cellulose, its valorisation has received little attention.

4. Ecological and social impacts

Originally, natural indigo was used to dye denim, however – thanks to mass production methods – cheaper, petroleum-based synthetic indigo replaced it in the early 1900s and now the denim industry uses more than 50,000 tonnes of it per year. And chemicals such as formaldehyde and cyanide are in the mix too, used during production to make the dye itself and prevent bacteria growth and staining.

If all those chemicals are released into local waterways after manufacturing, they can starve aquatic life of oxygen, killing the natural ecosystem – and the issue with water doesn't end there. Levi's found that a single pair of 501 Jeans uses as much as 3,781 litres of water in a lifecycle, while researchers at the University of Toronto discovered that one pair of used jeans can release around 56,000 microfibres (tiny strands of material) per wash. The issue is that these fibres are discarded with the wastewater from the wash, flowing into rivers, oceans and environments.

Then there's the manufacturing process: a single pair of jeans has a heavy carbon footprint, including the production, daily wear and disposal. Levi's also found that 33.4 kg of carbon dioxide (CO2) is released throughout the lifetime of a pair of jeans – with 16.2 kg of CO2 estimated to be from the creation and packaging process. And Oxfam found that the emissions produced from making enough jeans for UK adults is comparable to flying a plane around the globe 2,372 times, or a petrol car travelling more than 21 *billion* miles.

4.1. Water consumption

Water use is one of the most critical environmental concerns in denim production. Growing cotton—the primary fiber in denim—requires immense quantities of water, particularly when irrigated conventionally.

Levi Strauss & Co, estimates that over 3,780 liters of water are used to produce just a single pair of 501® jeans. This includes the water needed to grow cotton and the water required to process the fabric. Cotton irrigation makes up 92% of the water footprint of a pair of jeans and the remaining water consumption is related with production processes of denim fabric. Organic cotton offers a promising alternative. It typically relies on rain-fed agriculture, significantly reducing water dependency. According to the Textile Exchange (2016), organic cotton uses around 182 liters/kg of lint, compared to 2,120 liters/kg for conventional cotton.

4.2. Chemical pollution

Denim production relies heavily on synthetic chemicals at various stages—from cotton farming to dyeing and finishing. The industry uses more than 50,000 tonnes of synthetic indigo and 84,000 tonnes of sodium hydrosulfite each year. These substances, along with formaldehyde, heavy metals, and other additives, pose serious environmental and health risks.

Factories often discharge untreated wastewater into rivers and waterways, polluting ecosystems and harming local communities. In some regions, entire rivers have been visibly stained blue due to denim dye effluent.

Furthermore, the health of factory workers is also at risk. Prolonged exposure to toxic substances such as formaldehyde and heavy metals can cause respiratory illnesses, skin irritation, and long-term organ damage.

For example, the use of synthetic indigo for dyeing jeans is quite toxic and persists in the environment. The finishing agents used to achieve a certain look or texture in one pair of pants contain hazardous chemicals like formaldehyde, which poses health risks to workers.

4.3. Carbon footprint

Every pair of jeans has a significant carbon footprint. Life Cycle Assessments (LCA) conducted by Levi's reveal that one pair of jeans emits approximately 33.4 kg of CO_2 over its lifetime. Around 16.2 kg of this total comes from manufacturing processes like spinning, weaving, dyeing, and finishing.

Transportation, consumer use (especially machine washing and drying), and disposal further increase emissions. According to Oxfam, the cumulative carbon emissions from jeans worn in the UK are equivalent to flying a plane around the Earth 2,372 times, or a petrol car traveling over 21 billion miles.

4.4. Waste generation

According to studies, up to 20% of fabric is wasted in the production of denim clothing. Much of this waste ends up in landfills or is incinerated, contributing to greenhouse gas emissions and other environmental damage.

Additionally, denim production generates millions of liters of wastewater that contain harmful chemicals and dyes. Dyeing and washing processes are the catastrophe of denim production. Chemicals used in the dyeing process make the water unusable after the process. Huge amount of waste water, contaminated with toxic chemicals, is released into the environment. Unfortunately, rivers are running blue in most denim producing places. The contamination of soil and waterways has a negative effect on both human beings, plants and animals in the surrounding areas.

4.5. Labor issues

Beyond environmental harm, the denim industry faces serious labor challenges. In many manufacturing hubs, workers endure low wages, unsafe conditions, and excessive working hours.

Some distressing examples include:

- Sandblasting, used to create a worn look, can lead to silicosis, a debilitating lung disease.

- Forced labo**r** in cotton harvesting, particularly in Xinjiang, China, where reports suggest over 500,000 Uyghurs are subject to coercive labor practices.

Although some brands are moving toward **ethical sourcing and third-party certifications**, exploitative labor remains a systemic issue, especially in fast fashion supply chains.

5 .Case studies

In this part of the seminar we will look at previous research that has been done by others on the manufacturing process of jeans. So we will see how they are developed in order to take them as a reference in our proposals. We have found these theses in google scholar and we will focus on the following Authors :

5.1.Elias Khalil

He is an academic and researcher specializing in Machine Learning, AI, Neural Networks, Fuzzy Logic, and ANFIS, with a focus on Textile Engineering. We will focus on his theses studies *Sustainable and Ecological Finishing Technology for Denim Jeans* and *Nano Bubble Technology: A New Way to Sustainable Jeans Finishing* .

Bangladesh's garment industry ranks second in the world in fast fashion production and in recent years has grown to become the spine of the country's economy. Understanding how manufacturing works from the author's empirical point of view will help us to better understand how the industry works and how to replace manufacturing models with more sustainable ones.

Both research papers present sustainable alternatives to traditional denim finishing processes, addressing the environmental impact of conventional methods. One paper focuses on nano bubble technology (e-flow) as a sustainable method for denim jeans finishing, while the other discusses laser, ozone, and water jet technologies.

Nano bubble technology paper explains that e-flow technology reduces water and energy consumption and eliminates chemical waste, by using an electro flow reactor to create nano bubbles that treat the denim garments. This process enhances the fabric's hand feel and reduces shrinkage. The author emphasizes the technology's role in reducing resource use and minimizing environmental impact.

The other research paper outlines laser finishing as a precise method for surface design, reducing the need for harmful manual processes like sandblasting. It also details ozone fading technology, which uses ozone as a bleaching agent, and water jet fading, a chemical-free process that enhances surface finish, especially with a water recycling system.

5.2.Researchers from Medellin, Colombia, and Valencia, Spain

To continue we will analyze the study of Federico González-López, José-Luis Alonso-Molina, José-Antonio Mendoza-Roca, Beatriz Cuartas-Uribe, Leidy Rendón-Castrillón, Carlos Ocampo-López and Margarita Ramírez-Carmonain *Native microorganisms for sustainable dye biodegradation in wastewaters from jeans finishing*.

Which is focused on the biological treatment of this type of wastewater using native microorganisms, without the need for external seed sludge to start-up the process.

The authors propose a more sustainable approach to treating wastewater from the jeans finishing process by using native microorganisms—those already present in the textile facility and its wastewater. This method avoids the need for external seed sludge, which can be costly and may introduce unwanted pathogens or persistent pollutants.

To test this approach, two lab-scale reactors were set up: one with added sludge and nutrients, and another with only nutrients to support native microorganisms. Over 25 days, both systems achieved similar efficiencies in removing color and chemical oxygen demand (COD), demonstrating that native microorganisms are fully capable of initiating and sustaining effective wastewater treatment.

This approach is especially beneficial for industrial plants in remote areas, where sourcing and transporting external biomass is difficult. The authors recommend

adopting native microorganism-based treatment to make denim production more environmentally friendly and self-sufficient.

5.3.Daniela Sofronova

And finally the thesis *Towards Sustainable Jeans Production: Experimental Evaluation of a Denim Fabric to Abrasion Resistance by Dry Fabric-to-Fabric Rubbing* wich compares two abrasion tests on cotton and cotton-elastane denim, revealing differences that support more realistic testing for sustainability.

The author addresses sustainable jeans production by focusing on the durability and wear resistance of denim fabrics, aiming to reduce textile waste. The research emphasizes the need for stricter quality regulations to combat the short lifespan of some denim products, which contribute to environmental pollution. The study uses experimental evaluation of denim fabric's abrasion resistance to provide data that can inform more sustainable manufacturing practices.

The author uses two test methods to assess abrasion resistance: the Martindale tester according to DIN EN ISO 12947-1:2007 and ASTM D4966-22, and a fabric-to-fabric rubbing method. The Martindale test uses a special abradant fabric, while the fabric-to-fabric rubbing provides a more realistic assessment by simulating wear from walking, particularly in the inner thighs. Two types of denim fabrics were tested: one made of 100% cotton and another containing 98% cotton and 2% elastane. The endpoint of testing was evaluated by the appearance of two or more broken threads.

The research also measured mass and color loss, as well as changes in thickness and air permeability, to comprehensively evaluate the fabrics' durability. The study found that denim structures with elastane experience greater mass loss and a significant reduction in thickness and air permeability after testing.

5.4.Conclusions

- **Finishing Technologies:**Using e-flow, laser, ozone, and water jet methods can greatly reduce water, energy, and chemical use, making denim finishing more eco-friendly.

- **Wastewater Treatment:** Demonstrate that native microorganisms can effectively treat denim wastewater without added sludge, offering a low-cost, efficient solution, especially for remote facilities.

- **Durability and Design:** Daniela Sofronova emphasizes that realistic abrasion tests and careful material choices are essential to improving jeans' lifespan and reducing waste.

The reviewed studies present key strategies for improving sustainability in denim manufacturing : cleaner technologies, smarter wastewater management, and durable design practices.

6. Our proposal : Jeans Local Lab

We propose a model of circular, local, modular micro-facilities called ‘Jeans Local Lab’ that can be integrated into urban or rural communities and produce jeans in a sustainable, low-demand, clean technology way. This separated system covers the entire product life cycle, from design to repair, and incorporates technological innovation, consumer education and renewable practices.

In order to make this process more sustainable without changing the long history of jeans, these practices will be applied in their renewed manufacture processes

1. Organic Cotton and Regenerative Agriculture

We’re all about using organic cotton that’s grown through regenerative agriculture practices. This approach not only boosts soil health but also cuts down on water usage and eliminates harmful chemical pesticides. Plus, it helps capture carbon from the atmosphere. By championing these methods, we’re playing our part in promoting sustainability right from the source.

2. Eco-Friendly Dyes and Alternative Fibers

We make it a point to use eco-friendly dyes, like those derived from plants or low-impact options, which help minimize water pollution. On top of that, we support the use of alternative fibers such as hemp, TENCEL™, or recycled materials. These choices require fewer natural resources and enhance the durability of our garments.

3. Clean Technology in Washing and Finishing

We’re advocates for sustainable technologies like e-flow, laser, ozone, and water jet methods. These innovative techniques drastically lower water, energy, and chemical use. Research by Elias Khalil shows that these technologies can achieve high-quality finishes while keeping environmental impact to a minimum.

4. Water Treatment with Native Microorganisms

Drawing from studies by Colombian and Spanish researchers, we suggest using native microorganisms for wastewater treatment in our facilities. This approach is not only effective and cost-efficient but also particularly beneficial for smaller plants or those situated in rural areas.

5. Circular Design and Durability

Inspired by Daniela Sofronova’s research, we’re committed to crafting jeans from durable materials, featuring reinforced seams and modular designs that make repairs a breeze. This not only extends the life of the jeans but also helps reduce waste and promotes reuse. We’ll also set up repair and upcycling stations in local microfactories to encourage mindful garment maintenance.

Moreover, these decentralised factories would not only be a mass production site like the ones we know and operate today. Instead they would also function as tailor shops, upcycling places and open to conferences and workshops on responsible production and consumption.

Some of its advantages include

- Decentralises production: eliminates time-consuming logistical processes and generates local employment.
- Combines manufacturing and waste treatment in a single closed system.
- Directly involves the consumer, who can see, participate in or even personalise their garment.
- It functions as an educational centre for sustainable fashion, repair and recycling:
    - Customised design and sewing module: reuses local fabrics, including second-hand ones.
    - Repair and upcycling workshop: extends the life of old garments.
    - Educational space: open to the public for workshops on responsible consumption.

7. How could this proposal be applied ?

7.1. Practical application in industry

To carry out this proposal in the real world, it is important to adopt a progressive and flexible approach, especially in large factories that already have complex production structures. The first step would be to carry out a thorough diagnosis of the current environmental impact of the manufacturing process, analysing aspects such as water consumption, energy, chemicals and waste generation. This would help to clearly identify the most damaging points that need intervention, such as the dyeing, washing, water treatment and product design stages.

In order to start the sustainable transition is crucial to start with technological aspects such as:

- Installation of e-flow, laser and ozone systems in finishing areas.

  What is E flow?

  The e-flow system transforms air and small amounts of liquids, such as dyes or softeners, into nano-bubbles that are mixed with the garments in a drum. These bubbles are incredibly effective at penetrating the fibres of the fabric, allowing visual and tactile effects such as softness, dyeing or wear to be achieved without the need to submerge garments in large quantities of water.

- Integrate biological reactors with native microorganisms for wastewater treatment:

  Native microbes are just as effective in removing color and pollutants, offering a low-cost, efficient, and self-sufficient solution especially for remote factories.

7.2.Change raw materials

- Start introducing organic or regenerative cotton and alternative fibres (such as hemp or TENCEL) in a percentage of production (e.g. premium line).
- Establish partnerships with sustainable suppliers such as Saitex

These tools offer look alike results that are similar to traditional methods, but with a much lower environmental impact. The transition does not need to be immediate or total; it can be carried out in pilot phases, using small production lines or sustainable capsules to help assess the technical and economic feasibility of these changes before implementing them factory-wide.

7.3.Modular and circular design

Train design teams to create jeans that are more durable and easier to repair. Adopt a new design mindset: focus on more durable garment structures that can be repaired or easily recycled. Incorporate circular design principles such as:

- Reversible seams
- Reinforcements in friction areas
- Removable parts
- Recyclable fabrics
- Biodegradable labels or unmixed components

Brands can accompany this with transparency to the consumer through digital QR labels indicating how the jeans were produced, how to care for them and where to return them at the end of their useful life.

7.4.Certifications and transparency

For this approach to work well, it needs to be applied in many places. Large companies can launch special products and test new ideas. In addition, they need to obtain certifications that prove they are sustainable.

For example, a clothing brand can create a line of T-shirts made from recycled materials and see how consumers react. Certifications such as GOTS or B Corp are important. These certifications ensure that brands follow good practices. They also help brands to promote themselves in an ethical way. Thus, consumers trust them more. Imagine a company that is B Corp certified. Customers prefer to buy from them because they know they care for the environment.

Finally, consumers need to be educated.

Educational campaigns can teach about repairs and resale should be implemented in the companyFurthermore they can also offer workshops on how to take care of clothes. This makes sustainability part of everyone's daily life. For example, a shop can organise a workshop where customers learn how to sew or mend their old clothes.

7.2.Practical operation - first steps

Pilot Phase (3–6 Months)

A major brand like Levi's or Inditex could launch a limited line of sustainable jeans to test key innovations. Made from organic cotton and hemp, the jeans would be finished using clean technologies such as ozone, e-flow, laser, and water jet—drastically reducing water, energy, and chemical use. Wastewater would be treated on-site using native microorganisms, offering a low-cost, efficient solution especially suited for remote factories.

Durability would be prioritized through reinforced, modular design, supported by free repair and recycling services. The pilot could run in a workshop in Bangladesh or Morocco, measuring environmental impact and consumer response. Results would guide gradual scaling across production lines, forming the first step toward the broader Jeans Local Lab model.

8. Companies already implementing such practices

In this section we identify some denim brands that are already implementing the practices described in the studies analysed above and that could serve as a model or inspiration for the Jeans Local Lab proposal. These companies demonstrate that it is possible to implement clean technologies, sustainable wastewater treatment, circular design and eco-friendly materials on an industrial or artisanal scale, thus validating the feasibility of our recommendations.

8.1 Saitex

Saitex is considered one of the most sustainable jeans factories in the world. This Vietnam-based company, with a presence in Los Angeles, integrates many of the technologies analysed by Elias Khalil, such as the use of e-flow, laser and ozone for finishing processes. Thanks to these innovations, they have managed to reduce water use by 98% compared to conventional methods, and recycle 100% of their wastewater.

In addition, Saitex implements an advanced biological treatment plant, which resonates with the micro-organism approach to wastewater treatment developed by researchers in Colombia and Spain. Its closed treatment system allows water to be reused in the production process, aligning with the Jeans Local Lab's vision of water sustainability.

8.2.Nudie Jeans

This Swedish brand is leading the way in adopting a circular model similar to what's proposed in Jeans Local Lab. Every pair of their jeans is crafted from certified organic cotton, and they even offer free lifetime repairs, plus they accept used jeans for recycling or resale.

Their focus on durability and repairable design aligns perfectly with the recommendations from Daniela Sofronova, who emphasizes tackling textile obsolescence through realistic durability tests and reinforcements in critical areas. Nudie Jeans also employs sustainable finishing techniques, like laser and ozone treatments, which help minimize environmental impact without compromising the style of their garments.

8.3.Outland Denim

With its social and eco-friendly approach They create jeans using organic cotton and low-impact dyes, and they utilize sustainable finishing technologies, as highlighted by Elias Khalil.

What's particularly fascinating about Outland Denim is their dedication to transparency and traceability. They're even looking to incorporate digital labels (QR codes) on their jeans to keep consumers informed about the production process. Plus, their factories serve as training and employment centers for women who have survived trafficking, showcasing the educational and community-focused mission that Jeans Local Lab promotes.

> Brands like Saitex, Nudie Jeans, and Outland Denim show that it is possible to use clean technologies, circular design, and sustainable materials in making jeans. Their practices show that the Jeans Local Lab model works well and is already being put into action in different ways. These real experiences support the idea that a more responsible and local denim industry is possible if it changes gradually and thoughtfully.

9. Comparison to traditional manufacture

Aspect	Traditional Production	Sustainable Production (Jeans Local Lab)
Water usage	High (up to 10,000 liters per pair of jeans)	Very low (e-flow, ozone, and water recycling technologies)
Energy consumption	High, with long, inefficient processes	Significantly reduced through clean technologies
Chemical use	Heavy use of harmful bleaches and synthetic dyes	Controlled use of eco-friendly or plant-based dyes
Wastewater treatment	Often absent or inadequate, polluting rivers and soil	Biological treatment with native microorganisms, water reuse
Labor conditions	Often poor, with low wages and little oversight	Fair local employment, with training and community involvement

Product design	Fast fashion focus, low durability	Durable, repairable, modular, with recyclable materials
Social impact	Disconnected from local communities, centralized production	Community-driven, educational, and participatory model
Scalability	Mass production, global supply chains	Scalable modular microfactories in urban or rural areas

Sustainable denim production is a smart and responsible choice compared to traditional methods. While the old-school systems often waste a lot of water and energy, use harmful chemicals, and focus on mass production, sustainable models like Jeans Local Lab are all about clean technologies, local manufacturing, and fair labor practices.

By embracing eco-friendly methods this approach not only lessens environmental harm but also brings social and economic advantages. It results in durable, repairable clothing while uplifting local communities and engaging consumers in the journey.

10. Analysis

The analysis of case studies, emerging technologies, and our proposal Jeans Local Lab shows us that more sustainable denim production is not only possible, but urgently needed. Innovations in clean technologies, circular design, and decentralized models offer concrete solutions to the environmental and social impacts facing the industry today.

Benefits	Disadvantages and Challenges to Overcome
Significant reduction in water, energy, and chemical use.	High initial costs: Sustainable technologies require investments in machinery and training.
Efficient, low-cost wastewater treatment.	Resistance to change: Large manufacturers may be reluctant to adopt decentralized models.
Promotion of local employment and fairer working conditions.	Limited scalability: Micro-workshops may not meet demand of large brands without strong network.

More transparent and participatory production.	Lack of local technical knowledge in some regions to operate technologies like e-flow or biological reactors.
Longer garment lifespan, thanks to a design for easy repair.	Consumer education: A cultural shift is needed to value repair, durability, and traceability.

10.1.Recommendations for implementations

- Implement pilot projects to validate technical and economic viability in real-life contexts.
- Measure indicators of the environmental, social, and economic impact of micro-factories.
- Explore hybrid models that combine industrial production with sustainable local units.
- Develop public policies that incentivize sustainable practices and support the textile sector's transition.
- Foster partnerships between universities, brands, manufacturers, and governments to develop a collaborative approach to sustainability in the denim industry.

11. Conclusions and Key Insights

Sustainable denim production is no longer a distant ideal but a necessary evolution for the industry. Through the integration of clean technologies, circular design, and decentralized, community-focused manufacturing models like the proposed *Jeans Local Lab*, we can significantly reduce environmental impact while fostering social and economic benefits.

11.1How to Shop Responsibly

When you're on the hunt for denim, it's a good idea to pick brands that are open about how they make their products. Keep an eye out for eco-friendly materials and reputable certifications like GOTS or B Corp, which guarantee ethical and sustainable practices. Another fantastic option is to shop for second-hand clothing. This not only helps cut down on the demand for new manufacturing—which often uses up a lot of resources—but also gives pre-loved items a new home. Embracing a minimalist mindset by opting for fewer, high-quality pieces can also help combat overconsumption.

Washing your jeans less often and treating them with care can really extend their lifespan while saving water and energy. At home, you can give your clothes a second chance with simple sewing repairs and creative upcycling, which helps keep waste to a minimum. It's also crucial to support brands that offer take-back and recycling programs. These initiatives collect used garments to either recycle or refurbish them, helping to close the loop in the fashion cycle.

11.2.What can we do?

As individuals, we should educate ourselves about sustainable fashion, back ethical brands, and take good care of our clothes by repairing and reusing them. Brands, on the other hand, need to invest in clean technologies and circular design, ensuring their clothes are durable and easy to fix. Transparency is essential—brands should inform consumers and provide take-back programs to encourage sustainability.

Policymakers can help accelerate change by offering subsidies for sustainable manufacturing and enforcing environmental regulations. They can also fund research and promote collaboration among brands, manufacturers, and governments. These steps will support the entire industry in moving towards more responsible practices.

11.3.Final Call to Action

The Jeans Local Lab model illustrates a way to achieve sustainable denim by blending innovation, local empowerment, and environmental care. Making this happen requires teamwork. Consumers should demand transparency, prioritize quality, and support circular systems. The industry needs to experiment with new technologies, forge partnerships, and develop local micro-factories.

Governments must create policies that encourage sustainable innovation and fund education on responsible consumption. Together, these efforts can transform the denim industry into a model of sustainability and resilience, preserving our jeans and the planet for generations to come.

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