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ACADEMIC YEAR
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SAMSARA WHEELS – CIRCULAR ECONOMY PRINCIPLES APPLIED INTO THE PRODUCTION OF LONGBOARD WHEELS

POLITECNICO
MILANO 1863

MASTER THESIS IN
INTEGRATED PRODUCT DESIGN

POWERED BY

SUPER
FORMA

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MATTIA CIURNELLI

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POLITECNICO DI MILANO, SCUOLA DEL DESIGN
POWERED BY SUPERFORMA

TO MY PARENTS, HELENA,
BENÍCIO E TIO MAURO.

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ABSTRACT

ENGLISH

The investigation in course at this master cycle has as main goal to introduce circular economy principles on the production of wheels for longboard freeride, aiming for a good durability and predictability, and minimizing the cost through an innovative and sustainable solution. The first part presents the dynamics and signs of the material culture and history of skateboard and longboard, emphasizing the evolution of wheels made from polyurethane (due to its balanced properties between grip/slide, rebound, impact resistance and abrasion durability, highlighting as a negative point those that leave marks under the asphalt when practicing slides).

Through a symbiotic design thinking methodology adapted for sustainability, this work analyse various study cases, including bio-sustainable materials like mycelium, and emerging technologies as 3D printing biodegradable filaments, towards the reduction of the impact caused by the wheel wear - an ongoing cost for the riders. Important findings on how the practitioners compensate the grip, slide control and durability, forms the requirements to shape the design of a wheel and its user experience.

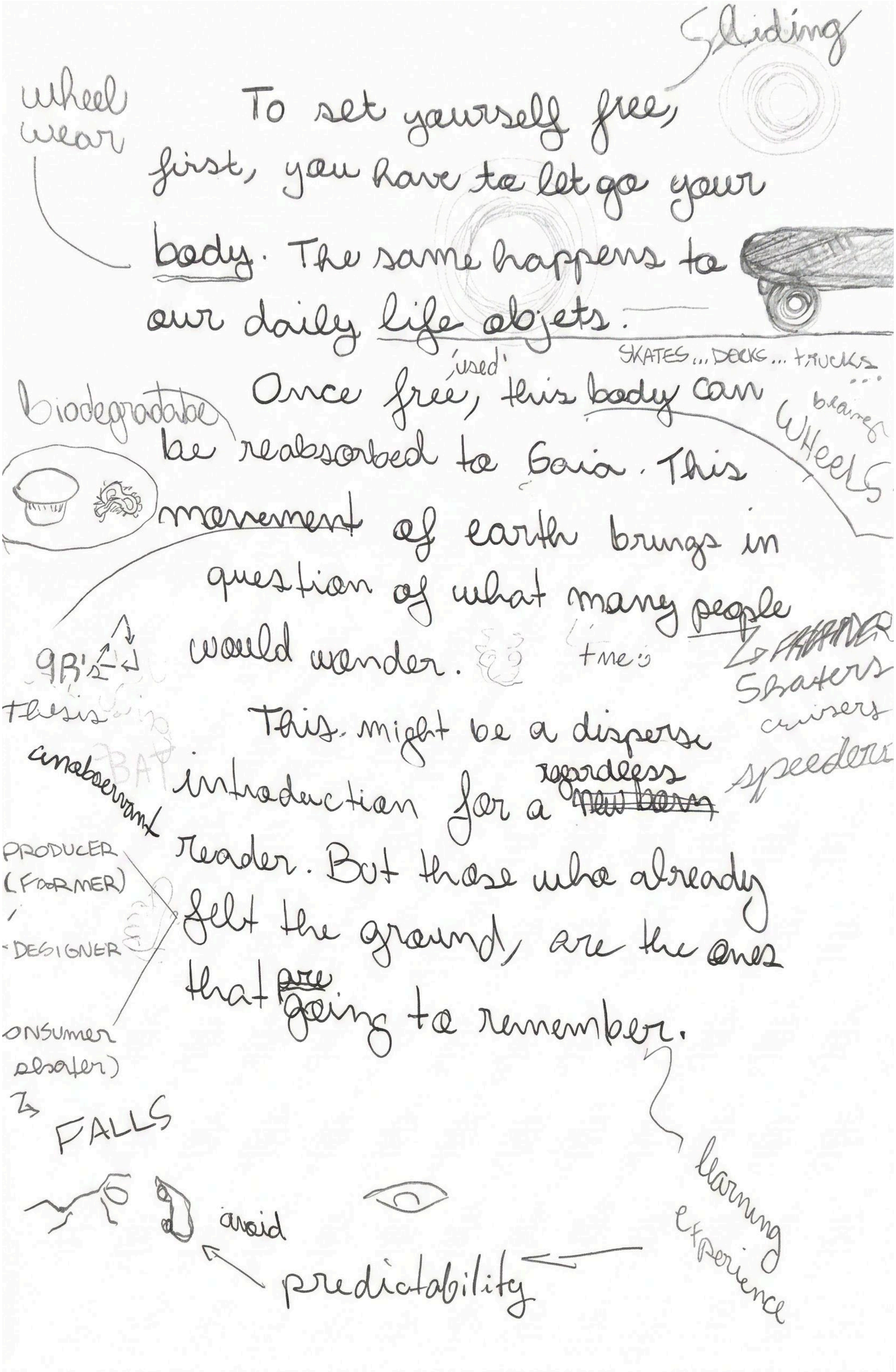
The thesis also explores assembly techniques, market feasibility, and assisted-AI for the bio-fabrication to guide an adaptive and circular production. This thesis contribution frames bio-design as a response to the sustainable challenges in the longboard and skate practices, centering the innovation at the balance of performance and environmental responsibility - offering an alternative for the freeride community. This approach centers on the wheels recognizing them as the most worn/used/consumed item, and key point to leverage sustainable practices within the longboard material culture.

ITALIAN

L'indagine in corso in questo ciclo di master ha come obiettivo principale l'introduzione dei principi dell'economia circolare nella produzione di ruote per il longboard freeride, puntando a una buona durata e prevedibilità, e minimizzando i costi attraverso una soluzione innovativa e sostenibile. La prima parte presenta le dinamiche e i segni della cultura materiale e della storia dello skateboard e del longboard, sottolineando l'evoluzione delle ruote realizzate in poliuretano (a causa delle sue proprietà bilanciate tra grip/slide, rebound, resistenza all'impatto e durata all'abrasione, evidenziando come punto negativo quelle che lasciano segni sull'asfalto durante la pratica degli slide).

Attraverso una metodologia di symbiotic design thinking adattata alla sostenibilità, questo lavoro analizza vari casi di studio, inclusi materiali bio-sostenibili come il micelio, e tecnologie emergenti come i filamenti biodegradabili per la stampa 3D, verso la riduzione dell'impatto causato dall'usura delle ruote – un costo continuo per i rider. Risultati importanti su come i praticanti compensano il grip, il controllo dello slide e la durata, formano i requisiti per plasmare il design di una ruota e la sua esperienza utente.

La tesi esplora anche tecniche di assemblaggio, fattibilità di mercato e l'IA assistita per la bio-fabbricazione per guidare una produzione adattiva e circolare. Il contributo di questa tesi inquadra il bio-design come una risposta alle sfide sostenibili nelle pratiche del longboard e dello skate, centrando l'innovazione sull'equilibrio tra performance e responsabilità ambientale – offrendo un'alternativa per la comunità freeride. Questo approccio si concentra sulle ruote riconoscendole come l'articolo più consumato/usato/deteriorato, e punto chiave per fare leva su pratiche sostenibili all'interno della cultura materiale del longboard.



To set yourself free,
first, you have to let go your
body. The same happens to
our daily life objets.
Once 'used' free, this body can
be reabsorbed to Gaia. This
movement of earth brings in
question of what many people
would wonder.
This might be a disperse
introduction for a regardless ~~new born~~
reader. But those who already
felt the ground, are the ones
that are going to remember.

Img. 0 - Introductory poem for Samsara Wheels, picture by the author.

INTRODUCTION

Longboard culture condenses a dynamic interchange between freedom and adaptation – a balance not only experienced in motion, but deeply rooted within the materiality of its practices. To free oneself, as beginners learn, is to break away from imposed barriers: physical, psychological and, ultimately, material. This same principle resonates through our everyday objects, such as wheels, which, with time and use, become repositories of wear, experience, and memory.

The fate of these objects—first essential, then consumed—raises questions for both practitioners and designers: how does the life cycle of these objects reflect our desire for sustainability? How can a wheel, once an integral part of movement and manoeuvring, be reabsorbed by the earth, exemplifying a return to “Gaia” through biodegradability and the principles of the circular economy?

The challenge persists from the origin of skateboard and longboard wheels, forged by waves of cultural management and revolutions in materials technology, to the contemporary complexity of customisable performance attributes such as grip/slide, durability and ecological impact mitigation.
Freeride longboard athletes recognise that wheel wear is inevitable. However, the prospect of minimising waste and maximising longevity raises questions about materials, design and broader ecological cycles.

CHAPTER ONE:

LOST MEMORIES

INSPIRATION, BACKGROUND AND IDENTIFICATION OF THE PROBLEM

Longboarding emerged as an extension of a broader cultural movement grounded in the 1940-1950s' spirit of freedom, nonconformity, and adaptation. Having an interesting debate from where it really originated, since the technology and its logic was available from at least a century past. The oldest recorded in New York, a DIY and easy assembly craft skates named kick scooter, made by kids and their parents by attaching roller wheels to a small wooden board. Although it is highlighted as one of the possible origins of skateboarding for its form and the motion propelled by the rider’s back foot, its use would be more similar to a scooter. [1]

Img. 1 - A kid was captured while building his kick scooter in Brooklyn, New York, by Life Magazine. / Img. 2 - Kick scooter / Scooter Craze.

Another accepted one came in the 1950s from Californian and Hawaiian surfers seeking to capture the fluid dynamics of ocean waves on dry land, early practitioners crafted wooden boards fitted with roller wheels, similarly to the kids toy, and calling the practice as “sidewalk surfing” [2]. Unlike skateboarding's emphasis on technical tricks and aerodynamics, longboarding prioritized flowing motion, speed, and a connection to the environment—values that continue to define its philosophy today.

This cultural and philosophical origin is crucial to understanding the evolution of longboard components, particularly the wheels, which have become central to both performance and sustainability challenges. Early longboard wheels were made from metal, clay and rubber, materials that limited ride quality and durability. The invention of polyurethane wheels in the late mid-20th century marked a breakthrough: their unique blend of grip, rebound, abrasion resistance, and slide control made high-speed freeride and downhill possible, revolutionizing longboarding as a sport and lifestyle.

Despite their performance benefits, polyurethane wheels come with significant environmental costs. Their production involves fossil-based materials and generates toxic emissions, contributing substantially to pollution. Furthermore, wheels experience constant wear due to friction with asphalt, requiring frequent replacement and leading to considerable material waste within the skating community. [3]

Understanding the origins and philosophy of longboarding provides essential context for addressing these sustainability challenges. The sport’s ethos of freedom and connection to nature contrasts with the ecological impact of traditional materials and manufacturing processes. This tension sets the stage for a design investigation aimed at reconciling performance demands with circular economy principles.

By framing wheels not only as functional components but also as cultural artifacts symbolizing longboarding’s spirit, this work seeks to innovate through bio-sustainable materials, adaptive manufacturing techniques, and user-centered design thinking. The goal is to extend wheel lifespan [4], minimize environmental harm, and honor the longboarder’s desire for fluidity and freedom.

The following sections will present a detailed history of the sport’s development, technical aspects of its parts, and the sustainability imperatives driving this research. Starting with a historical overview ensures clarity in tracing the evolution of materials and philosophy that ground the growing demand for sustainable longboard wheels.

1.1 - Longboard vs. Skateboard: Roots & Evolutions

Longboarding traces its roots back to the 1940s and 1950s in Hawaii and California, where surfers sought to extend their wave-riding experience onto pavement during flat water days. Early adopters modified wooden surfboards, attaching roller metal wheels, and coined the practice “sidewalk surfing.” [5]. These initial longboards were heavier and longer than today's models, often using metal or clay wheels, which limited performance but allowed surfers to mimic wave motion on asphalt.

Commercial availability began in the late 1950s with companies like Makaha [6] introducing mass-produced longboards resembling surfboards in shape and feel. The 1960s introduced critical innovations such as urethane "Cadillac Wheels” by Frank Nasworthy [7], which greatly improved grip, durability, and ride smoothness. This innovation marks the transition of longboarding from a dangerous toy to a technical sport by enabling freeride and downhill styles that emphasized speed, carving, and extended distance.

Flex Appeal

Makaha Proflex II, the competitor's dream.

Makaha's new Proflex II gives the optimum balance between strength and flexibility to the competitive skateboard rider. More than 15 years and a half-million skateboards combined with constant input from the best skateboarders around — guys like world champion freestyler Bruce Logan and the rest of the Makaha team — went into producing the Proflex II.

They all said the same thing. “Give us a board with more strength and flexibility.” We listened. Proflex II's aerospace “sandwich structure” construction — four layers of premium fiberglass over a center of hard core isothalic polyester resin and silica cells, a layer of uni-directional glass, and a special nonslip, gel-coated deck for positive footing — means control and maximum flexibility.

Flexibility, snap, spring, non-torque, and footing control in the chassis. And underneath — Makaha's new Zamac-5* trucks (the strongest, most versatile trucks made), and Makaha's pure, handpoured 2 x 2 urethane wheels with fully sealed instrument-grade precision bearings. Plus, there's Makaha's proven and patented kicktail for full-on control.

Proflex II's flexibility gives you exceptional response when cranking full-on turns, 360's or fast-wheeling up to the blue tile to sink into the fall off the wall.

Flex appeal for your riding flexibility.

Makaha — the experts' skateboard
from the skateboard experts!

1612 West 139th Street
Gardena, California 90249 (213) 539-9190
*Patent pending

Img. 3 - Makaha advertisement poster. / Img. 4 - Makaha rider.

Skateboard industrialization advanced notably in 1963 when Patterson-Forbes produced the first mass-manufactured complete skateboards with improved trucks, transitioning the activity from DIY versions to widely accessible sports equipment [8][9]. This period also saw the first organized contests and growing media attention, which solidified skateboarding's cultural presence.

The pivotal kicktail innovation, patented by Larry Stevenson in 1969, transformed board design and performance by enabling curved tails manufactured via thermopressing laminated wood, greatly expanding trick and maneuver possibilities [10].

Img. 5 - DIY skate. / Img. 6 - Pioneer industrial manufactured skate, by Roller Derby.

On the other hand, the scientific journal PNAS Nexus points out that the dissemination of the skateboard industry was not a mere coincidence. The extended drought of 1976–1977, one of the driest periods on record, drastically reduced water usage resulting in numerous empty kidney-shaped swimming pools in suburban areas [Büntgen et al., 2023]. These curved pools became innovative playgrounds, enabling surfers to adapt to changing environmental conditions by developing vertical pool-skating and pushing skateboarding from an amateur pastime into a professional sport. This environmental catalyst, combined with advances such as the industrial production of polyurethane wheels and the emergence of mass media technologies, created a confluence of factors that propelled skateboarding — and by extension, longboarding — into global prominence [2].

Longboards diverged from skateboards in design, purpose, and culture. While skateboards evolved towards agility, tricks, and aerial maneuvers, longboards focused on stability, flow, and transportation, keeping closer philosophical and functional ties to surfing. Longboards are typically longer (33–60 inches), wider, and equipped with larger, softer wheels designed for grip and smooth rides rather than technical stunts.

This divergence reflects not only different mechanical requirements but also distinct user expectations and lifestyle values—a foundational understanding necessary when addressing the sustainability challenges unique to longboard wheels.

1.1.1 - Skate & Longboard Culture

The culture of skateboarding and longboarding shares common roots yet exhibits significant differences not only in technical capabilities but also in social and economic dynamics. Skateboarding, historically urban in nature, evolved as a more accessible and economically inclusive sport, with lower barriers to entry and broad participation across social strata. Its culture embraces improvisation within city spaces—streets, parks, and other concrete terrains—often grounded in a base mindset and youth subcultures that creatively challenge urban landscapes as “grey spaces” for play and resistance.

In contrast, longboarding often represents a more specialized and sometimes elitist segment, associated with suburban or rural spaces where riders invest in larger, costlier equipment and require specific terrains such as downhill roads or smooth asphalt. Despite these socio-economic distinctions, both cultures maintain a deep connection to nature and community. This manifests through group events, shared practice spaces, and a collective emphasis on freedom, flow, and experiential riding [11].

This duality underscores a core paradox in the sport’s evolution: balancing skateboarding’s open accessibility with longboarding’s more exclusive, performance-driven community, all rooted in a broader culture of nonconformity and ecological awareness [12]. Understanding this paradigm is essential for sustainable design efforts, as cultural values directly influence user priorities and openness to innovation. Such insights are critical for developing bio-design and circular economy approaches that integrate ecological responsibility without compromising rider experience and identity [13].

Technical advancements—like urethane wheels and truck engineering tailored for longboarding demands—embody this cultural distinction but also highlight the material challenges and environmental footprint inherent in current designs. Recognizing and respecting these cultural differences is fundamental to crafting sustainable longboard wheels that resonate with rider values and support environmental direction.

1.1.2 - Free world and dynamic spaces

The primary distinction between surfing and skateboarding/longboarding lies in their respective environments. Surfing is confined to the water, depending on the presence and behavior of waves; riders can only stand up and maneuver when sufficient speed is generated by wave action. This inherent dependence on natural, often unpredictable ocean conditions imposes limitations on practice and skill development [14].

In contrast, skateboarding benefits from the availability of specific, often purpose-built urban sites designed to promote community engagement and environmental well-being. These designated skateparks and public spaces offer controlled environments that promote inclusion and safety for practitioners [15]. Longboarding, however, faces unique challenges in urban integration, as it primarily requires long, paved roads suitable for downhill, cruising, or freeride styles. These roadways frequently compete with vehicular traffic, making it more difficult for cities to support longboarding practices without significant infrastructure adaptations [11].

Thus, while skateboarding more naturally fits within urban fabric and community spaces, longboarding exists in a more contested and dynamic relationship with the city planning and transportation systems, signaling ongoing tensions between recreational freedom, public space allocation, and safety considerations.

Img. 7 - Longboard (above) and skate (below) most common spaces.

1.1.3 - Modalities, Styles and Tribes

Longboarding embraces diverse riding styles that reflect its rich cultural and functional range. Rooted in the desire to emulate surfing’s fluid motions on land, longboarding styles include cruising, carving, freestyle, freeride, downhill, and dancing — each characterized by specific board shapes, wheel configurations, and rider intentions [16].

Cruising and carving emphasize smooth, flowing turns and ease of movement, often associated with relaxed urban or suburban rides. **Freestyle and dancing** blend technical maneuvers and artistic expression on flat terrain, requiring highly responsive boards. **Freeride** centers on controlled sliding and speed modulation, while **downhill speed** focuses on high-velocity racing, demanding precision and stability [17].

By contrast, skateboarding, with generally smaller boards and harder wheels, concentrates on street and park environments where agility, tricks, and aerial maneuvers predominate.

Skateboarding culture tends toward urban youth expression, repurposing city spaces creatively. Longboarding culture, however, often attracts riders valuing connection with nature, community collaboration, and freeride expression in open, often non-urban terrains [11]. This dynamic creates subcultural distinctions, with longboard communities organizing around specific modalities and shared values like freedom, flow, and environmental awareness [17].

Img. 8 - Illustration of carving, dancing (left), freeride and speed (right) modallities, AI generated.

This work searches to not exclude any modalities, but by focusing on its extreme practices, **freeride and downhill**, it permits to understand the material maximum potential and derive to a similar material/object with a less harmful production method and diminishing pollutant emissions. Initially, the cost is expected to be higher than the raditional costs, expecting to have a distant and lasting return.

Milan longboarding tribe:

While skateboarding's prominence provides a cultural baseline, longboarding's evolving tribes are characterized by their particular engagement with landscape and personal style, highlighting the sport's adaptability and diversity of experiences.

The longboarding scene in Milan, Italy, is growing with a mix of urban cruising and freestyle riding. According to local sources like Technogym's history of longboarding [18], Milan's community thrives on creative use of city parks and promenades, balancing style and mobility in a compact urban environment. The culture here is characterized by small, enthusiastic groups often connected through events and local shops, highlighting a trend towards embracing the sport both as transportation and lifestyle.

São Paulo longboarding tribe

In São Paulo, Brazil, the longboard culture is deeply rooted in the city's sprawling geography and challenging terrain. Based on empirical observations and interviews with local riders [19], freeride and downhill are dominant, with practitioners adapting to fast traffic and rough road conditions using protective gear and custom setups. Socially, São Paulo's longboarders form diverse tribes with strong community bonds, organizing street runs and competitions that blend performance with urban socializing. The harsh urban conditions underscore the need for durable, high-performance wheels, tying directly into the sustainability considerations of this thesis.

1.1.4 - Parts, Assembly and Manufacturing

Skateboards and longboards share similar typology of components — 1 board (deck), 2 trucks, 4 wheels, 8 bearings, bolts, and grip tape — yet they differ significantly in performance requirements and functionality. The design and materials of each part reflect the distinct riding styles and cultural philosophies of these sports.

Img. 9 - Skate parts assembly, by Element.

Wheels

In contrast, skateboard wheels are harder, averaging 95A to 101A, optimized for smooth, hard surfaces like concrete skateparks, promoting speed and slide control20. The size of wheels also differs: longboard wheels tend to be larger, often around 70mm or more, balancing rolling efficiency with slidability, while skateboards usually use smaller wheels for quicker response and technical tricks [20].

A longboard wheel is composed of two pieces:
The core is harder for stability and resistance because it is the interface between the patch and the bearings 608 (standard skateboard bearings).
The tire or the band is a rubbery part that varies with the durometer, offering different types of grip/slide rate. Wheel core placement—centerset, offset, or sideset—affects the grip and slide characteristics, influencing performance for downhill, freeride, or cruising styles. Advances in urethane formulations and precise aluminum mold manufacturing have significantly increased wheel durability and consistency, critical to the growing demands of freeride longboarding [21].

The wheels are the only component in contact with the ground and thus play a crucial role in ride quality, control, and safety. Longboard wheels typically have a softer urethane composition, measured between approximately 75A to 85A on the durometer scale, providing greater grip and smoother roll over technical and rough surfaces like asphalt [22].

Img. 10 - Comparison side-by-side of a skateboard and a longboard wheel.

Board / Deck

Img. 11 - Different shapes and concaves of longboard deck’s, by Caveman Outdoor.

Skateboard decks have evolved since the 1970s to incorporate the kicktail—a curved upturned tail that improves “pop” for jumping and technical tricks. Modern decks typically use seven layers of maple wood laminates, valued for their strength, lightweight, and sustainability due to fast growth and certification protocols [23]. Weights range from 1.2 to 1.5kg, balancing impact resistance and mobility.

Longboards, addressing speed and stability, have longer decks weighing 1.8 to 2.5kg with 7 to 9 maple laminates. The design of the shape brings another particularity to longboards. Distinctive concave designs improve foot locking and aerodynamic stability for downhill or freeride use, reinforcing the rider’s connection and control.

Trucks

Trucks are the metal T-shaped components mounted under the board that connect the wheels to the deck, enabling turning by pivoting around an axle attached to the baseplate via a kingpin. Longboard trucks are generally wider, with hanger widths commonly ranging from 150mm to 180mm, accommodating the broader deck sizes typical of longboards [24].

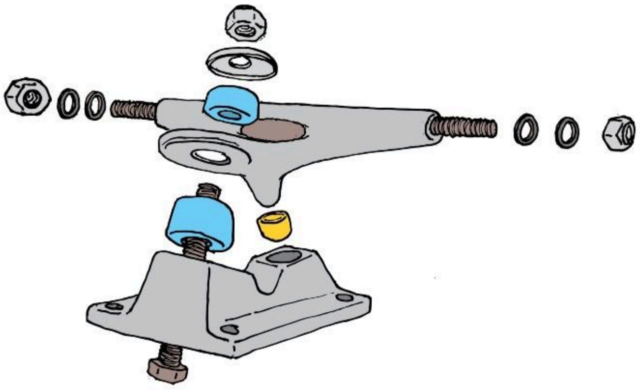
Their design often features a reverse kingpin configuration, where the kingpin is positioned on the upper side of the hanger, opposite to standard skateboard trucks. This configuration, brought to mass production by Sector 9 in the 1990's, provides greater stability and smoother turning, essential for controlling high speeds and carving on longboards [25].

Skateboard trucks, in contrast, are narrower and usually have the kingpin on the inside of the hanger, optimized for quick, precise turning necessary in street and park skateboarding [26]. Additionally, skateboard trucks must withstand repetitive impacts and abrasion since they are frequently used in tricks such as grinds, necessitating a higher durability and impact resistance compared to longboard trucks [27].

Bushings, the rubber-like rings within trucks that facilitate movement, differ between the two sports as well. Longboard trucks typically use softer bushings to provide easier turning and better responsiveness at varied speeds, with stiffer bushings used in downhill-specific trucks for added stability. Skateboards generally feature harder bushings to favor responsive, controlled maneuvers.

Precision trucks, increasingly popular in longboarding, are CNC-machined from single pieces of metal rather than cast, resulting in stronger, lighter, and more finely tuned components. This precision engineering yields smoother, more predictable turning and enhanced overall stability, which is critical for high-performance freeride and downhill [27].

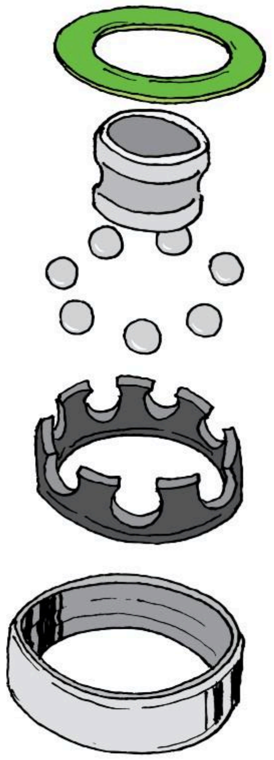
The equilibrium between truck size, kingpin placement, bushing hardness, and manufacturing quality critically shapes performance, rider safety, and the environmental footprint of these pivotal components.



Img. 12 - Truck part's assembly, by Element.

Bearings

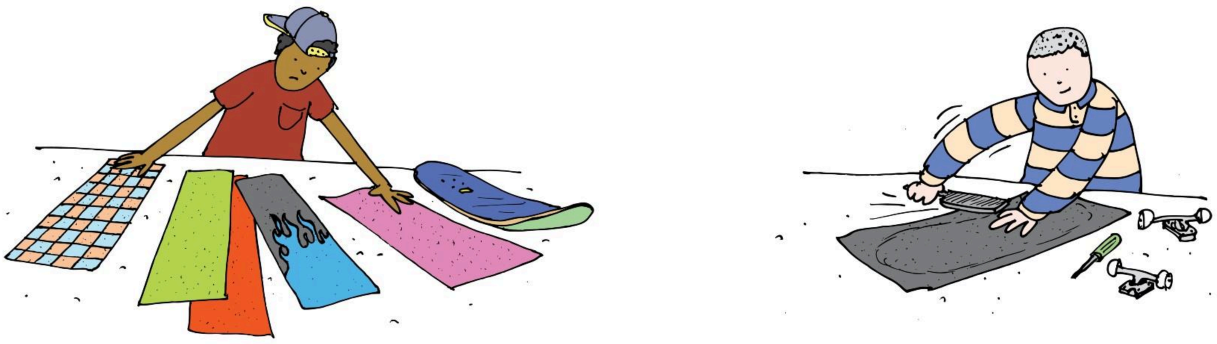
Bearings are critical for wheel spin efficiency and overall ride smoothness. Both skateboards and longboards primarily use 608 standard bearings, typically made of steel or ceramic. Steel bearings, especially high-grade chrome steel, are durable and cost-effective but prone to rust if not maintained properly. Ceramic bearings, more common in longboarding for downhill and freeride due to their hardness and heat resistance, offer faster speeds and less friction but at a higher cost and somewhat lower resilience to heavy impacts. The choice of bearings affects not only performance but also maintenance needs and lifecycle sustainability, with well-maintained bearings significantly extending wheel life [28][29][30].



Img. 13 - Bearings part's assembly, by Element.

Grip Tape

Grip tape provides the necessary friction between the rider's shoes and the deck, ensuring control and safety. Both sports use similar grip tape materials—silicon carbide or aluminum oxide abrasive sheets adhered to the deck. The grain and coating can vary to adjust grip level suitable for technical skateboarding tricks or freeride longboarding stability. While grip tape is easily replaceable, its disposal and environmental impact should be considered in sustainable practice discussions [31].



Img. 14 - Grip tape samples, by Element.

Safety Equipment

Safety gear such as helmets, gloves, knee pads, and elbow pads are essential, particularly in longboarding, where speeds and injury risks are greater. Skateboarding often emphasizes protection for impact from tricks and falls, while longboarding requires equipment designed for high-speed stability and crash absorption. Innovations in safety gear incorporate advanced materials like EPS foam, reinforced plastics, and moisture-wicking fabrics, balancing protection with comfort. Sustainability concerns in safety equipment focus on materials sourcing, recyclability, and product lifecycle management [32].

Img. 15 - Safety equipment gears, AI generated.

1.2 - Wheels history: how polyurethane made it possible

Img. 16 - Polyurethane sampes, by Garzanti Specialties.

The industrial take-off of longboarding coincided with the introduction of polyurethane wheels in the early 1970s, when Frank Nasworthy commercialized skateboard-specific urethane under the Cadillac Wheels brand, shifting the sport from clay/metal instability to grip, rebound, and predictability at speed [7]. Urethane’s higher traction and rebound damping reduced wheel chatter and crash risk, allowing riders to explore speed, carving, and vertical terrain confidently.

Img. 17 - Cadillac Wheel.

The innovation on material technology spawned the technical evolution of the sport while embedding it within a petrochemical production chain with environmental costs [3]. This transition marks the point at which performance and safety increased together with material intensity, framing the sustainability problem this thesis addresses [4].

1.2.1 - Wheels evolution: from metal/clay/rubber to PU (longboard revival)

Early material's wheels were metal or clay, offering low grip and harsh ride quality, limiting speed and control on the road. The invention was borrowed from roller wheels that used metal wheels with embedded bearings to roll down a cart-specimen at high speed using a wooden box. Integrated bearings facilitate its assembly while it doesn't favour the production of different types of wheels.

The second advancement on wheels was using rubber, improving comfort but lacking the abrasion resistance and tunability needed for advanced riding [8]. Here, bearings were assembled in the wheels, facilitating its individual part production and personalization of sizes.

With the arrival of polyurethane wheels, they replaced these legacy materials due to its unique combination of adjustable hardness, elastic rebound, abrasion resistance, and tear strength, enabling smoother pavement rides, stable sliding, and reliable high-speed lines; this change supported the "second boom" and longboard revival anchored in downhill and freeride disciplines [33]. Museum and industry records document the rapid diffusion of Cadillac Wheels and the maturation of urethane formulations, which together normalized higher speeds and technical riding as safer and more controllable practices [34].

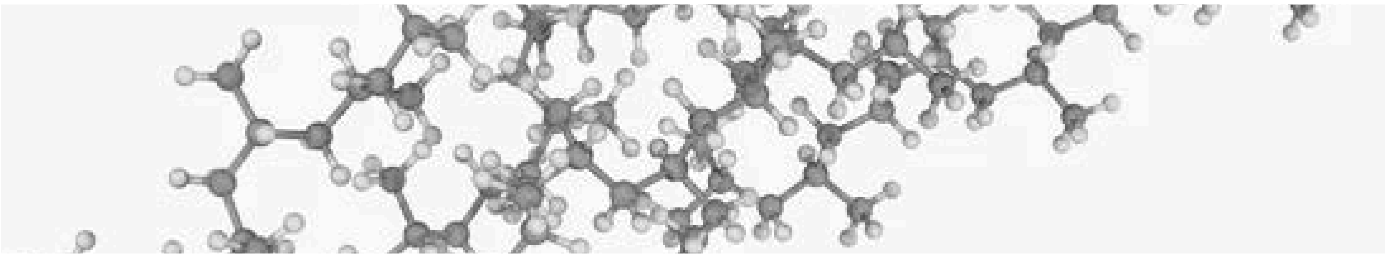
Key inflection:
Nasworthy leveraged roller-skate ***urethane*** insights into skateboard-specific wheels (circa 1970–1973), seeding a manufacturing ecosystem around urethane casting and molding for boardsports [35].

Cultural-technical loop: As urethane improved, riders escalated terrain ambition (banks, pools, hills), reinforcing demand for larger diameters and softer durometers that defined longboarding's differentiated wheel market [2].

1.2.2-PUR properties: stiffness, elasticity, durability

Polyurethane's advantage derives from its tunable microstructure and processing, providing application-specific trade-offs across hardness, rebound, grip, and wear. Urethane wheels can be cast or injection molded to deliver a wide hardness spectrum, from "sponge-soft" to "iron-hard," while retaining high tear strength, abrasion resistance, shock absorption, and elastic memory relative to plastics and rubber, which enables smooth rolling and predictable edge hold at speed [36].

Mechanical datasets for cast PU show high tensile strength, elongation to break, and favorable rebound, mapping to real-world grip and damping that reduce vibration and increase control of wheels on rough asphalt [37]. Industrial guides emphasize chemical resistance, noise reduction, and the ability to recoating/retooling treads, which extend service life and support circular maintenance strategies compared to single-use compounds [36].



Img. 18 - Polymer chain, representation.

Two technology notes illustrate how properties translate into wheel performance and sustainability levers:

Chemical/mechanical bonding to hubs: Patented processes for injection molding and cast-bonding create treads that are both chemically bonded and mechanically interlocked to the hub, improving durability and reducing delamination at high loads, which lowers failure rates and waste [38][39].

Pressurization and core engineering: Iterations like pre-pressurized or engineered-core wheels redistribute stress, enhance rolling efficiency, and modulate deformation under load, pointing to geometry-material co-design opportunities for longevity [40].

Contemporary proprietary formulations (e.g., "high-rebound street urethanes") aim to balance slide initiation with surface compliance, making rough-ground skating feasible at harder durometers, which underscores how formulation chemistry drives use-case expansion and potential SKU rationalization for sustainability gains [36].

1.2.3 - Mechanical fundamentals: hardness, size, weight, geometry

Wheel behavior emerges from the interaction between material and geometry.

Hardness (durometer): Higher durometer increases roll speed on smooth concrete and improves slide initiation but reduces compliance and grip on rough asphalt; lower durometer increases damping and grip for downhill and freeride, improving safety margins at speed.

Size and mass: Larger diameters (e.g., ~65–75 mm for longboards) improve rollover and momentum retention but add weight and slower acceleration; smaller diameters favor technical agility but transmit more vibration, limiting control on rougher surfaces.

Contact patch and edges: Wider contact patches and square/lipped edges increase mechanical keying and lateral grip for downhill; rounded edges and narrower patches reduce grip and promote controlled slides for freeride, shaping wear patterns and replacement cycles.

Core design and placement: Rigid cores with optimized spoke geometry reduce hysteresis losses and heat buildup; core placement (sideset/offset/centerset) tunes breakaway and wear symmetry, with offset/centerset often preferred for balanced slide life in freeride and downhill [36].

Production route: Liquid casting supports small-batch, high-rebound formulas and thick treads; injection molding supports high-volume precision and strong hub bonds; both pathways influence defect rates, consistency, and the feasibility of recoating or retreading for circularity [39].

Together, these parameters define safety envelopes and sustainability profiles: softer, larger wheels improve safety on real-world asphalt but may wear faster under slide-heavy use, while bonded cores and robust treads reduce catastrophic failures and enable potential refurbishing, thereby lowering lifetime environmental impact relative to frequent full replacements [40].

1.3 - User’s perspectives: From the edge to the core

Projecting an artifact like a freeride wheel might be a complex task that requires a collective effort from both the designer and the one that will use his design object. A process composed by iteractions of material research, understanding of the user needs, prototyping and testing.The aim is to produce knowledge to give the tools required for users to produce their own personalized and sustainable wheel.

An interview was performed with Thiago Gomara, a friend and freerider for 12 years, to better understand an active player’s perspective. This section is dedicated to this collaborative conversation and supplemented with the analysis previously presented of circularity rate of downhill freeride wheels.

1.3.1 - Wheel’s behaviours when sliding

Early material’s wheels were metal or clay, offering low grip and harsh ride quality, limiting speed and control on the road. The invention was borrowed from roller wheels that used metal wheels with embedded bearings to roll down a cart-specimen at high speed using a wooden box. Integrated bearings facilitate its assembly while it doesn’t favour the production of different types of wheels.

Skateboarding and Longboard Downhill Freeride are practiced on asphalt roads. Thiago points out that some wheels are designed to perform in rough terrains and rainy soil, beyond highway traditional sites. Concrete and Shark Wheels[1], for example, are known for being marketed as hybrid or all-terrain wheels. Even though slides can be performed using this type of wheels, hardly one will prefer these instead of already established good freeride wheels.

Img. 19 - Slide leaving urethane lines on the road.

This is justified for two reasons. First, because freeriding over smooth surfaces is preferred to riding on rough terrains. Safety, speed, balance, smoothness and grip are the main attributes when one is looking for a nice spot to practice this technique when sliding or entering a sharp curve. Off-road terrain wheels can possess all those attributes but it lacks precision and control on extreme speed.

The other reason is that even if these wheels can perform in both types of terrains (road and off-road), there's bigger interest for the freerider athlete to have only good grip on road instead of having some grip on diverse terrains surfaces.[1] The preference for roads instead of rough terrains is clear when freeride downhill longboarding is the main goal, and hardly a spot with rough terrain will be elected for this practice. This information is crucial when designing wheels for good performance on asphalt roads.

For Thiago, he also disbelieves 3D printed wheels could perform good, since the tread must be inseparable from the cube (hub) that fixes the tire around it, submitting stability and security. The crucial task is to ensure that both parts are fused together, and the tire won't tear apart or unstrap from the hub "when a top speed of 90km/h is achieved", according to him. Safety is one of the most critical points for these athletes, because a simple mistake can lead to serious injuries or worse.

Performing at this degree of high speed it's only possible because of the evolution of the material technology, from metal and clay to rubber and, finally, polyurethane. High rebound, good abrasion resistance, and controlled shore hardness are the main characteristics that offer such high performance on wheels when compared to other materials. Although it offers the best performance on highway roads, polyurethane also has its disadvantages.

The high cost of production and oil-based derivative imposes the main issues of polyurethane wheels. Not only sets a line of who can afford for this item, but also implicates in consuming fossil based materials, what is being pointed out as one of the most harmful practices of humanity to nature.

1.3.2 - Coring: wearing wheels

The wear of downhill freeride wheels occurs due to the abrasion with asphalt. Rolling them and practicing slides requires a lot of energy from the material, and to obtain control over the wheels they also should have some grip, which provokes the abrasion. To avoid this, one might prefer icy wheels rather than butter wheels, preferred for their longer durability and lifespan.

Regular wheel wear is expected and accepted in the world of freeride and, when achieved, its practice is called coring. Worn wheels have different shapes that suggest if the wear was consumed regularly. Oval/square shapes and flat spots are known to be the main irregularities. It can occur because the material is non isotropic, meaning its weight is distributed differently along the volume and produces different abrasion wear over the wheel, making it become square/oval.

Img. 20 - Wheel's graveyard - collection of consumed wheels, by Thiago Gomara.

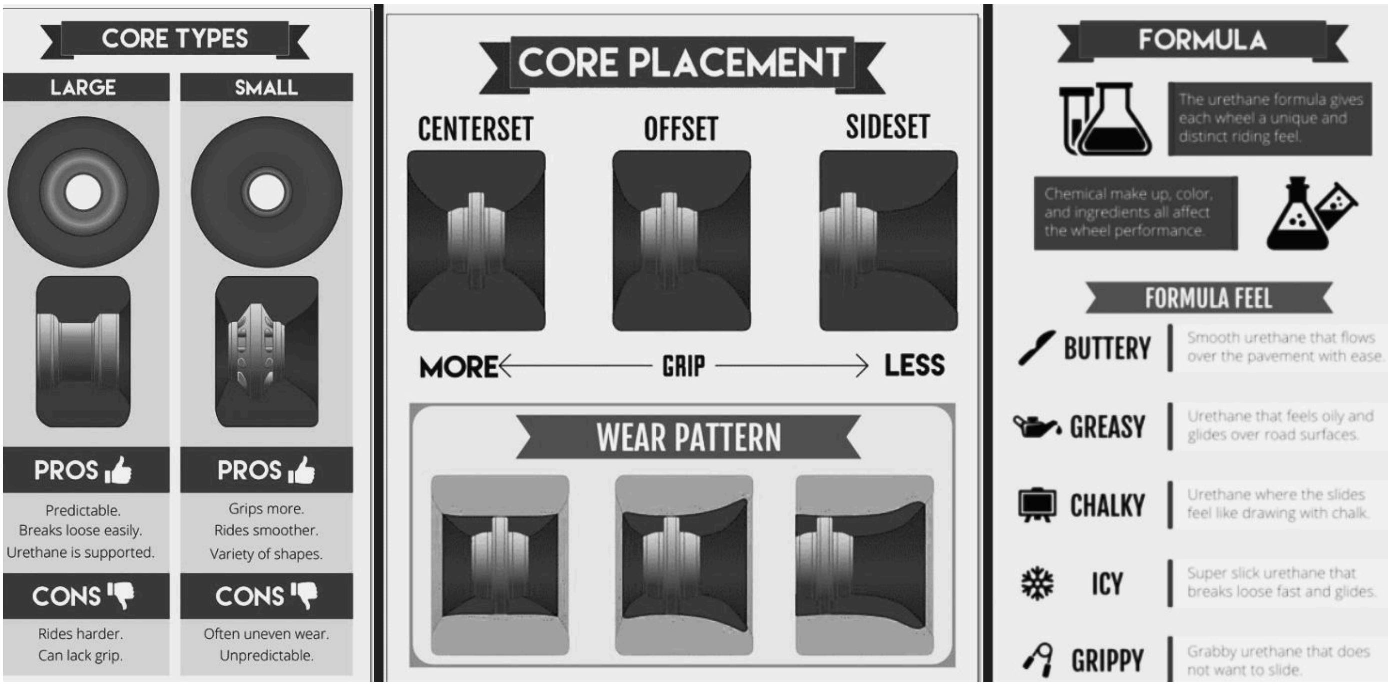
Another reason, significantly more common, is when a power-slide (turning the skate sideways at high speed, making it slide) is performed in a straight angle (90°), impelling the wheels to turn, wearing them in only one spot. To avoid it, the skate should be turned in a lower degree than 90°, assuring it can turn and produce constant wear. This is a technique that can extend a wheel’s life span and has to be learnt voluntarily over practice. One that uses wheels with these types of wear will experience a lot of wheel chattering and vibrations, limiting its top speed and possibly causing falls. Once this is understood by the rider, he might only have regular wheel wear, since the first reason barely appears and it's related with the manufacturing flaws.

Equally, the core placement carries different types of wheel wear. The highest amount of weight will always be found at the core’s position, meeting the point where it is most consumed by friction. Having this in mind, it's possible to understand that centered wheels will have the biggest grip and even wear, but lacks the ability of producing slides. For this reason, off-set and sideset positioned cores are preferred for the practice of downhill freeride. The weight applied on the wheels is transferred to the core making the lip’s wheel slightly rise, diminishing the contact path and letting the slide go easier and smoother. By noticing the side set worn pattern, it’s visible that uneven wear in the format of a cone will occur.

The last crucial characteristic that affects wheel wear is the polyurethane formula. The classification of them is based on perceived sensations when performing freeride, precisely described on the wheel’s infographic of Stoked Skateboards. Its parameters are balanced with the wheel's geometry to control grip/slide, consistency and predictability. This consideration will matters for freeride and regardless for cruising, since it defines the slidability of a wheel.

The classification composed of 5 categories defines them as **buttery, chalky, icy, greasy and grippy**, following this presented order as its desireness for sliding, varying between the first three from personal freeride styles. This can be considered an informal terminology because its information is not provided by the producers, but found in community forums. [41]

Described in the image as what their names represent, it is possible to also reflect in a weariness rank without defining it, because it uses relative and subjective parameters.



Img. 21 - Skate wheel infographic, by Longboarder Labs.

Categorized based on the feeling of riding them, brands started to use it for naming their wheels. For example, a very well known buttery wheel, one of the pleasant adjectives used to describe smooth and controlled slides, might be the Sector 9 Butterball series, with an impressive characteristic of wearing out completely in just a few warm days of intense freeride practices. Following the classification previously mentioned, buttery in this case would represent a rapid consumable wheel.

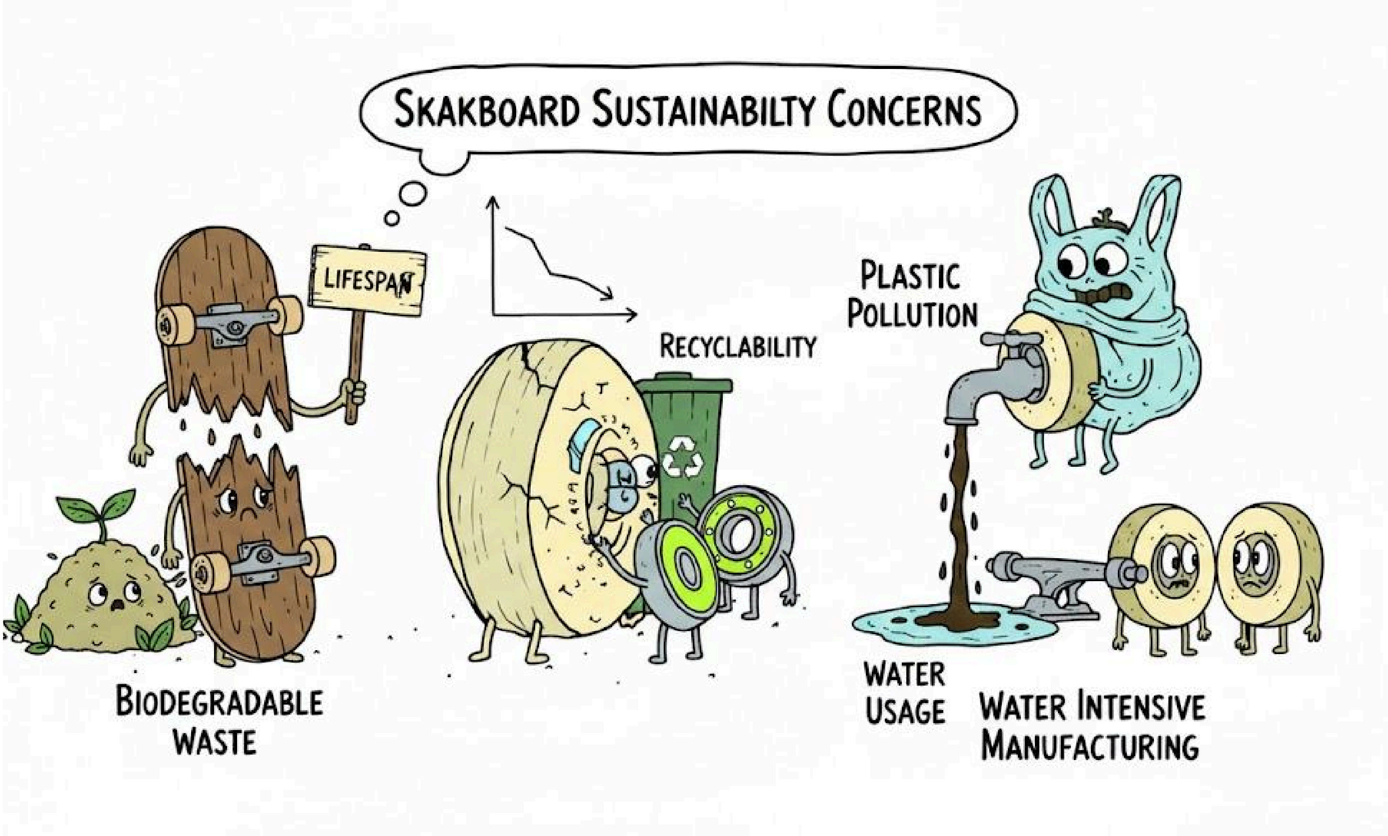
The analysis that can be made with all these presented aspects is that consuming, wearing and coring wheels is a topic concerned to downhill freeride practitioners. The slidability, longevity and the way it wears out could be the main attributes one will look for when buying a wheel. However, different styles and tastes diverge opinions of what wheel is the most suitable for its use, once the experience of how it feels is subjective for each individual.

Moreover, along the reflection of how to prevent wheels from wearing out while maintaining good slidability parameters, its problem might be perceived by the skate community [42] as less important in terms of sustainability than usability. Although some of them wondered for its truly impact on the environment, a precious effort should be considered for introducing ecological awareness to the ‘open-minded’ skate society.

1.4 - Filling the present

The wear of polyurethane wheels in freeride and downhill skateboarding presents a dual challenge: ensuring wheel longevity while preserving desirable ride and slide characteristics. Riders accept that wheel material will wear during use, yet excessively rapid deterioration forces frequent replacement. These wheels, predominantly made from fossil-based polyurethane, confront limitations in reuse and recycling, thus perpetuating a linear consumption model. Misuse or improper wheel selection further accelerates wear, diminishing both performance and sustainability. This reality highlights barriers to an ecologically responsible production-consumption cycle; however, substantial opportunities exist to mitigate rapid wear, shift toward non-fossil materials, and embed circular sustainable practices in freeride wheel manufacturing [3][43].

Velenturf and Purnell's principles of a sustainable circular economy emphasize regenerative design, systemic recycling, and renewable feedstocks beyond conventional biodegradable criteria. This broad framework inspires the thesis foundation by advocating a continuous collective endeavor integrating design, material science, and community engagement, transcending immediate economic incentives [43].



Img. 22 - Skate sustainable frame, AI generated.

1.4.1 - Role of Symbiotic Design and Bio Compounds in the recent industry

Introducing lifecycle assessment (LCA) and cradle-to-cradle concepts frames sustainable wheel development as more than material substitution—it mandates holistic consideration of environmental and user performance metrics [3]. The transitional phase in wheel manufacturing reveals increasing incorporation of sustainable biomaterials. Bio-polyurethane formulations, such as those pioneered by Mogu, and 3D printable TPU filaments (e.g., Ballena) exemplify collaboration between designers and living materials, fostering bio-integration and enhanced circularity [44][45]. These approaches emphasize bio-based feedstocks and regenerative production aligned with user expectations of durability and ride quality, signaling a disruptive evolution in wheel technology.

1.4.2 - Intersection between sustainable practices and Skate/Longboard Culture

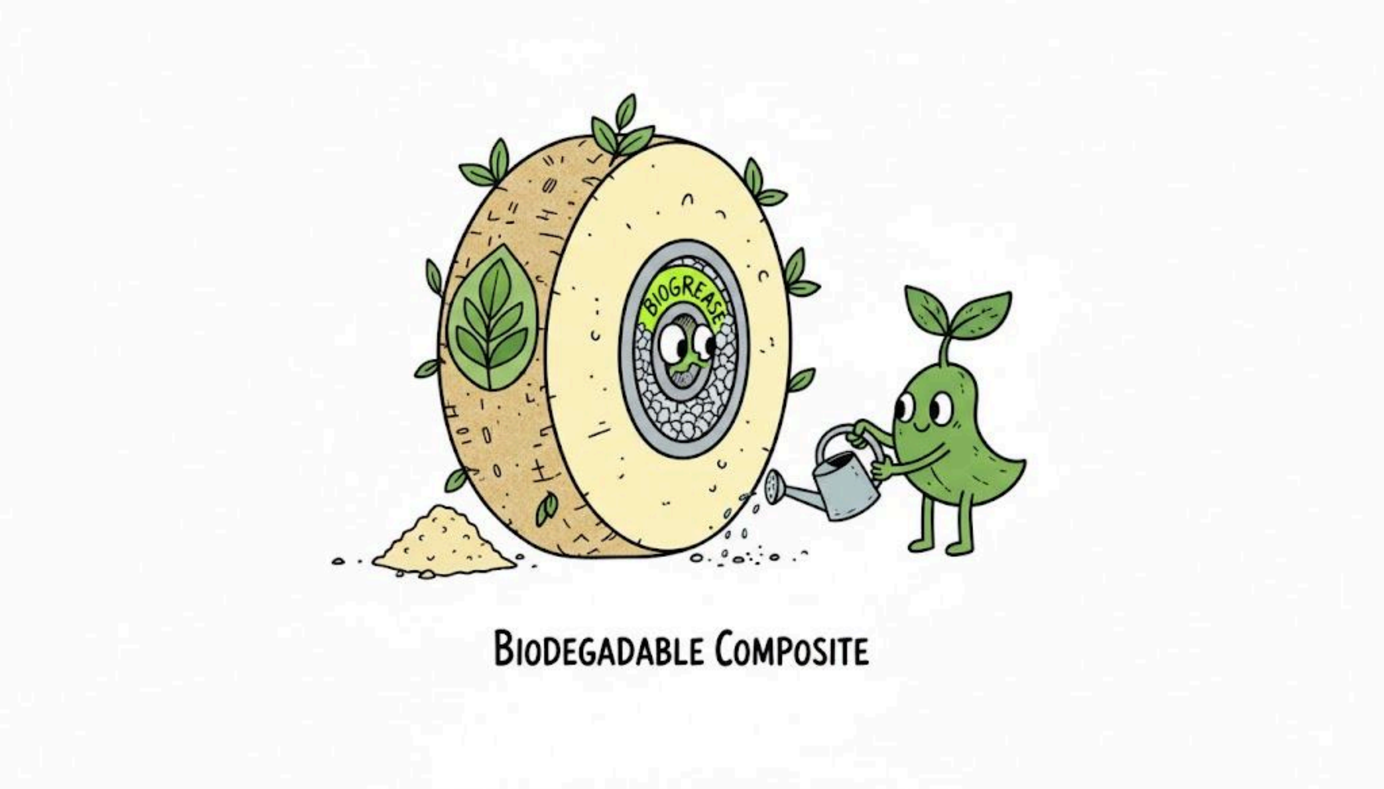
Stakeholders in skating culture demonstrate rising environmental consciousness reflected in material experimentation. Vans' gum wheels utilize recycled chewing gum, reflecting a commitment to waste reclamation and product innovation. Similarly, industry pioneers like Sector 9 employ bio-urethane, and Arbor advances sucrose-based wheel formulas, though comprehensive comparative data remain sparse [46][47]. Sustainable practices extend to board manufacturing, where bamboo—a renewable, fast-growing material—offers mechanical resilience and reduced ecological footprint, illustrating how alternative biomaterials can provide functional diversity without compromising longevity [48]. These developments, yet classified as premium products, illuminate pathways for material appropriation in longboard wheels, parallel to innovations pursued in this thesis project.

1.4.3 - How Might Wear of Longboard Wheels Be Prevented or Reduced?

Traditional wheel longevity methods include surface coatings to reinforce grip zones and precision machining to refine lip geometry, improving slide control while forestalling premature lip fractures [49]. Sanding textures during finishing stages also generates ideal sliding surfaces that prolong functional use. Inadequate surface preparation accelerates localized wear and performance degradation, underscoring the importance of manufacturing precision.

Emerging opportunities lie in integrating advanced bio-design materials, additive manufacturing, and smart factory protocols to engineer wheels with tailored resilience and renewability [36]. Circular economy principles applied to sports wheel development seek to maximize durability and minimize waste through such technical innovations, enhancing sustainability without sacrificing athletic performance [43].

In this way, a question was generated to guide the project direction, clearing realistic goals to be pursued and achieved. "How to apply circular economy principles to the development of sports wheels, maximizing durability and minimizing waste through innovative technical solutions?"



Img. 23 - Biodegradable wheel, AI generated.

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CHAPTER TWO:
CREATIVE WORLD

Creative practice is inherently driven by curiosity, experimentation, and the desire to transform available resources into meaningful artifacts. Makers, designers, and skaters alike demonstrate a willingness to work with materials and spaces that may initially appear marginal or overlooked, yet hold strong transformative potential. This chapter introduces a series of DIY study cases that have been carefully selected and analyzed for their capacity to reshape the skate experience and its surrounding environment. In parallel, bio-fabrication is presented as a promising response to the growing climate debt faced by contemporary production systems.

Img. 24 - Historic picture of the early Burnside Skatepark in Portland.

2.1 - DIY Study Cases

The construction of a skate park in one’s own backyard represents a widely shared aspiration within the skate community. However, due to economic, spatial, and regulatory constraints, this vision remains inaccessible to most practitioners. As a result, skaters often appropriate what is already present in the urban environment, creating improvised ecosystems composed of diverse and unconventional obstacles. Street skate spots are rarely located within private interiors due to spatial limitations and noise tolerance, leading abandoned parking lots, underutilized basketball courts, and city centers to become preferred sites for practice.

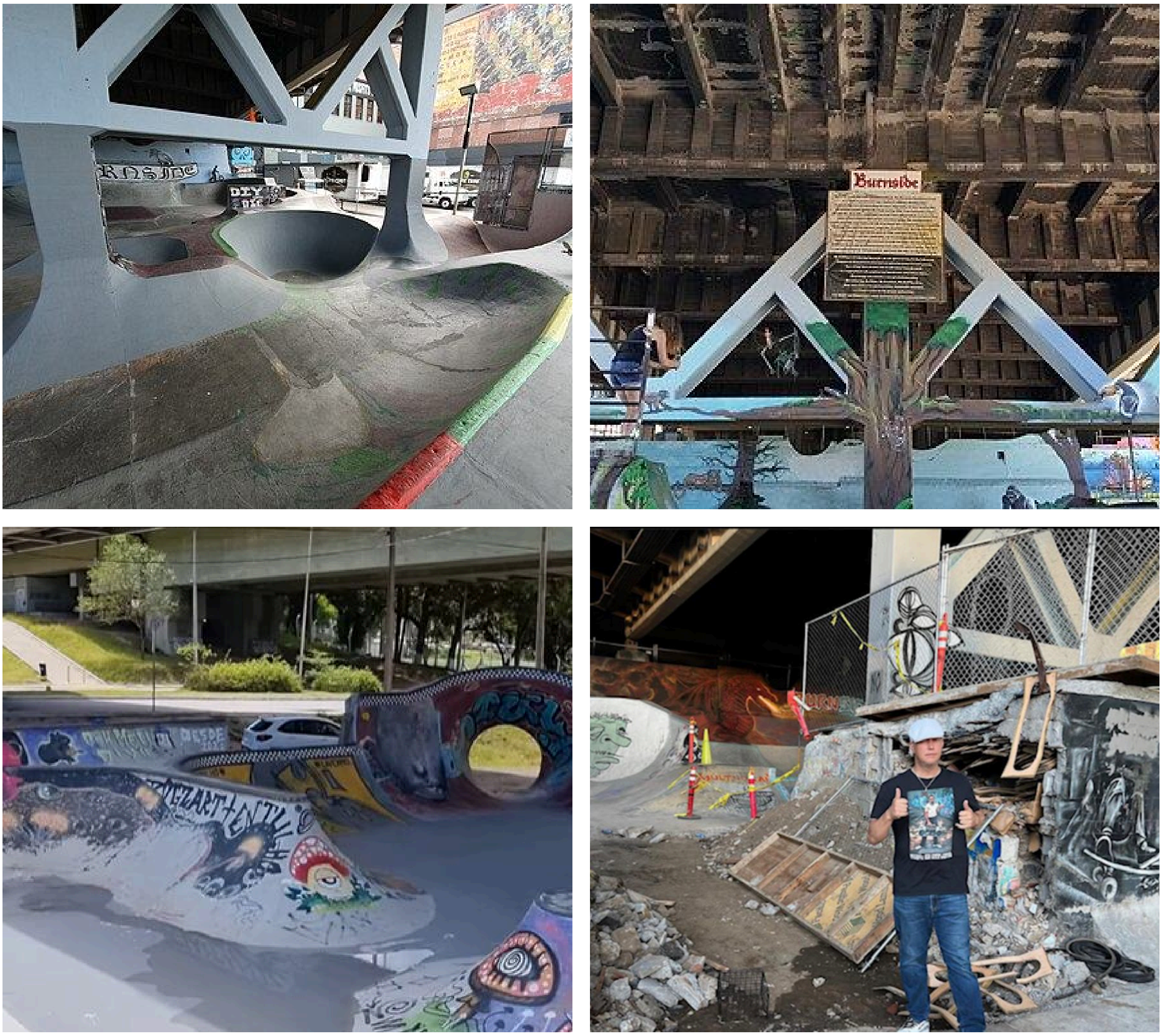
In contrast, downhill freeride is practiced on existing road infrastructures that naturally provide high momentum and technical challenges. In this modality, the road itself becomes the obstacle, with surface characteristics such as asphalt texture, grip, smoothness, and irregularities directly influencing riding behavior and performance.

These conditions shift investment priorities toward safety equipment and technical gear, as these elements have a direct impact on rider safety and experience. A similar dynamic occurs in improvised skate environments, where users frequently adapt or fabricate their own equipment. This practice can be traced back to the origins of skate culture, when creators experimented with readily available components sourced from other artifacts. Pads, glove caps, shield guards, and other forms of personal protective equipment are often substituted with homemade versions or materials acquired from hardware stores.

These re-signified objects generate new forms of experience while contributing to the preservation of equipment integrity. The following sections present examples of redesigned skating objects, open-source instructions, and improvised creations that operate across varying scales of sustainability and production.

2.1.1 - Creation of open and collaboratives spaces and objects for skating

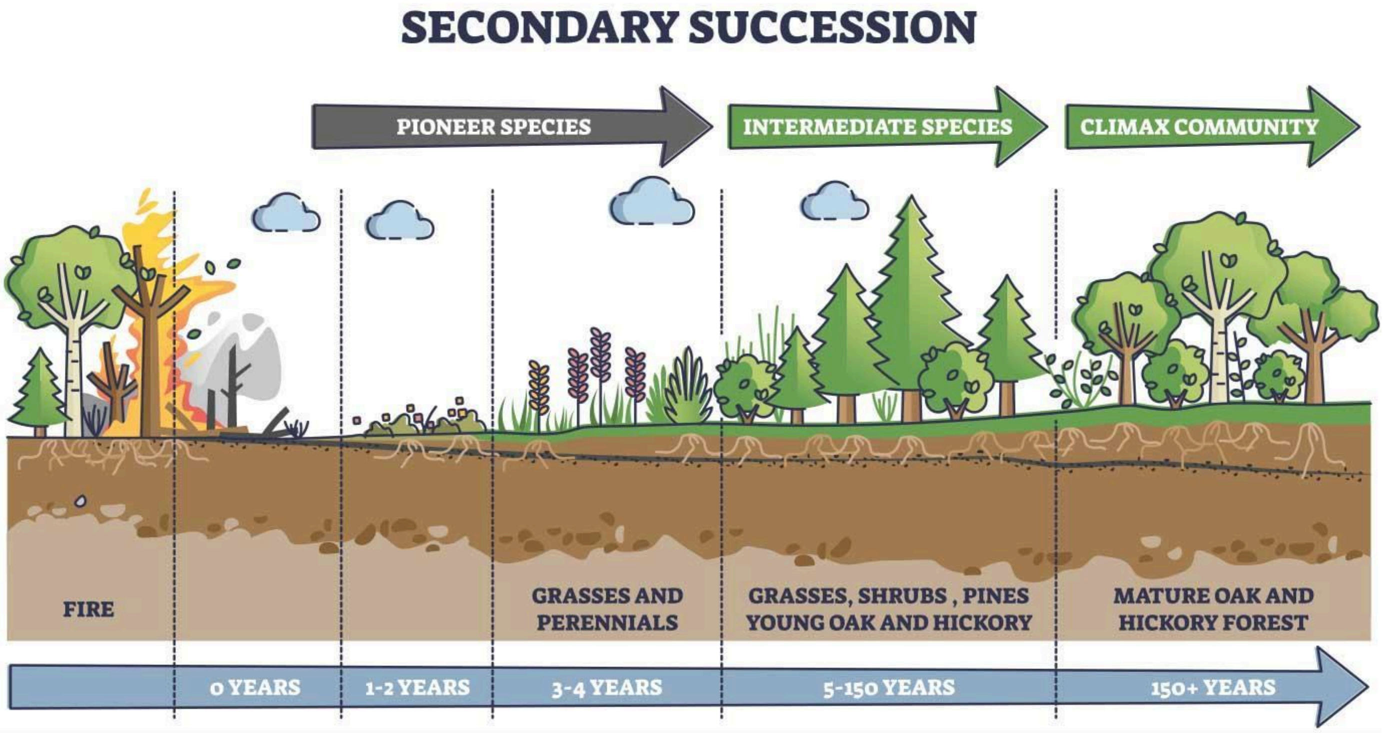
The availability of spaces for skating is constrained by societal norms, regulations, and urban planning frameworks. However, the reinterpretation of space through a skater's mindset enables the discovery of new environments and alternative objects suitable for skating. Through collective action, makers and users re-signify abandoned or overlooked spaces—such as areas beneath bridges, unused private facilities, or discarded materials—transforming them into functional skate environments. [1]



Img. 25 - Burnside Skatepark in Portland, USA. (1st, 2nd and 4th frames). Entulhos.diy Skatepark in Florianópolis, Brasil (3rd frame).

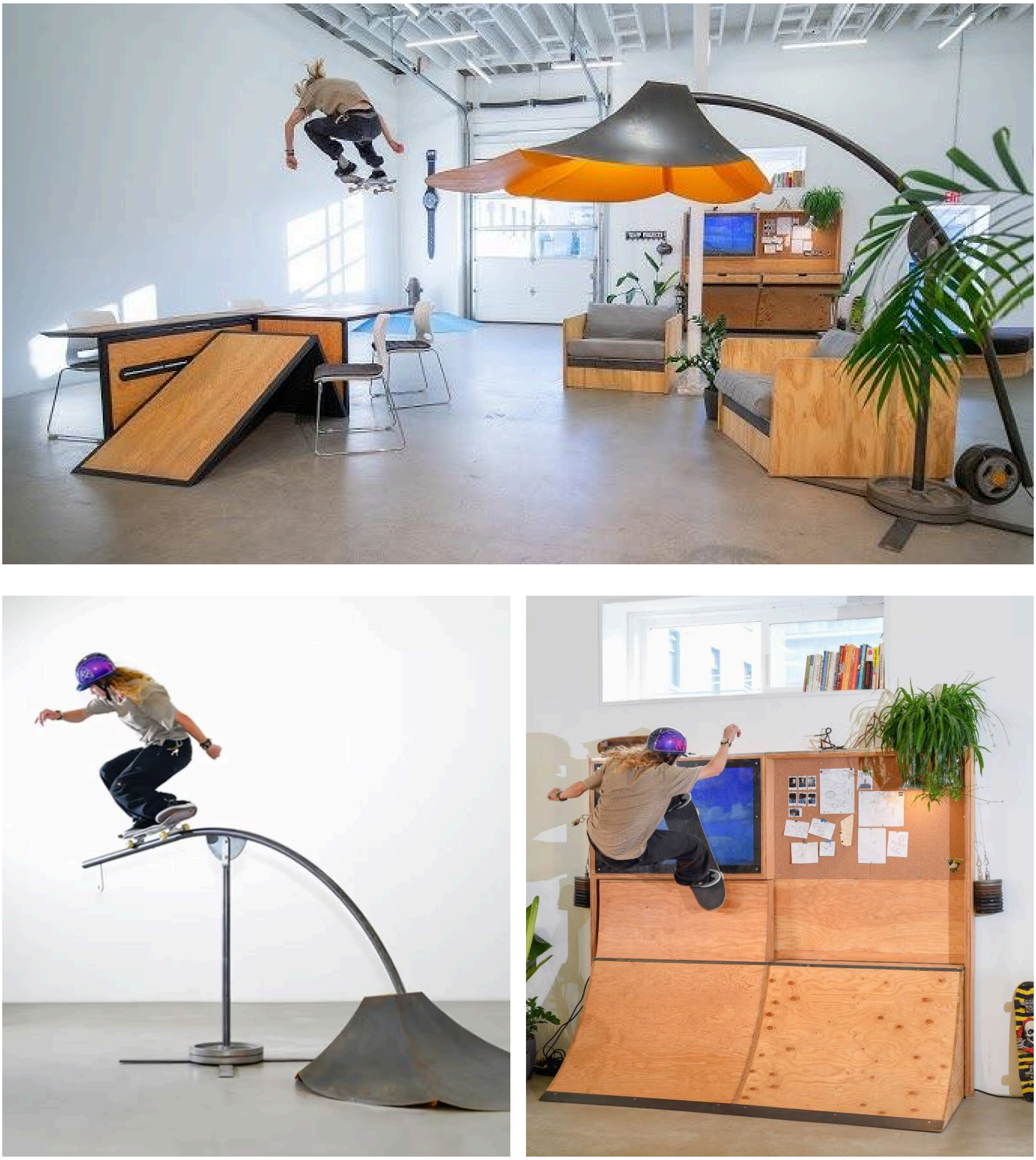
During the 1990s, skaters worldwide formed collectives to preserve the presence of skate spots within the urban fabric, responding to widespread prohibitions imposed by city authorities. These collective practices persist today and unite makers and users in the co-creation of space. Skaters actively participate in defining curves, obstacles, and surfaces, working collaboratively to craft paved areas, install metal rails, and adapt existing structures.

Notable examples include the Entulhos.diy collective in Florianópolis, Brazil, and Burnside Skatepark in Portland, USA—the latter recognized as one of the first DIY skateparks in a major city. Those collective's activities illustrate a process comparable to ecological succession, in which nature and human intervention progressively reclaim and redefine a site following disruption. [2]



Img. 26 - Ecological succesion, by University of Chicago.

As skate practice has become increasingly accepted, collaborations between private entities and public actors have emerged. An example of co-creation between users and designers is the series of mobile environments developed through a partnership between skater **Andy Anderson** and the Canadian design studio **ZengaBros**, supported by Swatch [3]. These projects transform conventional office typologies into hybrid spaces accommodating both work and skate activities.

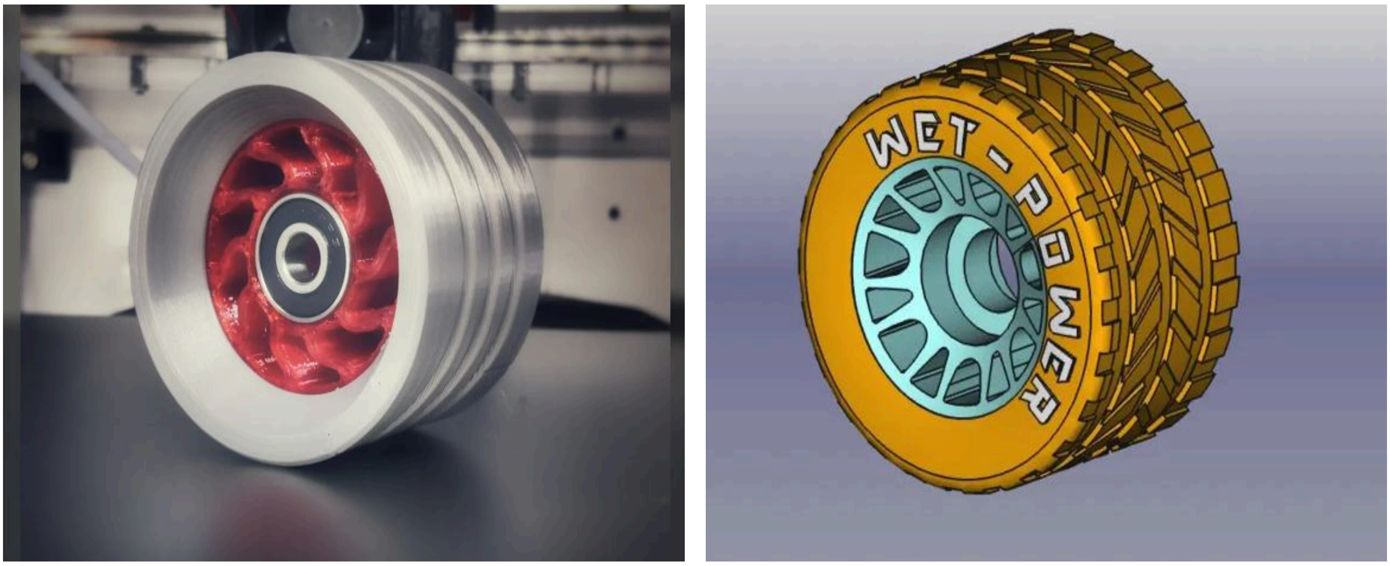


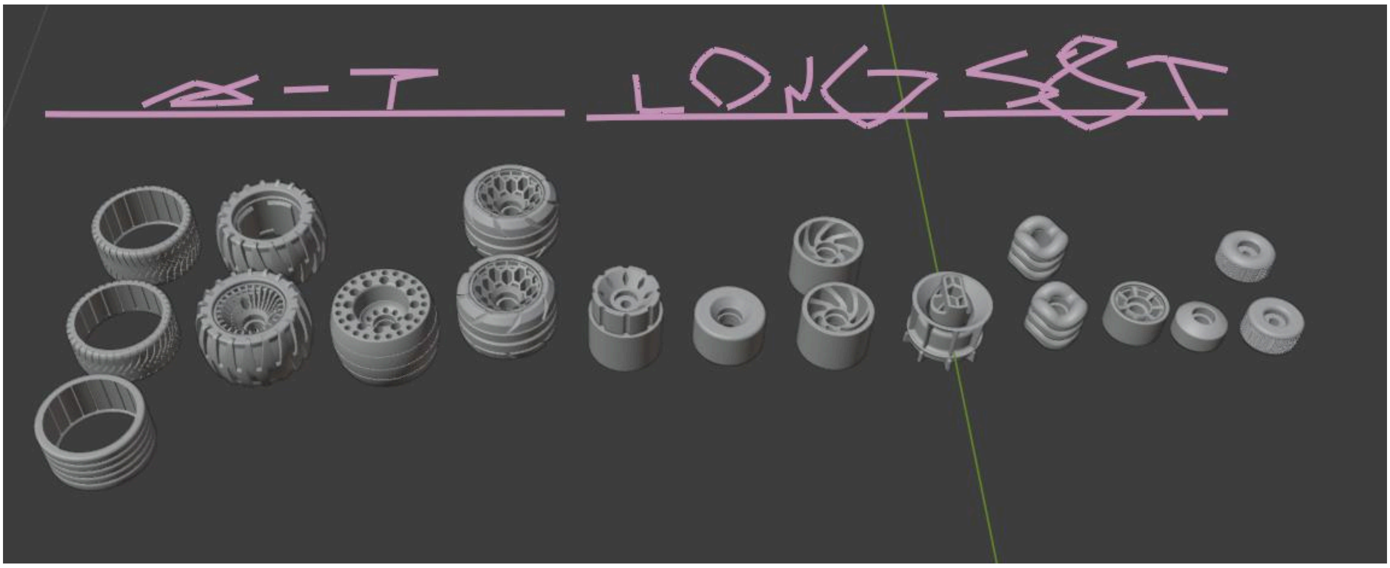
Img. 27 - Skate Break, by Swatch and ZengaBros.

The Skate Break environment integrates desks, lounge seating, and meeting tables that transform into ramps and ledges, as well as lighting elements and vehicles adapted for skating. Although initially conceived for an individual user, the project's relevance lies in its reliance on accessible manufacturing methods, enabling potential reproduction and scalability.

At the scale of individual artifacts, a similar approach emerges through the fabrication of custom skate hardware using diverse materials and techniques. Projects shared through social media platforms and online forums foster community engagement and knowledge exchange. While some experiments prioritize aesthetic or conceptual exploration, others focus on functional and technical performance [4].

Digital fabrication communities, such as MakerWorld, further extend these practices by leveraging advances in 3D printing to produce functional skate components. These projects explore complex geometries and unconventional materials that are difficult to achieve through traditional industrial processes. Following an analysis of diverse open-source projects, a curated collection of wheel designs was developed, categorized according to use: all-terrain wheels, longboard freeride wheels, and skateboard wheels for street and park applications [5].





Img. 28 - 3D printable wheels, on Printables. / Img. 29 - Collection of printable wheels, picture by the author.

2.1.2 - High-school experiments vs. mass production

An illustrative example of bio-fabrication at an experimental scale is the project **Grow It Yourself**, developed by Babette Hendryckx and shared on the Instructables platform. Conceived as a high-school assignment, the project explores collaboration with living organisms through the fabrication of a Penny-style longboard deck using mycelium. Organic substrates such as hemp, hay, and coffee grounds were combined with fungal roots inside a mold, allowing the mycelium to grow and bind the structure. After full colonization, the material was heat-treated to halt biological activity while preserving structural integrity. [6]

The wheels were produced using a similar process but required the addition of epoxy resin to maintain shape and abrasion resistance. While the artifact lacks the durability and performance required for practical use, it demonstrates the regenerative potential of mycelium-based materials. Although principles of circular economy are partially addressed through material selection, the reliance on epoxy resin limits overall sustainability.
Scaling bio-fabrication for market applications presents challenges related to efficiency, structural integrity, cost, accessibility, and environmental performance.

Img. 30 - Fungi wheels and board, produced by Babette Hendryckx.

In contrast to experimental artifacts, recent industrial initiatives adopt more integrated approaches. The French company **Koz** produces biodegradable and bio-sourced surfboards using mycelium as a substitute for polystyrene, combined with flax fibers and biodegradable resins. This strategy enables the product to fully reintegrate into natural systems at the end of its lifecycle [7].

Similar initiatives, such as **Shroomery Boards**, remain in prototyping stages yet demonstrate strong potential to reduce environmental impact while competing with conventional manufacturing [8]. A mature example is **Mogu**, an Italian company producing insulation panels and interior coatings based on mycelium networks. These products address performance requirements such as acoustic insulation and fire resistance while remaining regenerative and aligned with circular economy principles [9].

Img. 31 - Mycelium surfboards, by Koz Surfboards (up). Mycelium hand pads, by Shroomery Boards (down).

Generally sound isolating have a spongy made of natural materials (wood, linoleum, canvas, jute, coconut fibre) or acrylic-based, but Mogu decided to use **Mycelium** not only for its biodegradable aspect, but for being regenerative, thus minimizing material exploitation and aligning with a circular economy. Its low technological requirements make the process scalable and accessible.

A comparative mapping was developed to identify gaps within the wheel industry for technical sports. By analyzing innovation potential and production scale, trends reveal increasing interest in bio-based materials, limited scalability of recycling initiatives, and high industrial investment requirements for advanced composites. Mycelium-based composites emerge as a frontier between sustainability and performance.

Img. 32 - Sound panels, by Mogu.

After observing this trend's mapping it reveals a clear opportunity gap in the High Innovation + Industrial Manufacturing quadrant for biodegradable and regenerative materials, one that the research on mycelium + bioplastic composites and bio-based resins has the potential to fill.

Collaboration with Mogu included material testing for potential application in skate wheels and longboard decks. The results indicated insufficient tear strength and shear resistance for downhill freeride applications, highlighting the need for further advancements in bio-resins and composite formulations.

Img. 33 - Fungi board samples, by Mogu.

2.1.3 - Exploring field

Intersecting the study cases presented in the previous sections reveals a persistent gap in the production of skate and longboard paraphernalia oriented toward sustainability. While DIY practices, bio-fabrication experiments, and industrial initiatives demonstrate growing awareness of environmental impact, they often remain fragmented—addressing either material innovation, production methods, or user experience in isolation. To better understand this landscape, an analysis was conducted considering material consumption (lifespan), production techniques, recyclability and circularity, resource use, and production cost. This investigation highlights the necessity for integrated solutions capable of balancing high-performance requirements with environmental responsibility.

Within this context, three initiatives developed in academic and research environments connected to Politecnico di Milano were examined. These projects—Delta 9, DAFF, and Sprint3D—explore alternative materials, fabrication processes, and system-level approaches to skate-related products. Although differing in scale and focus, they collectively offer valuable insights into constraints and opportunities relevant to the present research.

Img. 34 - Delta-9, by Gabriele Basei.

Delta 9

Delta 9 is a research-driven project developed within Polifactory that explores the use of hemp-based composites as an alternative material for product design, including applications related to skate culture [10][11]. Hemp is characterized by rapid growth, low water requirements, and high carbon sequestration potential, positioning it as a promising bio-based resource for sustainable manufacturing.

From a material perspective, hemp fibers offer favorable mechanical properties such as tensile strength and flexibility, making them suitable for composite structures. In Delta 9, these properties are leveraged to demonstrate how agricultural waste and renewable fibers can replace conventional petrochemical materials. However, the project remains largely conceptual and prototypical, highlighting challenges in standardization, consistency, and scalability when transitioning from experimental composites to high-stress applications such as skate equipment.

For this thesis, Delta 9 illustrates the opportunity of bio-based fibers as structural components while simultaneously exposing a key constraint: the difficulty of achieving predictable performance and durability without hybridization with synthetic resins or advanced processing techniques. This insight reinforces the need to carefully balance bio-content with mechanical reliability, particularly for safety-critical components like wheels.

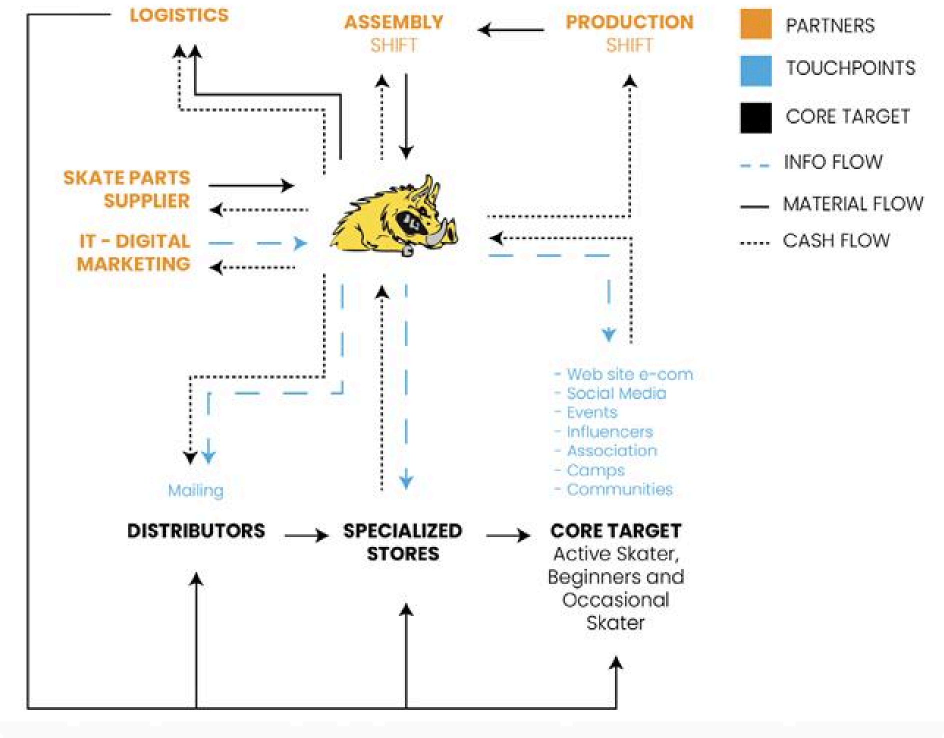
Img. 35 -Delta-9 by Gabriele Basei, source: Polifactory.

DAFF

The project DAFF, developed as a Product-Service System (PSS) thesis at Politecnico di Milano, investigates the transformation of a skate brand into a startup through a sustainable and experience-oriented approach [12]. Rather than focusing solely on material substitution, DAFF adopts a systemic design perspective, integrating product development, user interaction, and service components into a cohesive model.

In the context of sustainability, DAFF emphasizes lifecycle thinking, user engagement, and lean production strategies to reduce waste and optimize resource use. The project demonstrates how sustainability can be embedded not only in material choices but also in business models, distribution strategies, and user relationships.

However, while DAFF successfully addresses systemic sustainability, it does not deeply engage with material innovation at the component level. For the purposes of this research, the project highlights an important opportunity: combining system-level sustainability frameworks with material and mechanical experimentation. It also underscores a constraint, namely that without innovation in core components such as wheels or decks, broader sustainability strategies may remain limited in their material impact.



Img. 36 - DAFFY system map in the scale up phase, by Giacomo Rho.

Sprint3D

Sprint3D explores the use of additive manufacturing to produce skateboard wheels with customized geometries and performance characteristics [13]. By leveraging 3D printing technologies, the project investigates rapid prototyping, localized production, and design flexibility as alternatives to traditional mass manufacturing.

The primary contribution of Sprint3D lies in its exploration of geometry-driven performance optimization and decentralized production models. Additive manufacturing enables the creation of complex internal structures and profiles that are difficult or impossible to achieve through conventional molding processes. This aligns with broader sustainability goals by reducing tooling waste and enabling on-demand production.

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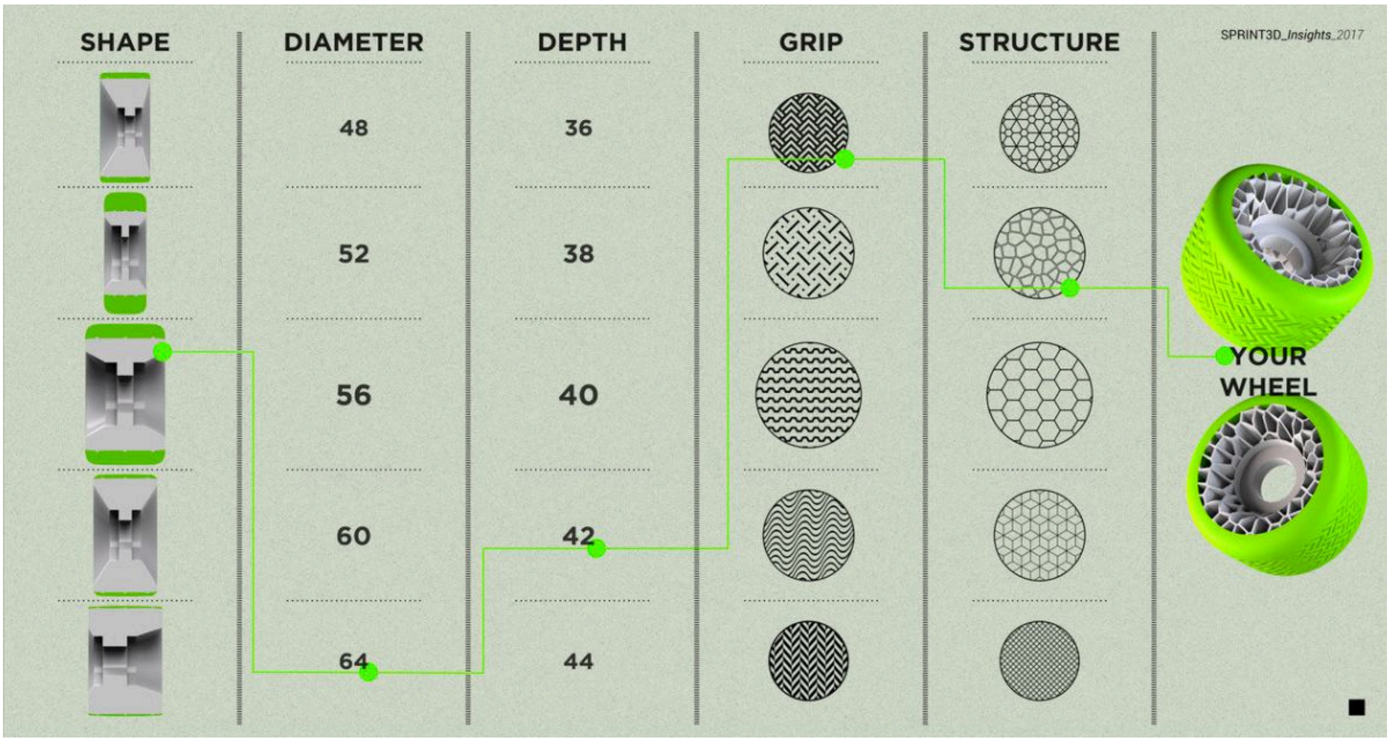

Img. 37 - Sprint3D variation frame, by Carlo Maestri.

Sprint3D

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Img. 38 - Sprint3D wheel, by Carlo Maestri.

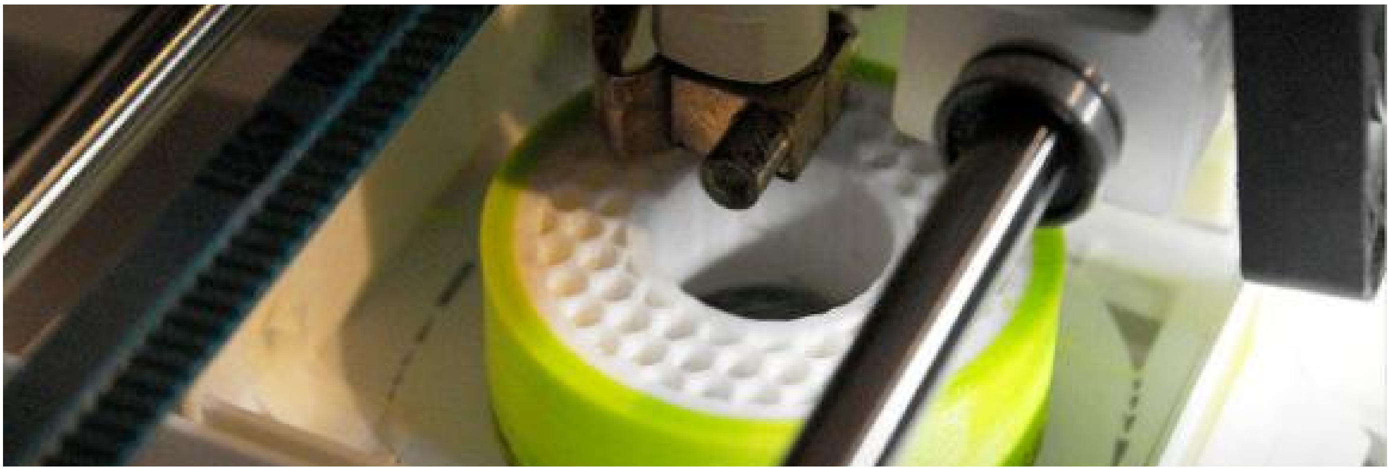
Nevertheless, the project also exposes critical limitations. The materials commonly used in additive manufacturing for elastomeric components often lack the abrasion resistance, rebound performance, and longevity required for real-world skate applications. As a result, Sprint3D remains closer to a proof of concept than a market-ready solution.

For this thesis, Sprint3D provides valuable insight into the potential of geometry optimization and digital fabrication, while reinforcing the constraint that material performance remains a decisive bottleneck. This reinforces the relevance of hybrid approaches that combine digital design freedom with advanced, possibly bio-based, material systems.

Synthesis: Constraints and Opportunities

Collectively, these three initiatives demonstrate that sustainable innovation in skate and longboard equipment can emerge from multiple entry points: bio-based materials (Delta 9), systemic design (DAFF), and advanced fabrication technologies (Sprint3D). However, none of them independently resolves the central challenge addressed in this thesis: achieving a balance between performance, durability, and environmental integration in high-stress components such as wheels.

The key opportunity identified lies in integrating these approaches—combining bio-based or regenerative materials with geometry-informed design and lifecycle-oriented systems thinking. At the same time, the constraints observed—material inconsistency, limited abrasion resistance, and scalability challenges—define clear research boundaries. These insights directly inform the direction of the present thesis, positioning it within the intersection of material research, mechanical performance, and ecosystem-oriented design.

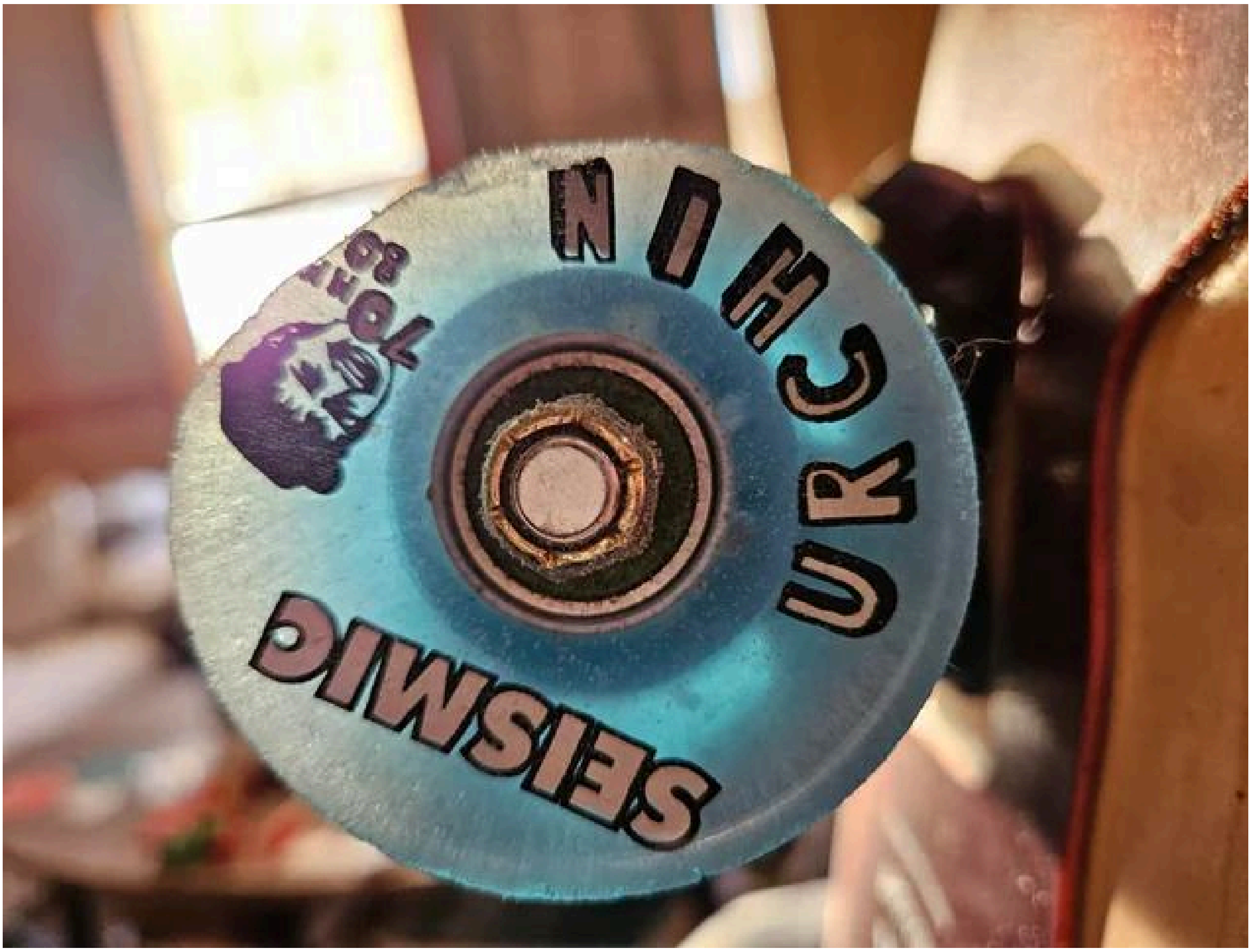


Img. 39 - 3D printing Sprint3D, by Carlo Maestri.

2.2 - Different alternatives for minimalizing environmet impact

Downhill freeride developed as a technically demanding discipline that incentivized innovation in wheel materials and manufacturing processes. The transition from early rigid polymers to modern polyurethane formulations significantly improved vibration damping, predictability, and safety at high speeds. As performance limits increased, wheel wear emerged as a critical issue affecting both usability and environmental impact [14].

Minimizing material loss from abrasion extends functional lifespan and reduces replacement frequency, thereby mitigating resource consumption and waste. The following sections examine mechanical, geometric, and material strategies aimed at reducing wheel wear while maintaining performance.

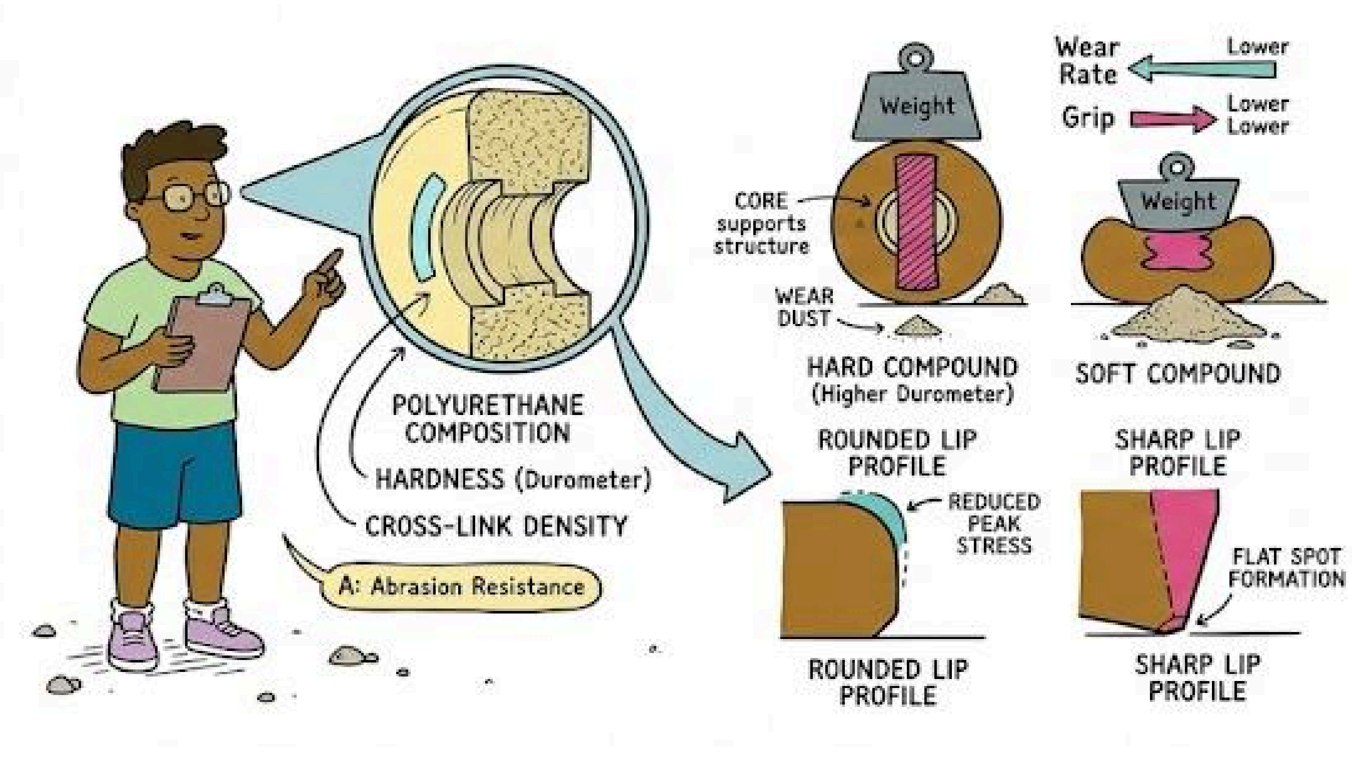


Img. 40 - Irregular worn of Seismic wheel.

2.2.1 - Assemblage or mechanical solutions

Material and Formulation Approaches.

The wear resistance of polyurethane wheels is directly influenced by the elastomer’s chemical composition, hardness, and cross-link density. Higher durometer (harder) polyurethane compounds tend to resist abrasive wear better than softer compounds, as they deform less under load, which reduces the rate of material loss during sliding and repeated contact with rough surfaces. Conversely, softer formulations offer greater grip but can wear more quickly under sustained stress [15]. Manufacturers experimentally balance these properties by tailoring polymer blends and additives to enhance abrasion resistance, resilience, and energy return, thereby extending wheel life before full replacement is necessary [16]. Additionally, the introduction of cores or hub designs that support the wheel structure reduces deformation under load and contributes to a more uniform stress distribution, which also slows wear progression [17].

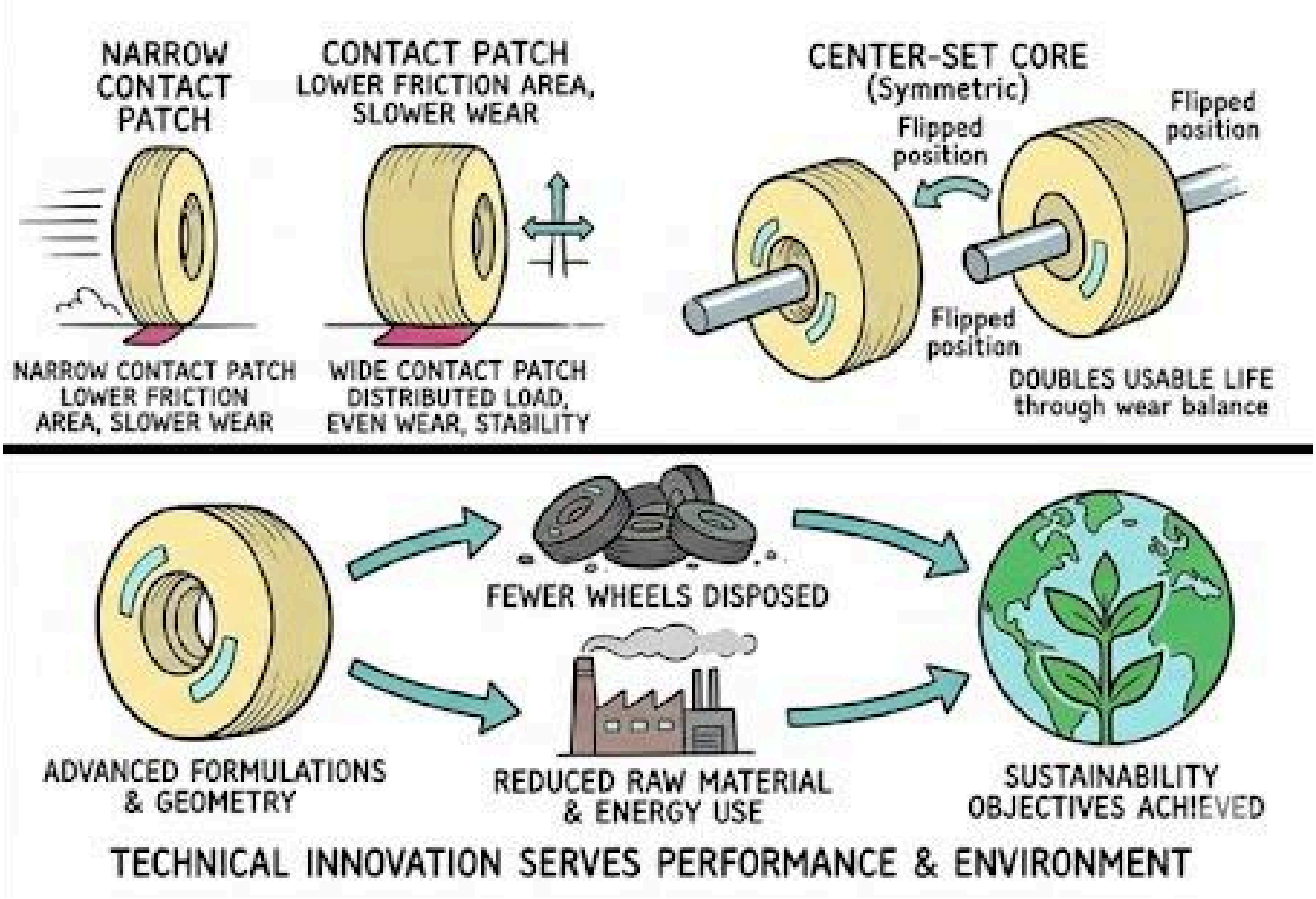


Img. 41 - Wheel waste scheme, AI generated.

Geometric and Profile Optimization.

Wheel geometry—including lip shape, contact patch width, and edge radiusing—fundamentally affects how load and friction forces are distributed across the wheel's surface. Rounded or radiused lip profiles decrease peak stress by minimizing large, abrupt contact areas during cornering or sliding, which in turn reduces localized wear and prevents the rapid development of surface irregularities such as flat spots [14]. Narrower contact patches can further diminish wear rates by lowering the total surface area under friction, though at the cost of reduced traction in some conditions. In contrast, wheels designed with larger contact patches distribute load over a broader footprint, enhancing stability while encouraging even wear patterns; such designs are particularly favored in downhill applications [18].

Another engineered solution for wear mitigation is the use of symmetric core placements (e.g., centerset cores) that allow wheels to be flipped on the axle when one side wears excessively, thereby doubling the usable life of the wheel assembly through balanced wear distribution [19].



Img. 42 - Wheel waste scheme, AI generated.

Linking Performance Optimization to Sustainability.

These material and geometric strategies not only optimize performance but also align with sustainability objectives. By increasing wheel resistance to abrasive wear and extending service life, fewer wheels must be manufactured and disposed of over time—thereby reducing raw material consumption, energy use in production, and waste generation. Collectively, the integration of advanced formulations and geometry-informed design exemplifies how technical innovation can serve both performance and environmental stewardship in the context of wheel-intensive sporting equipment.

Img. 43 - Sustainable wheel representation, AI generated.

2.2.2 – Shark Wheels Case Study

This section analyzes Shark Wheels as a case study of geometric innovation aimed at minimizing wheel wear and extending service life. Unlike conventional cylindrical wheels, Shark Wheels employ a non-circular, sinusoidal geometry often described as a helical or wave-shaped profile. This configuration alters the wheel–ground interaction by creating multiple sequential contact points rather than a single continuous contact patch, redistributing frictional forces during motion [20].

From a mechanical perspective, the alternating geometry reduces localized stress concentration on the wheel surface, which is a primary contributor to abrasive wear and flat-spot formation in traditional wheels. Laboratory and field testing conducted by the manufacturer, as well as independent mechanical evaluations, indicate that Shark Wheels demonstrate increased resistance to uneven wear patterns and improved durability under comparable riding conditions [21]. Comparative tests against conventional polyurethane wheels of equivalent diameter and durometer have reported wear resistance improvements of approximately 15 %, alongside enhanced rebound efficiency and reduced rolling resistance [22].

Img. 44 - Shark Wheels, by Shark Wheels.

The wave-shaped profile also introduces a lower effective approach angle when encountering surface irregularities, facilitating smoother transitions over debris and uneven terrain. This characteristic contributes to reduced impact stress and vibration transmission, factors that are known to accelerate material fatigue and surface degradation [20][23]. As a result, the wheel's usable lifespan can be extended without relying solely on changes in material formulation.

However, the Shark Wheels solution involves certain trade-offs. The unconventional geometry produces a riding sensation that differs from traditional wheels and may not be optimal for all disciplines or user preferences, particularly in applications requiring high precision or predictable lateral sliding behavior [24]. Additionally, manufacturing complexity and niche adoption may limit scalability when compared to standardized circular wheel designs.

From an environmental standpoint, the Shark Wheels approach aligns with sustainability principles by emphasizing lifespan extension through geometric optimization. By reducing wear rates and delaying replacement cycles, this design strategy contributes to lower material consumption, reduced manufacturing demand, and diminished waste generation over time.

Img. 45 - Shark Wheels, by Shark Wheels.

2.2.3 – Ecourethane

Ecourethane represents a material-based strategy aimed at reducing the environmental impact of polyurethane wheels through the partial substitution of fossil-derived components with renewable bio-based inputs. Conventional polyurethane elastomers used in wheel manufacturing are predominantly synthesized from petroleum-based polyols. In contrast, Ecourethane formulations incorporate plant-derived polyols—most commonly soy-based oils—into the polymer matrix, reducing dependence on non-renewable resources [25].

Studies on bio-based polyurethane systems indicate that the inclusion of soy-derived polyols can significantly lower fossil fuel consumption and greenhouse gas emissions associated with material production. Reported data from soy-based polyurethane applications demonstrate reductions of up to 61 % in petroleum usage and approximately 30–36 % in associated carbon emissions when compared to fully petrochemical equivalents [26]. While exact formulations remain proprietary, skateboard and longboard wheel manufacturers utilizing Ecourethane have historically reported renewable content levels ranging between 30 % and 50 % of the total polyol composition [27].

Img. 46 - Sucrose Initiative, by Arbor.

In addition to material sourcing, Ecourethane wheels are often paired with mechanical design strategies—such as center-set cores—that allow wheels to be periodically rotated, promoting uniform wear distribution and further extending functional lifespan [18]. This combination of material innovation and design optimization enhances the overall sustainability profile by reducing replacement frequency and associated environmental burdens.
Despite these advantages, Ecourethane presents important limitations. Although it incorporates renewable content, it remains a polyurethane-based elastomer and is not fully biodegradable under natural conditions. End-of-life disposal therefore continues to pose environmental challenges unless recycling or controlled degradation processes are implemented. Furthermore, the availability and agricultural impact of bio-based feedstocks introduce additional considerations related to land use and resource competition [28].

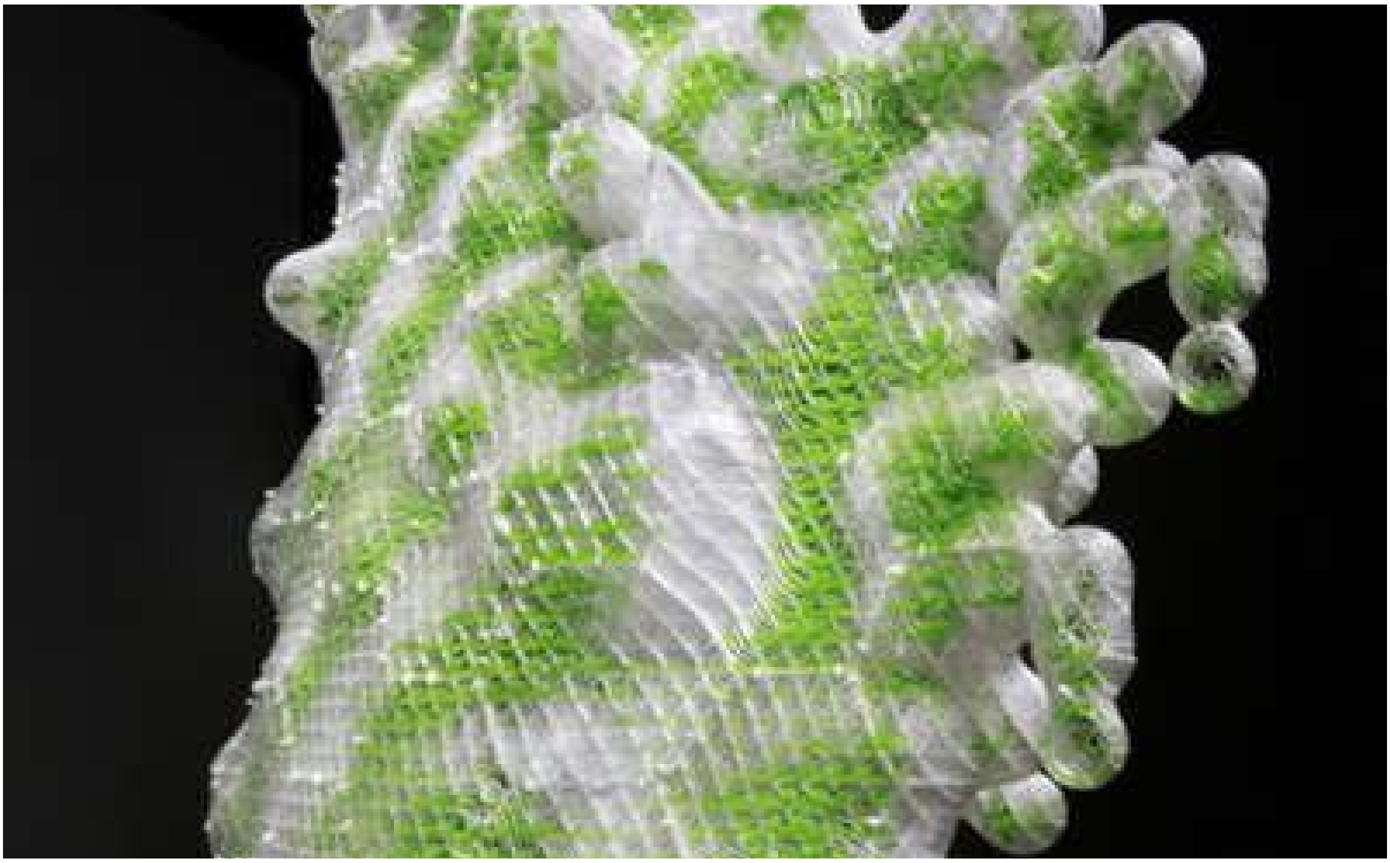
Overall, Ecourethane demonstrates how incremental material innovation can contribute meaningfully to sustainability goals, particularly when combined with wear-minimizing design strategies. However, it should be regarded as a transitional solution rather than a complete substitute for fully circular or biodegradable material systems.

Img. 47 - Ecourethane, by Roundhouse.

2.3 - Producing for a connected environment

Building upon the mechanical and material strategies discussed in Section 2.2, this section shifts the focus from isolated technical solutions to a broader systemic perspective on design and production. Sections 2.2.1, 2.2.2, and 2.2.3 demonstrate that minimizing wheel wear and mitigating environmental impact can be addressed through geometry optimization, material innovation, and lifespan extension. However, these approaches largely operate within existing industrial paradigms, addressing symptoms of environmental pressure rather than questioning the underlying relationships between production, use, and ecosystems.

To move beyond incremental optimization, it becomes necessary to reconsider how designed objects relate to their environments, users, and material cycles. This transition introduces a conceptual framework in which products are no longer treated as autonomous artifacts but as active participants within interconnected ecological, social, and material systems. In this context, the principles outlined in Deep Green by Claudia Pasquero and Marco Poletto provide a relevant theoretical foundation for rethinking design practices toward more regenerative and relational models.



Img. 48 - Bio structures for architecture landscapes, in Deep Green.

2.3.1 – Deep Green: Shifting Design Paradigms Toward Ecosystem Thinking

In Deep Green, Pasquero and Poletto propose a fundamental shift in design thinking, moving away from linear, object-centered paradigms toward systems that are adaptive, relational, and embedded within ecological processes [29]. Rather than conceiving design as the creation of isolated products optimized for performance and efficiency, the authors argue for an approach in which artifacts are understood as nodes within larger networks of material flows, biological cycles, and human practices.

Central to this framework is the concept of interconnectedness, where materials, users, environments, and technologies co-evolve over time. Design is reframed as an act of facilitating relationships rather than imposing fixed forms. This perspective aligns with biological systems, where resilience emerges from diversity, feedback loops, and continuous adaptation rather than from static optimization [29].

Applied to the context of skate and longboard equipment, this paradigm challenges conventional assumptions about durability and sustainability. Instead of merely extending lifespan through harder compounds or alternative geometries, a Deep Green approach encourages the exploration of materials that grow, regenerate, or reintegrate into natural cycles, as well as design strategies that acknowledge wear as a meaningful interaction rather than solely as degradation. The earlier discussion on mycelium-based materials, DIY practices, and bio-fabrication experiments resonates strongly with this framework, as these initiatives already blur the boundary between making, growing, and using.

Furthermore, Deep Green emphasizes the importance of local conditions, accessible technologies, and participatory processes, all of which echo the DIY ethos present in skate culture. By valuing adaptability and open-ended evolution over standardized mass production, this approach supports the development of artifacts that are responsive to specific environments and communities rather than universally optimized but ecologically detached.

2.3.2 – Opportunity to Grow: Expanding a Bio-Design Approach

The convergence of wear-minimization strategies, bio-based materials, and ecosystem-oriented design principles reveals a clear opportunity for future development. As demonstrated throughout this chapter, current solutions tend to address isolated stages of the product lifecycle—performance during use, material sourcing, or durability—without fully integrating production, usage, and end-of-life within a coherent regenerative system.

This research identifies a gap for design interventions that operate between technical performance and ecological integration, particularly in the domain of high-performance sports equipment. The skate wheel, as a consumable yet safety-critical component, represents a compelling test case for exploring how bio-design principles can be scaled beyond experimental artifacts while maintaining functional reliability.

By adopting a Deep Green perspective, future work can investigate hybrid systems in which material growth, mechanical design, and user interaction are co-developed. This may include the exploration of composite bio-materials that balance abrasion resistance with biodegradability, modular systems that encourage repair and material recovery, or production models that integrate local fabrication and circular material flows.

Rather than positioning sustainability as a constraint, this approach reframes it as a driver of innovation, capable of generating new forms, practices, and relationships between riders, materials, and environments. In doing so, it lays the conceptual groundwork for the following chapters, where design experimentation and material research aim to translate these principles into tangible, testable outcomes.

Img. 49 - Deep Forest, in Deep Green.

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CHAPTER THREE:

GROWING MARKET

As competencies and performance levels in skateboard freeride evolve, new requirements emerge—not only for enhanced efficiency but also for novel user experiences and interactions. Digital fabrication and smart factories have increasingly influenced skateboard component production, enabling innovations that combine performance, sustainability, and personalization. This chapter analyses study cases illustrating these transformations and explores potential avenues for further innovation.

3.1 - Competitive Wheels Study Cases

Performance, consistency, and durability under high-speed freeride conditions dominate longboard wheel development, reflecting structured evaluation frameworks observed in market guides. Leading brands such as Powell Peralta, Sector 9, Arbor, and Orangatang command the market through advanced urethane formulas, core technologies, and slide predictability, targeting professional riders globally [1].

These dynamics indicate a maturing market where traditional leaders compete on urethane expertise, while emerging brands leverage affordability, sustainability, and customization to gain traction.

3.1.1 - Ranking Criteria Methods

Industry standards for evaluating wheels can be compound into five pillars:

1. Urethane Quality

consistency, bonding integrity, ovaling resistance, and core rigidity.

2. Innovation

novel core placements (offset, centerset), surface treatments, and ride-enhancing geometries.

3. Sustainability

bio-based content, recyclability, and overall lifecycle impact.

4. Value Proposition

durability relative to cost.

5. Company Values

rider support, community engagement, and ethical production practices.

Rider feedback and service metrics, while subjective, provide holistic validation when aggregated across multiple sources.

3.1.2 - Market Analysis: best downhill wheels

At the market's core of wheels, it is possible to see different well set brands competing in terms of performance and consistency in their formulas.

Powell Peralta leads with race-oriented Pasters (72mm, 81a) and technical Snakes (70mm, 81a), renowned for minimal ovaling, predictable slides, and 1-2 week lifespan under intensive pro use; their high-thane consistency suits aggressive downhill, commanding premium pricing ($70-90/set) [2]

Arbor specializes in Summit Daniel McDonald (71mm, 80a) with composite fiber offset cores resisting deformation for fast freeride; eco-materials like sucrose compounds position it as sustainable premium ($70-90) [3].

Orangatang excels via Happy Thane Caguama/Kegel (70mm, 82a/80a) for rough-road damping and grip modulation, premium construction ($80-100) targeting discerning downhill riders [4].

88 Wheels (Chinese entrant) provides budget freeride models (70mm, 82a) with precision-molded cores matching slide life of leaders at $30-50/set, gaining traction via volume production and affordability [5].

Blood Orange Morgan Wheels offers Morgan Pro series (70mm, 81a) with hybrid urethane providing smooth, chatter-free slides and extended wear life, gaining competitive freeride popularity at mid-premium pricing ($60-80/set) [6].

Sector 9 offers versatile Nine Balls (70mm, 78a) with cosmic cores for smooth roll-to-slide transitions, alongside Biothane soy-polyol wheels introducing sustainability without performance sacrifice; mid-range pricing ($50-70) appeals broadly [7]. In compensation the Butter Balls (70mm, 80a) are known to be very buttery, as the name says, and can last for two days on intense sessions on a summer day. This rapid deterioration, which makes riders frustrated because of its good performance, can equally cause issues to the environment if both consumption and production are mishandled.

Img. 55 - Biothane and Butterballs, by Sector 9.

Img. 50 - Pasters and Snakes, by Powell Peralta.
Img. 51 - Sucrose and Daniel McDonald, by Arbor.
Img. 52 - Caguama and Kegel, by Orangatang.
Img. 53 - Moon Walkers and McFly, by 88 Wheels.
Img. 54 - Morgan Pro Series, by Blood Orange.

3.2 - Manufacturing feasibility

Downhill and freeride wheel production typically uses polyurethane casting or injection overmolding around a prefabricated rigid core, employing two-component liquid polyurethane (polyol + isocyanate) with additives [9].

This method ensures strong bonding between the flexible outer tread and rigid core, providing structural integrity and bearing support. Post-pour curing, machining, and inspection verify adhesion, concentricity, shore hardness, surface finish, stiffness, and abrasion resistance, producing a durable product suitable for high-speed freeride demands.

3.2.1 - Parameters range for stable processes

Core Fabrication: Radial spokes, bearing seats (608 standard), and weight-relief holes designed via CAD; tool steel molds (P20/H13) for injection volumes >10,000 units [10].

Injection/Casting: Engineering plastics (PC, PA6/PA66) injected at 250–300°C, 80–120 MPa; aluminum cores die-cast at 650–700°C [9][11].

Cooling and Finishing: Water cooling to 40–60°C; post-processing includes CNC facing, deburring, surface roughening (Ra 1.6–3.2 μm) for PU adhesion [12].

Surface Preparation & Core Positioning: Grit-blasting, silane primers, concentricity <0.05 mm; mold preheated to 90–110°C [9][13].

Polyurethane Processing: Polyol/isocyanate mix (NCO:OH 1–1.2), chain extenders, catalysts, degassing; Shore A 85–98; antioxidants to extend life 20–30% [9][14].

Demolding & Finishing: Hydraulic ejection, lathe turning ±0.02 mm, chamfered lips, tread grooving; final inspection includes Shore A/D, micrometer, adhesion (>10 MPa), abrasion (<150 mm^3 loss) [9][10][11].

3.2.2 - Available and Innovative Technology

In today's industry, traditional manufacturing methods take the biggest stakes reinforcing similar paradigms to the latest century. Mass production, lower costs, quality control and exploration of natural resources combine the main attributes, while increasing environmental stress due to the reliance on finite resources. The current wheel's market relies almost completely on this approach, putting in perspective alternatives that distance from those methods more close to a contemporary issue than a comfortable surplusage [15].

Going in the opposite direction, digital fabrication and smart work focuses on long-term relations and benefits rather than immediate profit. Its characteristics goes much beyond personalized on-demand items, but to create an environment that stands out for a balanced relationship between human, nature and technology can coexist respecting each other's values. [16]

Img. 56 - Alluminium skate frame, by Quantum project.

An experimental application of additive manufacturing in skateboard components can be observed in the **Quantum project**, developed at UT El Retoño, which explores the use of **3D-printed metal structures for skate frames**.

By leveraging metal additive manufacturing, the project demonstrates how complex geometries, lattice structures, and weight-optimized forms can be integrated into a single component without the need for molds or subtractive machining. This approach highlights the potential for material efficiency, structural optimization, and design freedom, enabling configurations that are difficult to achieve through conventional fabrication processes.

While the current implementation appears more aligned with experimental prototyping than scalable industrial production, it illustrates how additive manufacturing can function as a proof of concept for future skateboard and longboard components, particularly in contexts where customization, rapid iteration, and reduced material waste are prioritized over mass production efficiency [17].

Additive manufacturing is one of its technological cores having attributes such as zero waste, material versatility, personalized on-demand and complex shapes. The production volume much lower than injection moulding or casting can be compensated for the needless to have a mould. Combining its potential with a bio-oriented production, whether assisted by living structures or thought to be biodegradable, can induce a more circular economy integrated with sustainable practices.

3.2.3 - Innovative Pathways

With the saturation of the traditional wheel’s market, shown by the extent of brands that compete for price, performance and duration, aspects such as personalization, sustainable cycles and different geometries started to be explored by new income brands.

A personalized wheel based on each user’s goals or needs can guarantee the desired experience while creating a pathway between user and producer, shortening the productive chain. This represents a significant link and facilitates on-demand fabrication, minimizing costs and stimulates the user perception over the wheel’s use and consumption.

Looking through different filters can help to develop a more coherent product for nowadays consumers. The sustainable spectre has been deeply issuing the consumption of fossil-based material, once its extraction heats up the climate change and puts in risk neighbour populations.

Aiming for bio-based and biodegradable materials helps to diminish the impact, but can’t supply the whole market chain, once its costly prices make them premium products with low access. In this way, a balance between production cost and consumption has to be found [18].

Beyond alternatives that aim for non-fossil materials, reusing or repurposing the wheels or its waste offers likewise a sustainable solution. Initiatives such as **Vans + Mentos** gum wheels concept suggests another interaction with waste. The company created a campaign where passersby are invited to glue chewed gums into a poster [19]. These discarded gums are then collected to be repurposed into skate wheels. Although this concept has little feasibility on the real market, it presents a shift by treating waste as a valuable resource.

Img. 57 - Skate Gum Wheel’s, by Vans and Mentos.

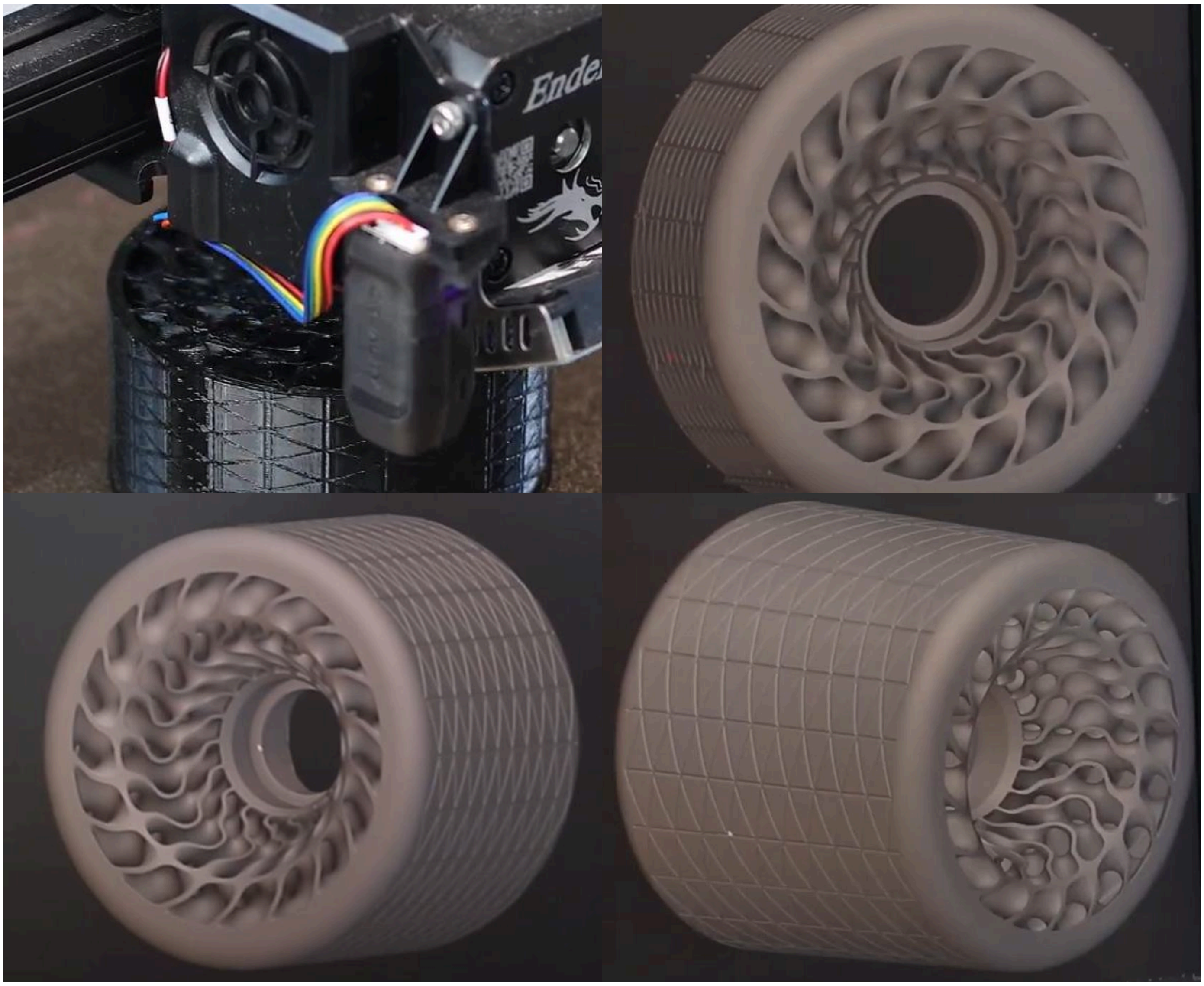
Another alternative was created by **Miracle.hardware**, a new income brand that increases the life span of wheels by offering a cover (40-55€) of soft polyurethane on them [20]. Adding this component to the wheel not only extends the wheel duration or gives a different experience by being produced for all-terrain , but creates another level of complexity with wheel artifacts. It highlights the importance of maintenance and preservation of an object that was initially thought to be disposable. Both of these examples are targeted in different ways on the production cycle, showing how versatile and challenging sustainability and circular economy approaches can be.

Img. 58 - Miracle wheels covers, by Miracle.hardware.

The last pointed out pathway takes alternative methods in its production, use and configuration. Brands that offer different kinds of geometries, enhancing different uses while maintaining consistency. Founded in 2013, **Shark Wheels** uses traditional manufacturing methods to display a more complex and versatile shape, marking the most recent radical innovation over skateboard wheels [21]. Its advantages go from increasing mechanical properties to prolong its life span. Through a sine wave shape and an approach angle of 30° it pushes small objects and debris out of the way, providing a smoother ride over rough pavements and wet conditions.

Img. 59 - Shark Wheels, by Shark Wheels.

A more recent experience was crafted to explore the constraints and opportunities of using additive manufacturing on the production of downhill wheels. **Extrudr**, a 3D printing company, decided to collaborate with a longboard athlete to test their wheels. The gyroid shape on the configuration provided dumping properties that are difficult to reproduce with traditional methods. To assure a durable and resistant to abrasion the selected material was TPU Flex Hard Carbon [22].



Img. 60 - 3D printed gyroid wheel, by Extrudr.

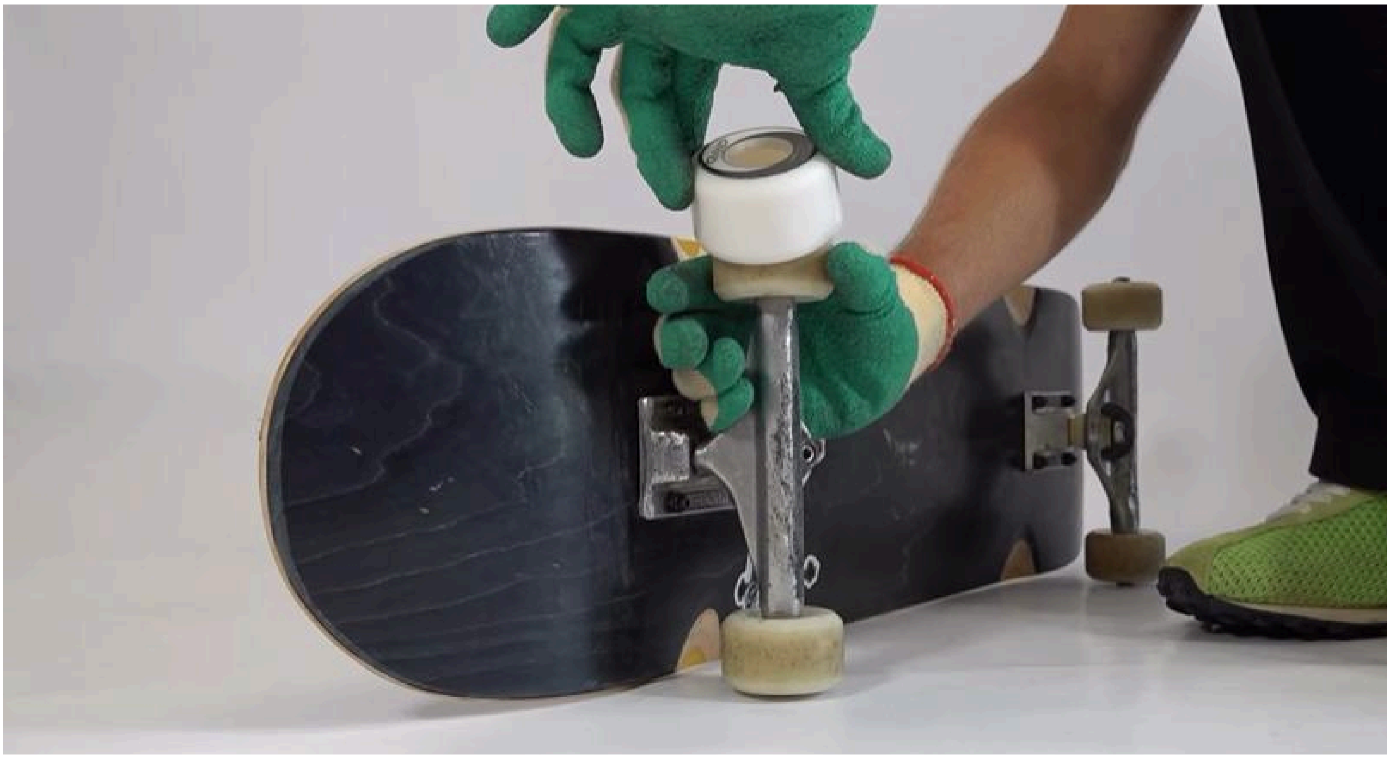
Innovating in shape and manufacturing can walk simultaneously towards a paradigm that's been envisioned over the past decade. This vision encapsulates the need for pushing limits and respecting its environment at the same time. The evolving technology opens new possibilities over shape and use, and in parallel, the sport is progressively taking new spaces and forms to interact, pushing the limits of digital fabrication and alternative materials to attend different conditions.

3.3 - Assembling systems

While skateboard and longboard wheels are traditionally conceived as monolithic components, emerging design approaches suggest that assemblage-based systems can introduce new functional, environmental, and experiential values. Assemblage in this context does not aim at complexity for its own sake; rather, it is justified only when it enables extended lifespan, modular repair, functional adaptability, or material optimization that cannot be achieved through single-piece manufacturing. This section explores existing assemblage strategies applied to wheels and wheel-related components, highlighting their benefits and limitations.

3.3.1 - Wheels assemblage systems

Conventional skateboard wheels are produced as single-piece polyurethane components, a choice driven by simplicity, durability, and cost efficiency. However, the introduction of auxiliary elements can redefine the role and lifecycle of the wheel within the skate system. A notable example previously discussed is the AMP Miracle cover wheel, which introduces a secondary polyurethane shell assembled over an existing wheel [20]. This solution establishes a dependency relationship between the cover and the original wheel, effectively shifting the wheel's purpose from a consumable object to a maintained core component.



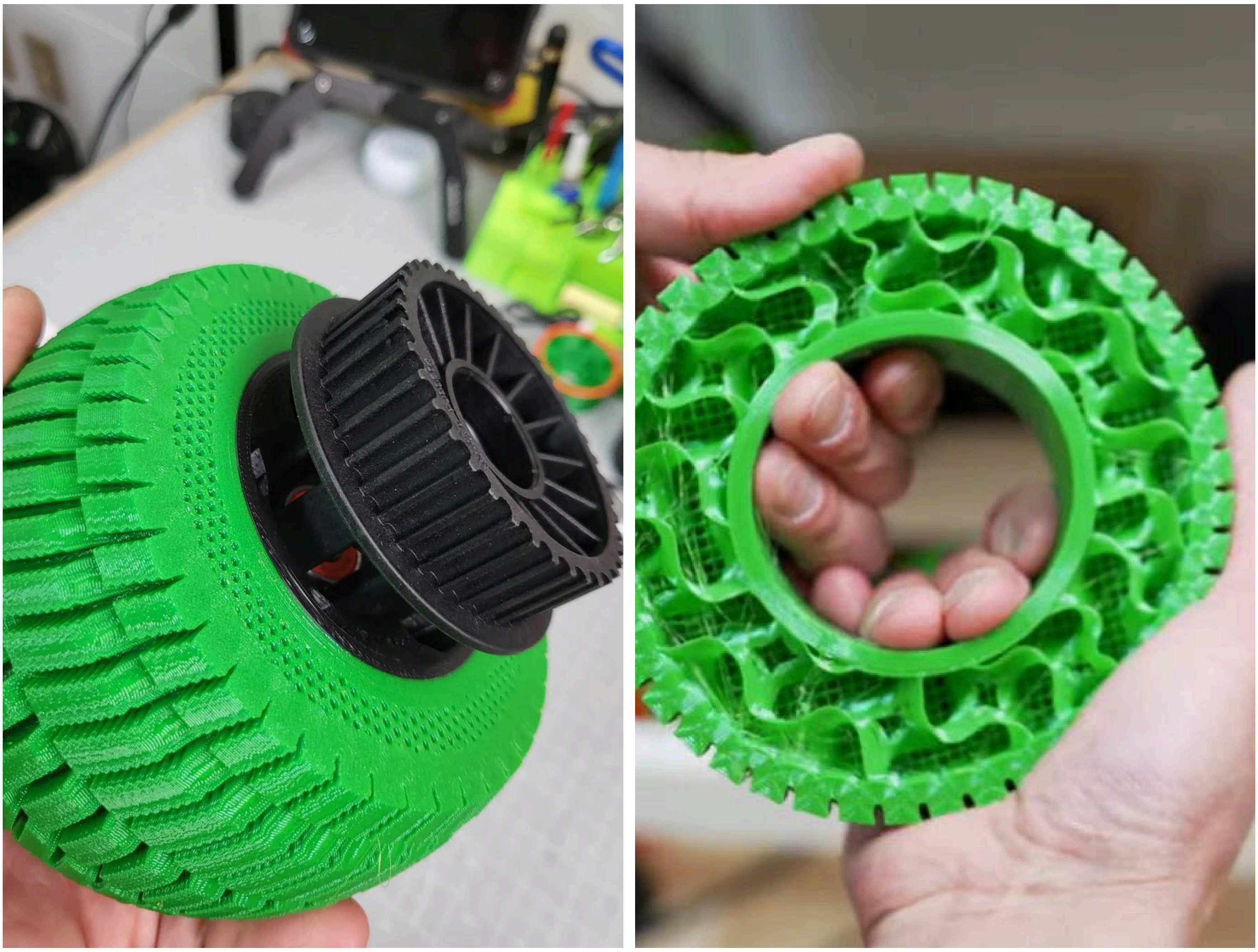
Img. 61 - Insertion of wheel cover, by Miracle.hardware.

3.3.2 - Longboard wheels assemblage systems

Unlike skateboard wheels, longboard wheels already incorporate an internal rigid core, making them structurally predisposed to assemblage-based solutions. This inherent modularity enables more advanced experimentation, particularly when combined with additive manufacturing technologies. An example of such an approach is the system developed by Dr. E, which proposes 3D-printed TPU wheels with a multi-part core assembly designed for electric longboards.

Img. 62 - 3D printed TPU wheels, by Dr. E.

In this system, the hub is fabricated from PLA and assembled from two threaded components, incorporating cantilever features that ensure mechanical fixation of the outer TPU tread. This configuration enables interchangeable tyres, allowing users to adapt the wheel to different terrains, riding conditions, or rider weights without replacing the entire assembly. While electric longboards remain less accessible than traditional setups, this case is significant for demonstrating how digital fabrication supports customization, repairability, and functional adaptability within wheel design [23].



Img. 63 - 3D printed TPU wheels assemblage and section, by Dr. E.

From a manufacturing perspective, such assemblage systems are particularly suited to low-volume, on-demand production, where the flexibility of additive manufacturing compensates for the lack of economies of scale. Although not immediately scalable for mass-market applications, these solutions illustrate how modularity and assemblage can open alternative pathways for innovation, especially in emerging or niche segments of the skating ecosystem.

3.4 - Assembly solutions

Building upon the analysis of materials, production logics, and assemblage systems presented in this chapter, it emerges that wheel design for skateboarding and longboarding is strongly constrained by performance requirements, while sustainability considerations are still marginal or fragmented.

The review of existing solutions highlights key opportunities for intervention, particularly in modularity, material replacement, and lifespan extension through assembly strategies. At the same time, it reveals structural limitations in current industrial practices, especially regarding recyclability and adaptability to different riding conditions.

These insights establish the foundation for the design exploration developed in the following chapters. Chapter 4 introduces an initial research trajectory grounded in symbiotic and bio-based production, supported by AI-assisted investigation. Chapters 5 and 6 then document the methodological pivot toward additive manufacturing as a viable pathway to reconcile performance, experimentation, and circular economy principles within wheel design.

Img. 64 - 3D printed TPU wheels texture, by Dr. E.

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CHAPTER FOUR:
SYMBIOTIC AI

This chapter documents the initial exploration of a symbiotic production approach aimed at integrating biological growth and circular economy principles into downhill freeride wheel design. Inspired by fungal networks and their capacity to generate structural systems through low-energy processes, the research initially investigated mycelium as a potential reinforcing element within a composite wheel structure.

Artificial intelligence tools were employed to support early-stage ideation, enabling rapid visualization of organic morphologies and material textures. This phase represents a speculative yet informed attempt to align performance-driven sports equipment with regenerative material systems.

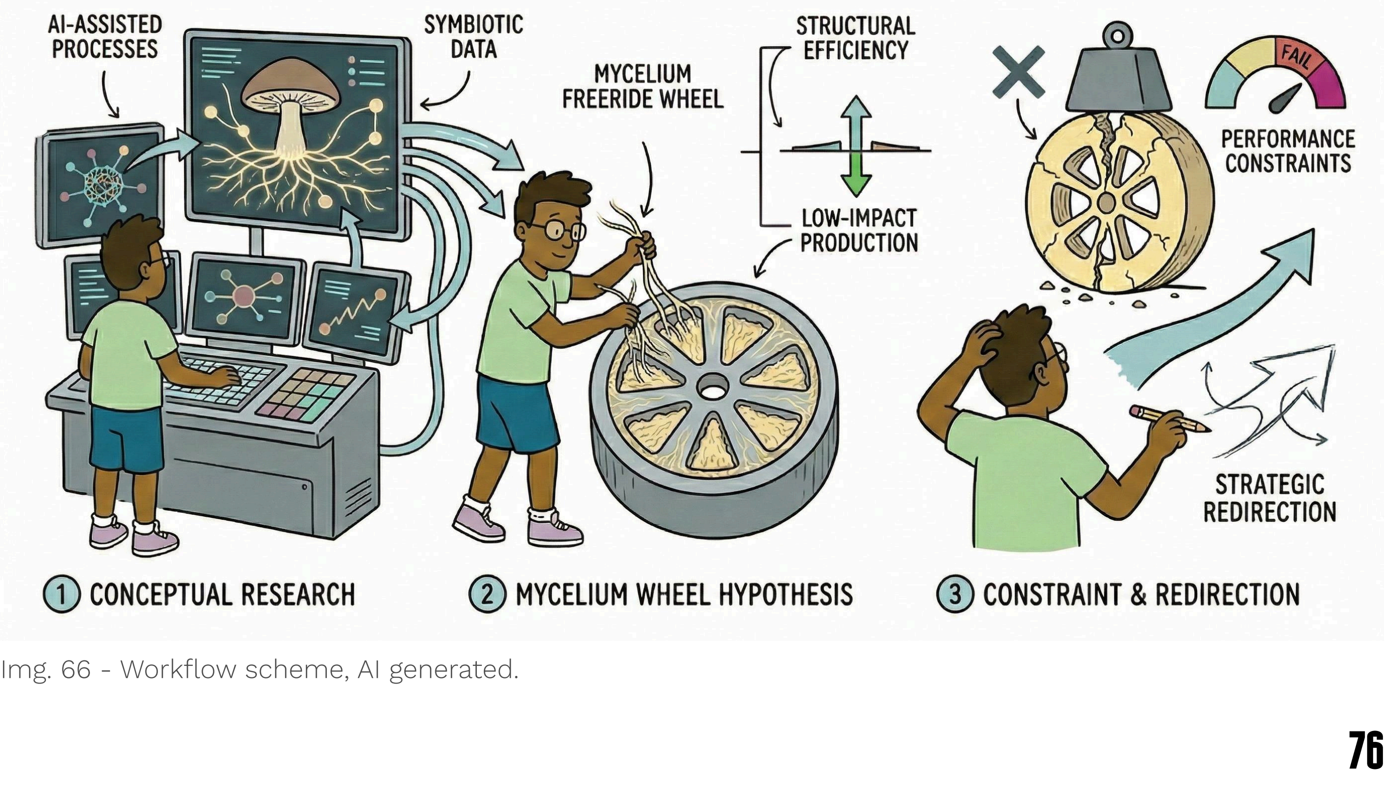
Img. 65 - Mushroom wheel, AI generated.

4.1 - Symbiotic Design and Circular Dynamics

This chapter frames the conceptual and material foundations that initially guided the project toward a symbiotic and biologically integrated manufacturing approach. The research explores how symbiotic design principles, circular economy strategies, and artificial intelligence–assisted processes can inform the development of sports equipment with reduced environmental impact.

Symbiotic design, in this context, refers to design approaches that leverage cooperative relationships between biological systems, materials, and technological processes, seeking mutual benefit rather than extractive exploitation [1]. Within circular economy frameworks, such approaches emphasize renewable resources, material regeneration, and lifecycle extension [2]. Recent research highlights how biofabrication and data-driven design tools can enable novel production paradigms where materials are grown, guided, or augmented rather than traditionally manufactured [3].

The initial hypothesis of this research positioned mycelium-based composites as a potential structural and functional material for downhill freeride wheels. This hypothesis was supported by emerging literature on fungal materials, their structural efficiency, and their low-impact production cycles. However, as discussed later in this chapter, material testing and performance constraints required a strategic redirection of the project.

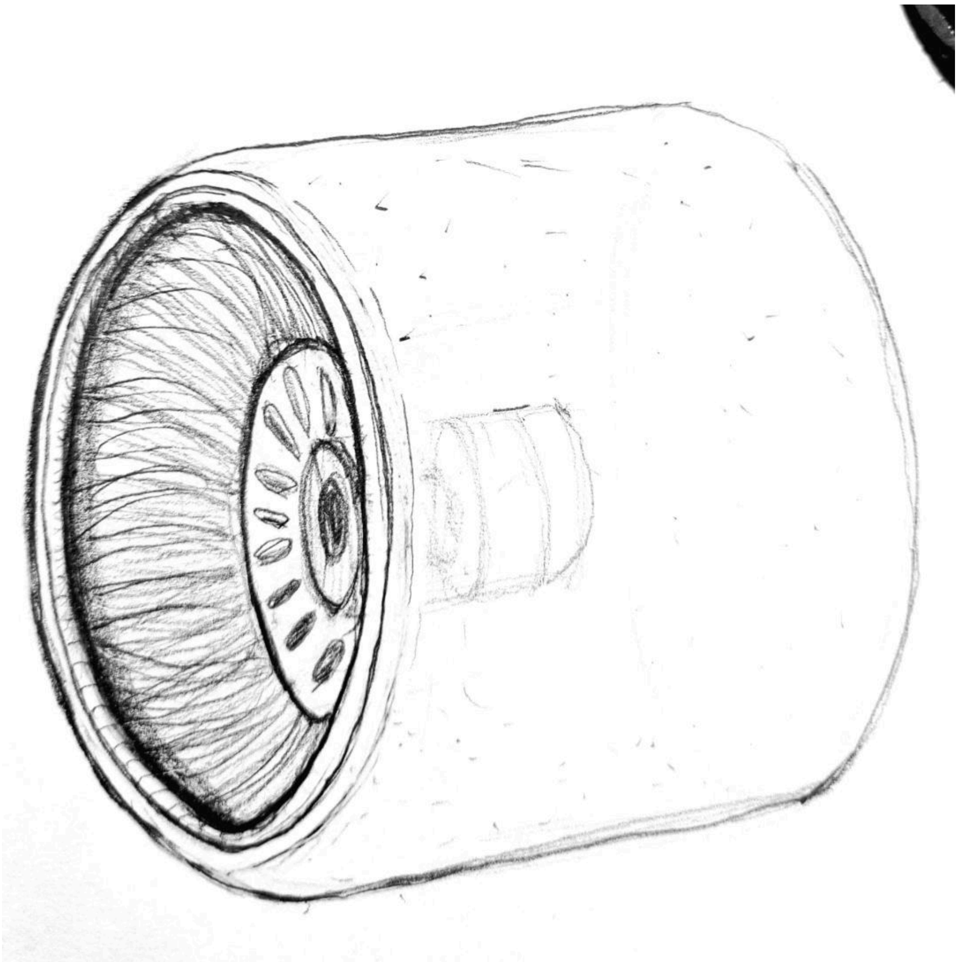


Img. 66 - Workflow scheme, AI generated.

4.2 - AI-Assisted Concept Generation

In early design explorations, AI-assisted generative tools were used to translate biological structures into visual and conceptual models for wheel design. Drawing inspiration from fungal networks and mycelium growth patterns through Sketch → AI workflows facilitated both analog and digital ideation. These methods enabled rapid visualization of complex topology without prescribing specific material or structural assumptions.

The platform used (Vizcom) supported an iterative design loop in which biological textures, forms, and material suggestions informed conceptual geometries that tensioned the boundary between natural morphology and engineered performance. Although not directly translatable to functional artifacts at this stage, these AI-supported models served as design probes that expanded the research understanding of potential forms and structural rhythms before material and mechanical constraints were introduced.



Img. 67 - Wheel sketch, picture by the author.

4.2.1 - Biological Growth as a Design Process

Biofabrication redefines production by shifting from subtractive or formative processes toward growth-based material systems, where biological organisms act as active agents in material formation. Mycelium—the underground network of fungi—has been extensively studied for its capacity to bind organic substrates into lightweight, structurally efficient composites [2].

Unlike conventional polymers or composites, mycelium materials grow through decentralized networks that adapt to environmental conditions, resulting in heterogeneous yet resilient structures. These characteristics have positioned mycelium as a promising candidate for applications in architecture, packaging, insulation, and product design, particularly where impact resistance, compressive strength, and low density are prioritized over tensile or shear performance [3].

Img. 68 - Fungi wheel, AI generated.

4.2.2 - Visual exploration through fungal morphologies

Artificial intelligence has increasingly been employed to analyze, interpret, and translate biological patterns into design data. Machine learning and generative algorithms enable the extraction of structural logics from natural systems—such as branching, porosity gradients, and fiber orientation—and their reinterpretation into manufacturable geometries [1].

In this project, AI tools were used as exploratory mediators, not as optimization engines. An initial sketch inspired by fungal growth patterns was processed through the Vizcom platform to generate concept models, using mycelial textures and morphologies as formal references.

This phase was not intended to produce a finalized geometry, but rather to establish a visual and conceptual language rooted in symbiosis, growth, and material intelligence.

Img. 69 - Fungi wheel, AI generated.

4.3 - Mycelium as Structural Material

Bio-based materials exemplify the potential for design to operate within circular and regenerative cycles rather than linear ones. Mycelium has garnered attention for its low-energy growth processes, biodegradability, and potential structural applications. Prior research and industrial precedents have shown that mycelium composites can be engineered for a range of mechanical properties, from insulating foams to rigid panels [4].

The research outcome highlights both the promise and the boundary of current bio-produced materials: while they embed ecological intelligence and offer regenerative end-of-life pathways, their mechanical performance must be matched to context.

Img. 70 - Fungi wheel, AI generated.

4.3.1 Mechanical Characteristics of Mycelium Composites

Despite their sustainability advantages, mycelium-based composites exhibit mechanical limitations that restrict their applicability in high-stress, dynamic environments. Literature consistently reports adequate compressive strength and energy absorption, but comparatively low shear resistance, tensile strength, and abrasion durability when subjected to repetitive mechanical loading [2] [3].

Downhill freeride wheels operate under extreme conditions, including high rotational speeds, lateral shear forces during slides, continuous abrasion against asphalt, and local thermal buildup. These requirements exceed the structural envelope within which current mycelium composites can reliably perform.

Img. 71 - Fungi wheel, AI generated.

This phase was not intended to produce a finalized geometry, but rather to establish a visual and conceptual language rooted in symbiosis, growth, and material intelligence.

4.3.2 - Collaboration with Mogu: material sampling and analysis

Img. 72 - Mogu material samples, picture by the author.

Following this theoretical assessment, Mogu—a company specializing in mycelium-based materials—was contacted to evaluate the feasibility of using their materials within the scope of the project. Technical datasheets, physical catalogues, and material samples were analyzed.

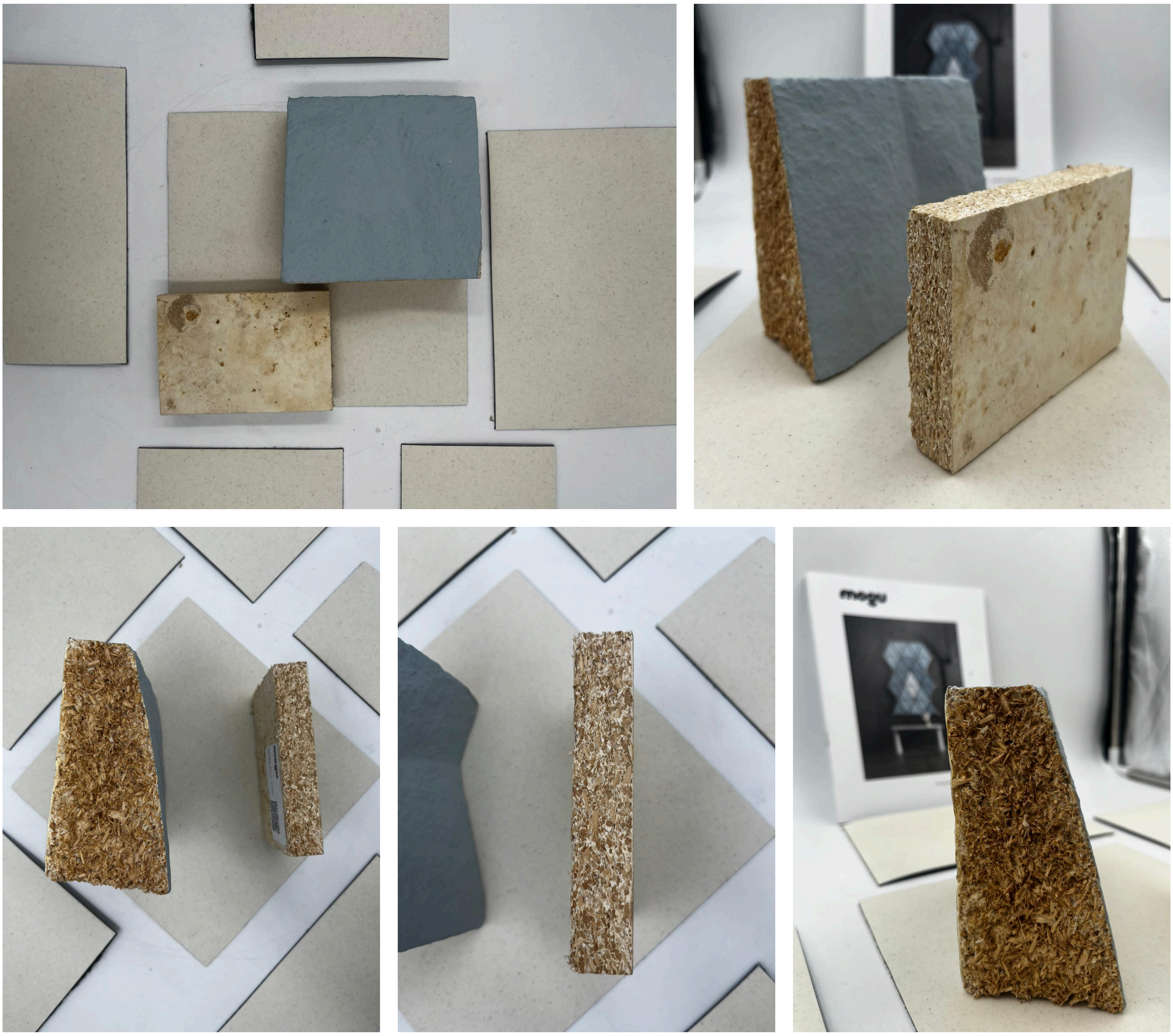
Mogu's bio-based products are primarily optimized for interior applications, offering advantages such as low VOC emissions, acoustic absorption, flexibility, and impact resistance, while complying with European standards for resilient flooring [4]. However, the data confirms that these materials are not designed to withstand high shear stresses or continuous abrasive contact.

As a result, it was concluded that mycelium composites were not suitable for wheel treads, but presented strong potential for other skateboard components, particularly decks and protective elements.
This realization marked a critical turning point, prompting a reassessment of manufacturing strategies while preserving the project's circular and symbiotic intent.

4.4 - Performance Constraints and Material Limitations

Mechanical testing and material observation revealed that, despite its favorable environmental profile, the mycelium-based composite **lacked sufficient shear resistance** to withstand the stresses generated during downhill and freeride practices on asphalt surfaces.

Conversely, the same material demonstrated promising behavior under compressive loads and impact absorption, exhibiting properties comparable to wood-based structures. This distinction proved critical in redefining the material's role within the project.



Img. 73 - Mogu material samples, picture by the author.

4.4.1 Shear Resistance and Technical Terrain Requirements

In freeride and downhill longboarding, shear resistance constitutes a primary functional requirement due to the intentional generation of lateral slip during slides and high-speed directional changes. Unlike cruising applications, where continuous grip is prioritized, freeride wheels are exposed to repeated tangential forces that induce controlled abrasion. These forces produce combined compressive, torsional, and shear stresses, requiring materials capable of maintaining structural coherence under cyclic lateral loading.

Thermoplastic elastomers typically used in skate wheels exhibit viscoelastic behavior, meaning their response to shear depends on strain rate, temperature, and deformation time [6]. Under technical terrain conditions—characterized by rough asphalt and heterogeneous aggregate—localized stress concentrations intensify wear mechanisms and surface degradation [7]. Furthermore, in additively manufactured polymers, internal layer orientation and structural anisotropy may influence resistance to transverse stresses, making mechanical consistency a relevant consideration in the definition of performance requirements.

From a product-design perspective, shear resistance must ensure predictable material consumption, stability at the bearing interface, and consistent behavior during progressive wear. Abrasion is intrinsic to freeride performance and therefore cannot be eliminated, but it must remain controlled and mechanically safe. Within a circular economy framework, durability under shear stress directly affects product lifespan and resource efficiency, reinforcing the necessity of defining this parameter as a foundational technical requirement for subsequent design development [5].

4.4.2 - Suitability for wheels vs boards

While unsuitable for wheels, mycelium materials demonstrate high relevance for components where impact damping, lightweight structure, and biodegradability are critical. Two application domains were identified:

A) **Longboard decks**, where mycelium composites can act as structural cores combined with fiber skins;

B) **Protective equipment**, such as helmet liners or padding elements, where energy absorption and controlled deformation are prioritized.

Img. 74 - Concept of board and protective equipment made from mycelium, AI generated.

These applications are explored conceptually in this chapter, serving as parallel demonstrations of symbiotic manufacturing potential beyond the wheel itself.

4.5 - Design Pivot: From Wheels to Structural Components

The combined insights from circular economy theory and symbiotic design thinking informed a strategic reorientation of the research. While mycelium composites offered valuable ecological metaphors and demonstrated potential in secondary applications (e.g., boards, insulation, protective foams), their limitations in freeride tread contexts necessitated a pivot toward a manufacturing alternative in which performance and sustainability could be more directly balanced.

Additive manufacturing via 3D printing emerged as a compelling alternative due to its:

i. **Reduced material waste** compared with subtractive processes

ii. Design freedom enabling **geometry optimization**

iii. Potential for **local, on-demand** fabrication

iv. Compatibility with **recyclable** and **bio-based** polymers

This pivot respects circular economy principles—reducing raw resource use, enabling tailored reuse (e.g., interchangeable treads, reusable cores), and emphasizing longevity—while acknowledging the current technological performance gap of purely bio-grown composites in high-stress mechanical contexts. The next chapter operationalizes this strategy by documenting experimentation with additive materials, parametric geometry testing, and criteria for validating performance against sustainability goals.

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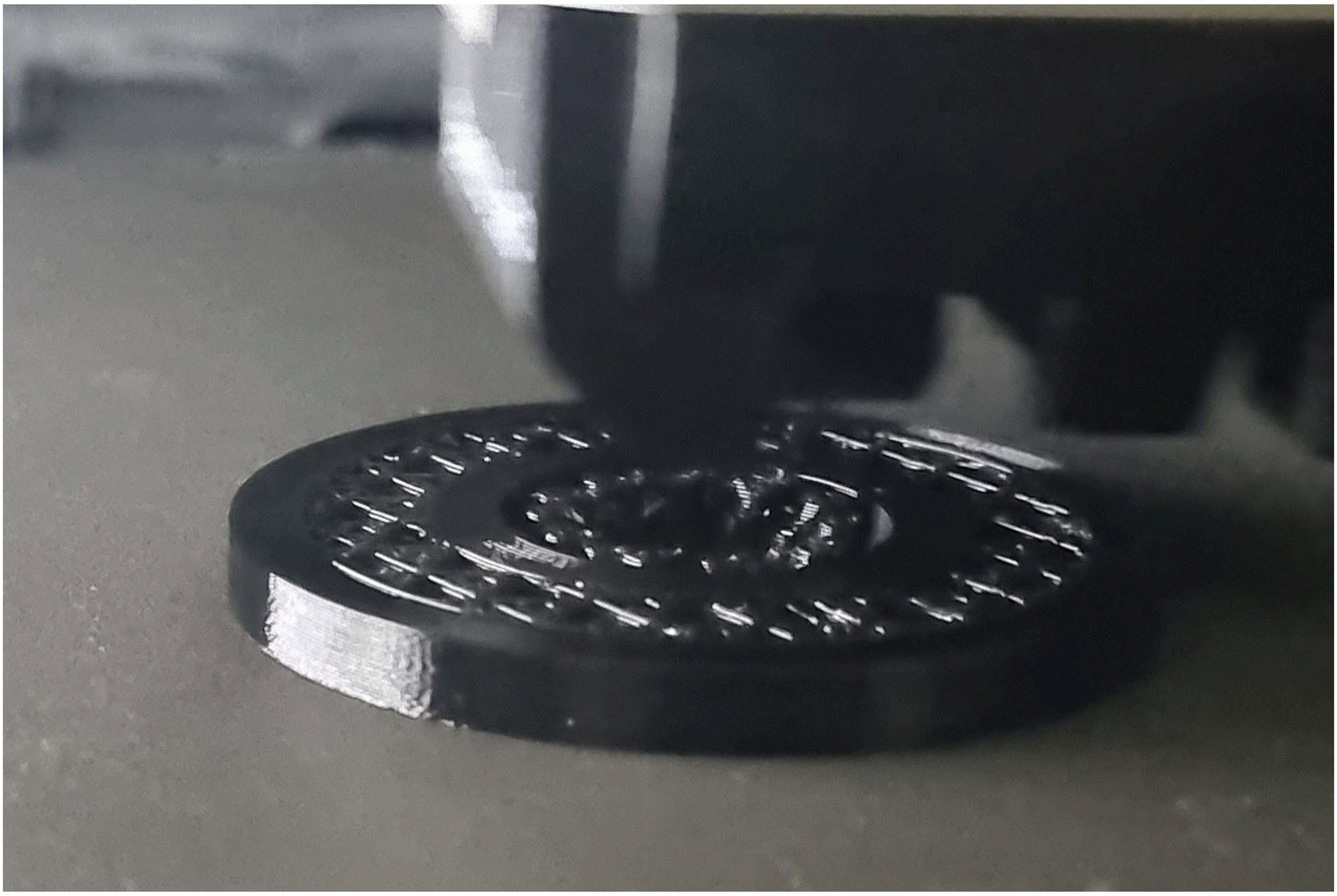
CHAPTER FIVE:
EXPERIMENTING
Experimentation through additive manufacturing

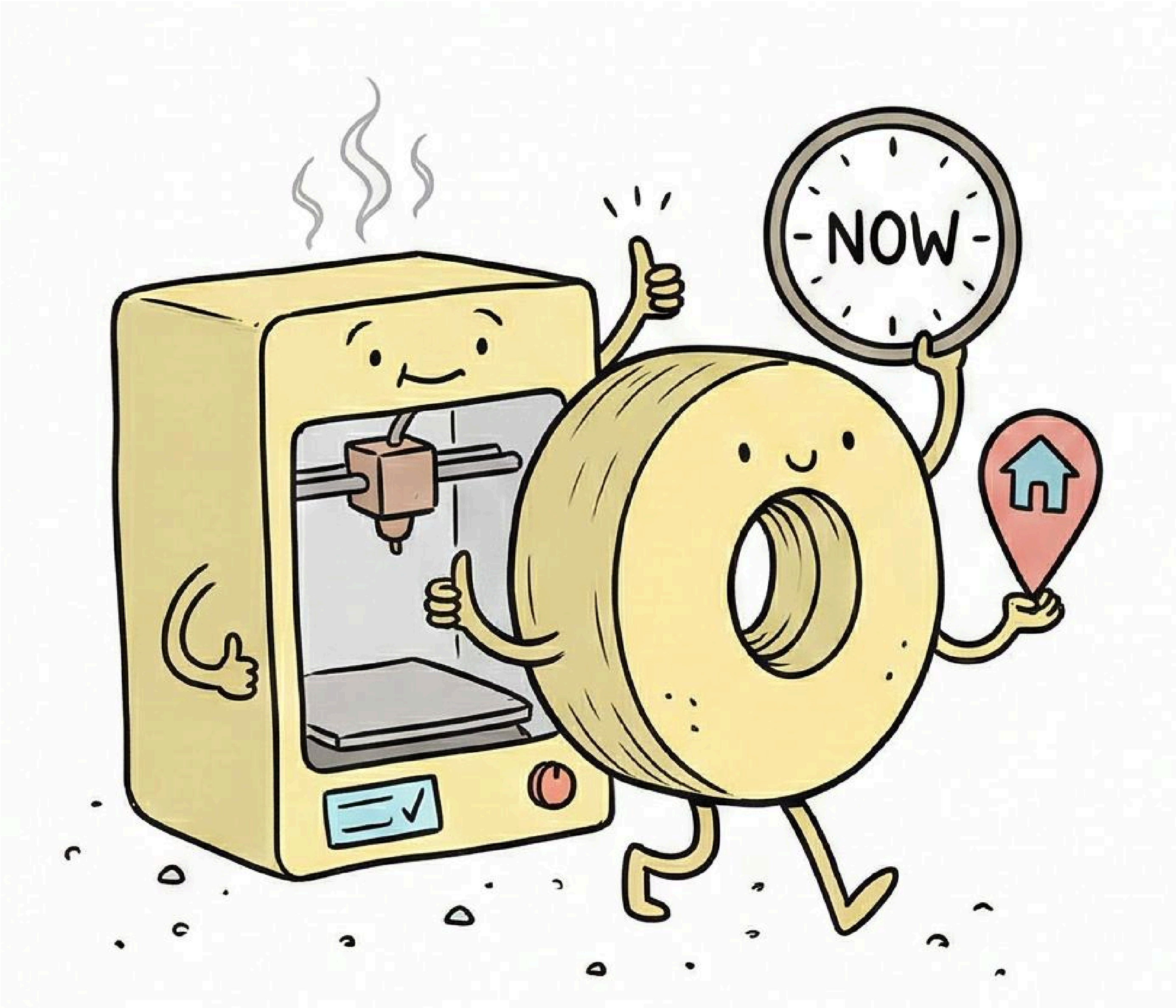
This chapter documents the first experimental phase of the research, focusing on the validation of additive manufacturing as a feasible pathway for wheel production. Following the initial hypothesis of symbiotic bio-growth through fungal composites, the project required a methodological shift towards industrially viable materials and fabrication methods. In this context, 3D printing was explored as both a rapid prototyping tool and a circular manufacturing strategy. The experiments presented here were designed to evaluate the behavior of flexible polymers under mechanical constraints typical of skate wheels, and to establish a reliable range of printing parameters to guide subsequent development stages.



Img. 75 - Additive manufacturing of a wheel, picture by the author.

5.1 - Methodological Shift: From Bio-Growth to Digital Fabrication

The experimental work presented in this chapter emerged from the need to maintain the sustainability objectives of the research while ensuring functional performance under real skating conditions. While bio-fabrication systems such as mycelium composites demonstrate promising potential for low-impact manufacturing, the preliminary material evaluation revealed limitations in shear resistance and abrasion suitability for high-speed asphalt riding. As a result, additive manufacturing was selected as the next feasible experimental strategy, enabling rapid iterations, controlled testing, and modular production possibilities.



Img. 76 - Additive manufacturing wheel, AI generated.

5.1.1 - Role of the internship at Superforma

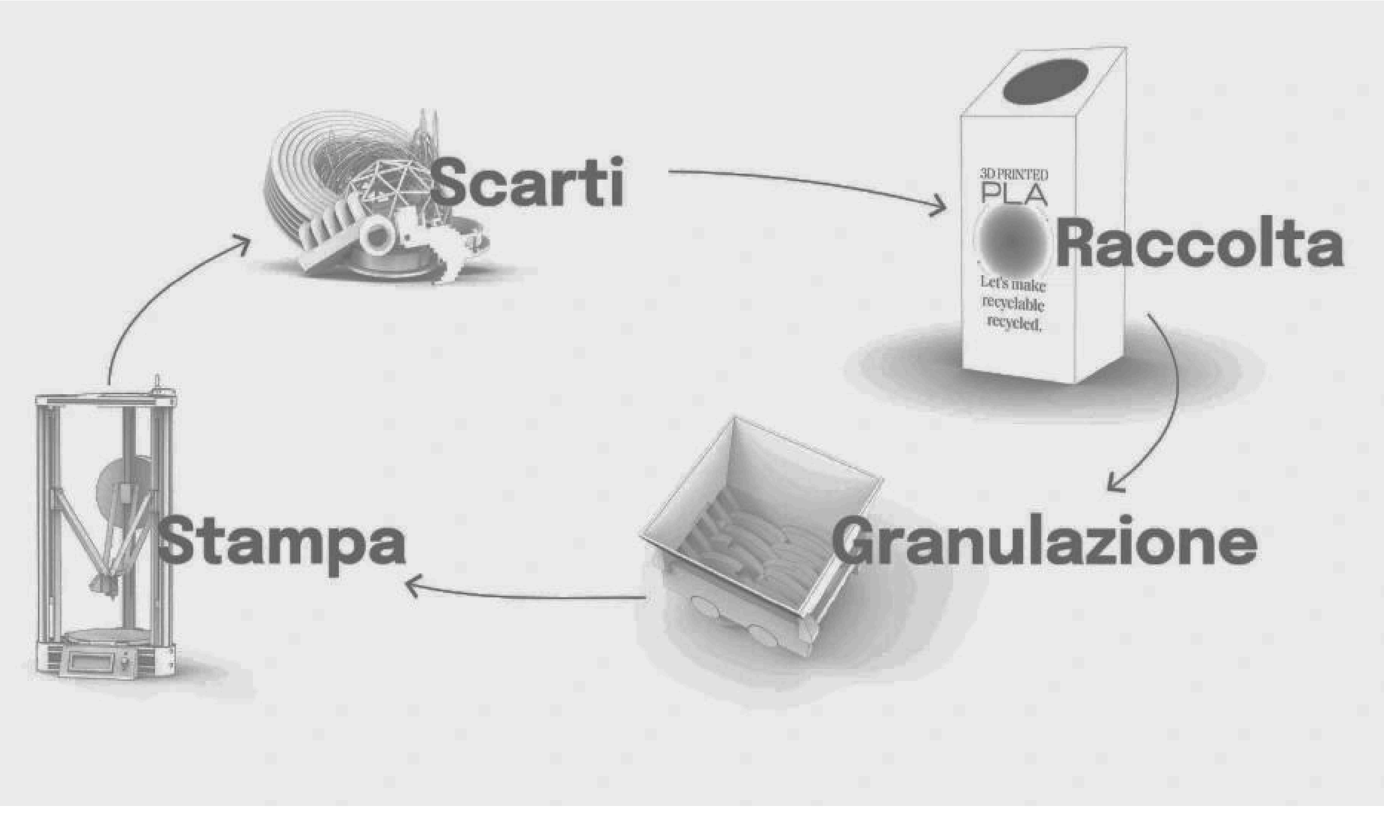
The internship experience at Superforma played a decisive role in enabling the experimental shift. Since the studio's main expertise lies in additive manufacturing workflows, access to printing infrastructure, slicing optimization, and iterative fabrication supported the transition from conceptual sustainability frameworks to practical prototyping. The availability of rapid printing cycles and systematic documentation tools made it possible to conduct multiple controlled trials, where geometry, infill, and wall parameters could be tested efficiently and compared through repeated production runs.

Img. 77 - Studio production, by SuperForma.

5.1.2 - Additive manufacturing as a circular tool

Additive manufacturing is frequently framed as a relevant technology for circular production models because it enables localized fabrication, reduces tooling dependency, and supports repair and modular replacement strategies. In contrast to injection molding or polyurethane casting, 3D printing eliminates the need for dedicated molds and allows the direct production of customized geometries, potentially reducing waste and extending product lifecycles through part substitution rather than full replacement. These characteristics align with circular design principles that emphasize maintenance, modularity, and minimized resource extraction [1].

In the context of skateboard wheels, additive manufacturing also introduces the possibility of producing wheels as hybrid systems, where different components (such as tread and core) may be designed as replaceable parts. This modular perspective becomes particularly relevant for freeride and downhill applications, where wheels are often treated as consumables due to wear and loss of shape after repeated slides.



Img. 78 - Closed-loop scheme, by SuperForma.

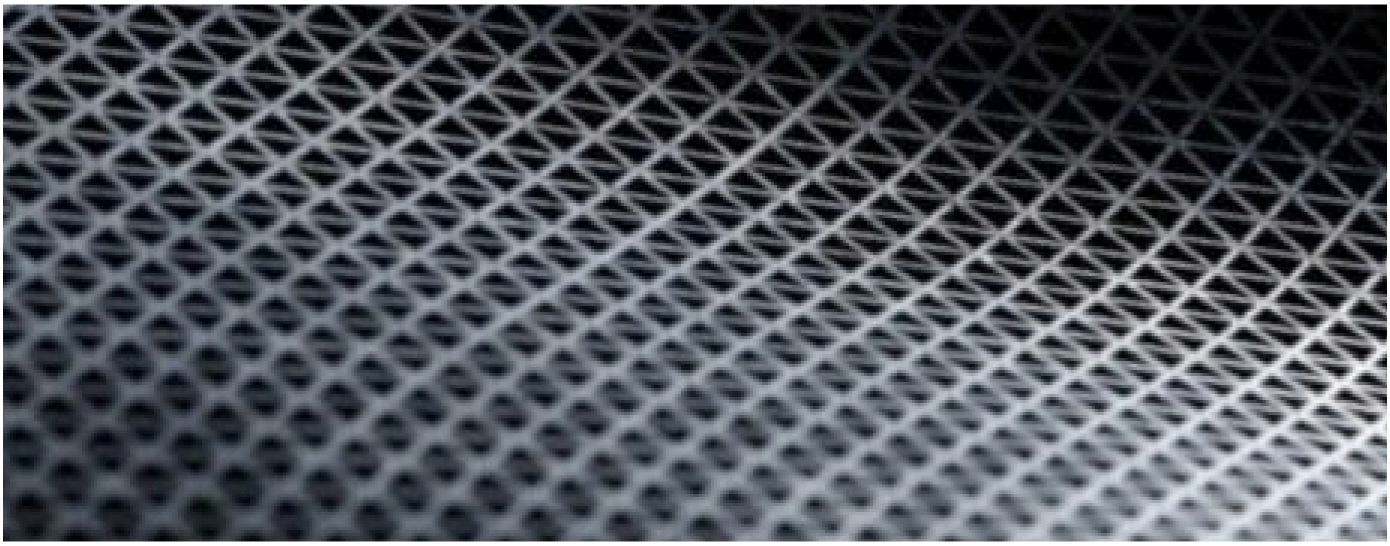
5.2 - Material Selection and Testing Strategy

This experimental phase was structured around the selection of a polymer material capable of reproducing the functional requirements of conventional skate wheels while remaining compatible with FDM printing constraints. Since the initial bio-based material approach proved insufficient for high-shear use, the first controlled testing campaign focused on flexible thermoplastics commonly used in additive manufacturing.

5.2.1 - TPU as a wheel-grade material

Thermoplastic polyurethane (TPU) was selected as the primary material for testing due to its known balance of flexibility, abrasion resistance, and elastic recovery. TPU is widely adopted in industrial applications requiring shock absorption and durability, and its tunable hardness allows it to approximate the Shore A range typically found in skate wheels. Additionally, TPU has been increasingly explored as a functional elastomer for additive manufacturing applications, where mechanical performance is influenced not only by material properties but also by printing parameters such as infill geometry and wall thickness [2].

The initial experiments were conducted using TPU 95A (TreeD), chosen as a reference filament for accessible printing and sufficient stiffness to maintain structural integrity. Printing was performed on Bambu Lab platforms (P1S and A1), allowing controlled slicing parameters and consistent fabrication cycles.

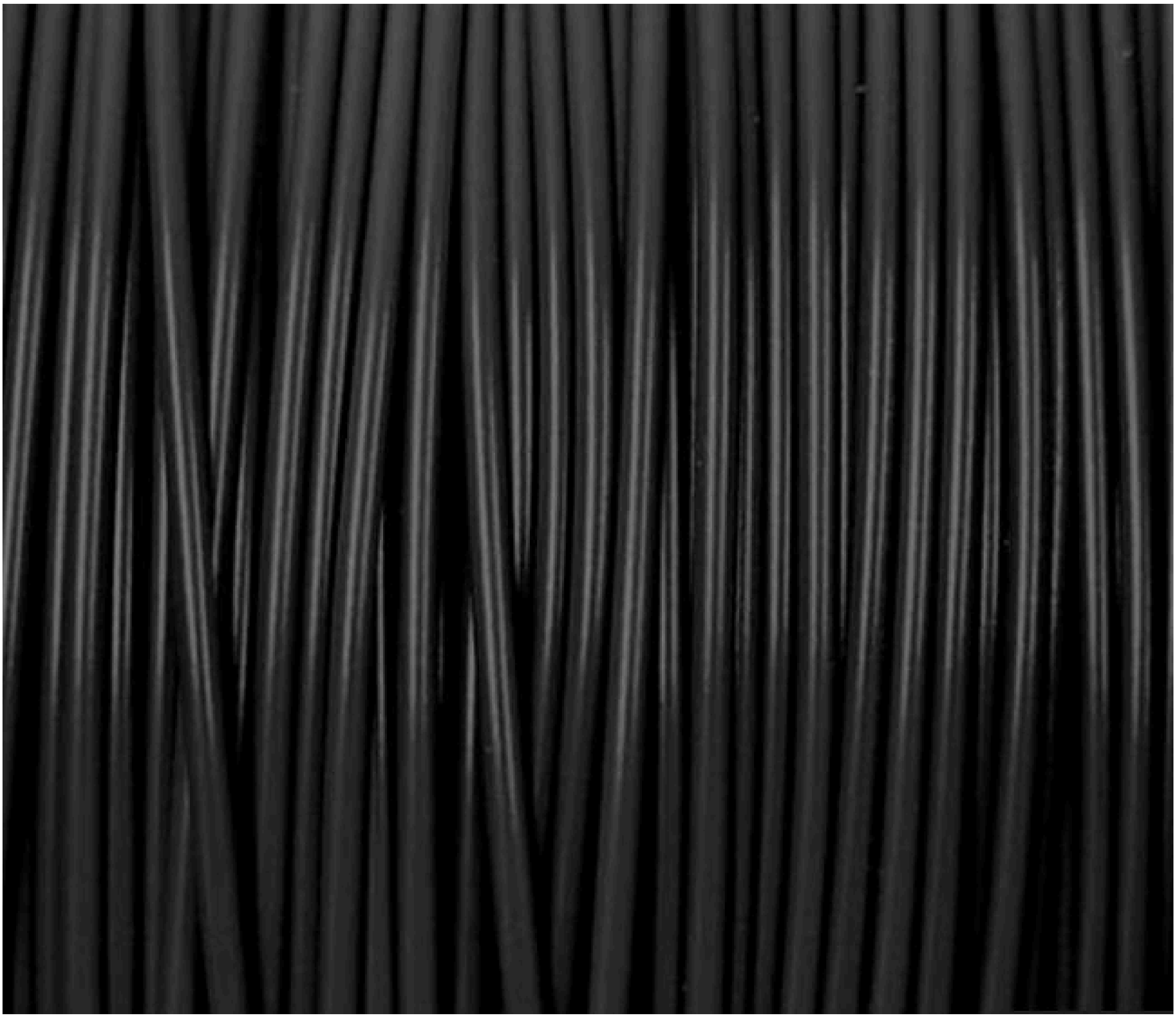


Img. 79 - Flexible tpu texture, by Markforged.

5.2.2 - Sustainability criteria and constraints

Although TPU is not inherently sustainable in its conventional form, it was selected as a necessary intermediate material to validate mechanical feasibility. The experimentation phase aimed to establish whether additive manufacturing could produce functional wheel geometries with reliable rollability and controlled damping.

Once functional feasibility was confirmed, the research could transition towards biodegradable or bio-attributed elastomers compatible with the same process. This approach reflects a design methodology where material substitution becomes possible only after validating structural behavior and performance constraints through a stable manufacturing baseline [1].



Img. 80 - Black TPU filament, by GL Robotics.

5.3 - First Experimental Phase: Skateboard Wheels

The first experimental phase was conducted using skateboard wheel geometries rather than downhill freeride wheels. This choice was deliberate: skateboard wheels typically function as monolithic components without a rigid core, reducing design complexity and allowing the study to focus on the material and print parameters without the additional constraints of multi-part assembly. The objective was therefore to verify whether FDM-printed TPU could achieve sufficient **rigidity**, **rebound**, and **rolling consistency** while maintaining the expected **damping** behavior.

5.3.1 Selection of reference geometries

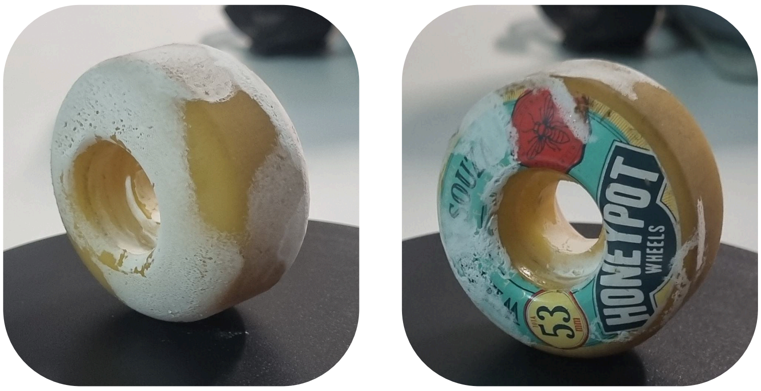
Img. 81 - Additive manufacturing of a wheel, picture by the author.

5.3.1 - Selection of reference geometries

To ensure that testing was grounded in real market standards, three reference geometries were selected. Each model represented a different structural logic and functional behavior, enabling comparative evaluation under similar material conditions:

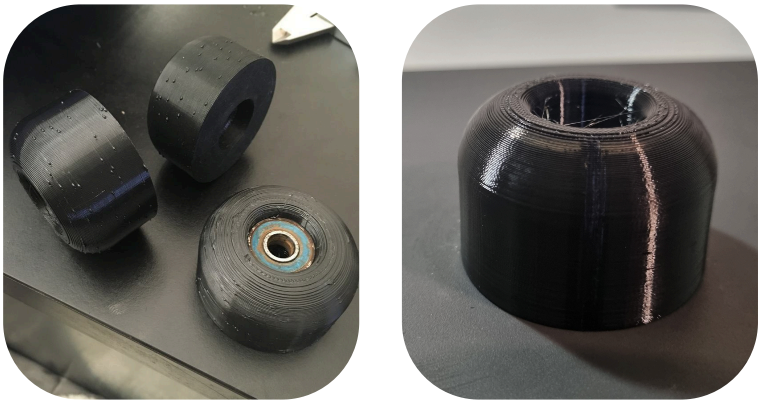
A) Centered symmetric wheel (53 mm Honeypot scan-based model)

A standard symmetrical wheel geometry, modelled from a physical scan, representing typical street skate configurations.



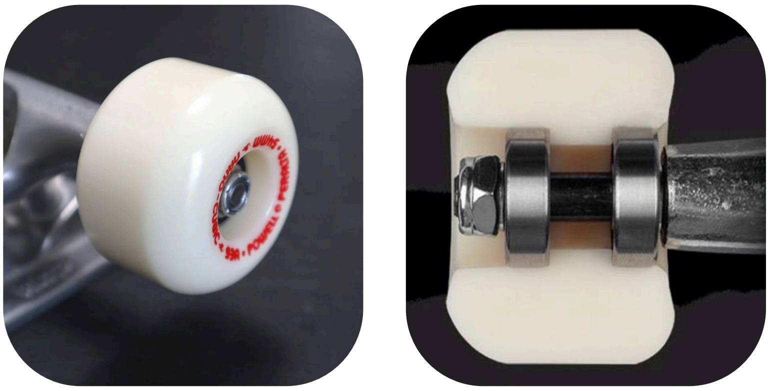
B) Side-set wheel optimized for support-free printing

A geometry sourced from an open 3D model platform, described as an efficient configuration for printing without support structures, minimizing surface defects and improving reliability [3].



C) Offset wheel derived from Powell Mini Cubic 54 mm

A geometry inspired by freeride-oriented wheels with an offset profile, chosen due to its known dual-side usability and functional edge behavior.



Img. 82 - Scannering Honeypot wheels, picture by the author. / Img. 83 - Side-set 3d printed wheels, by Nick Lindenmuth / Img. 84 - Mini Cubic, by Powell Peralta.

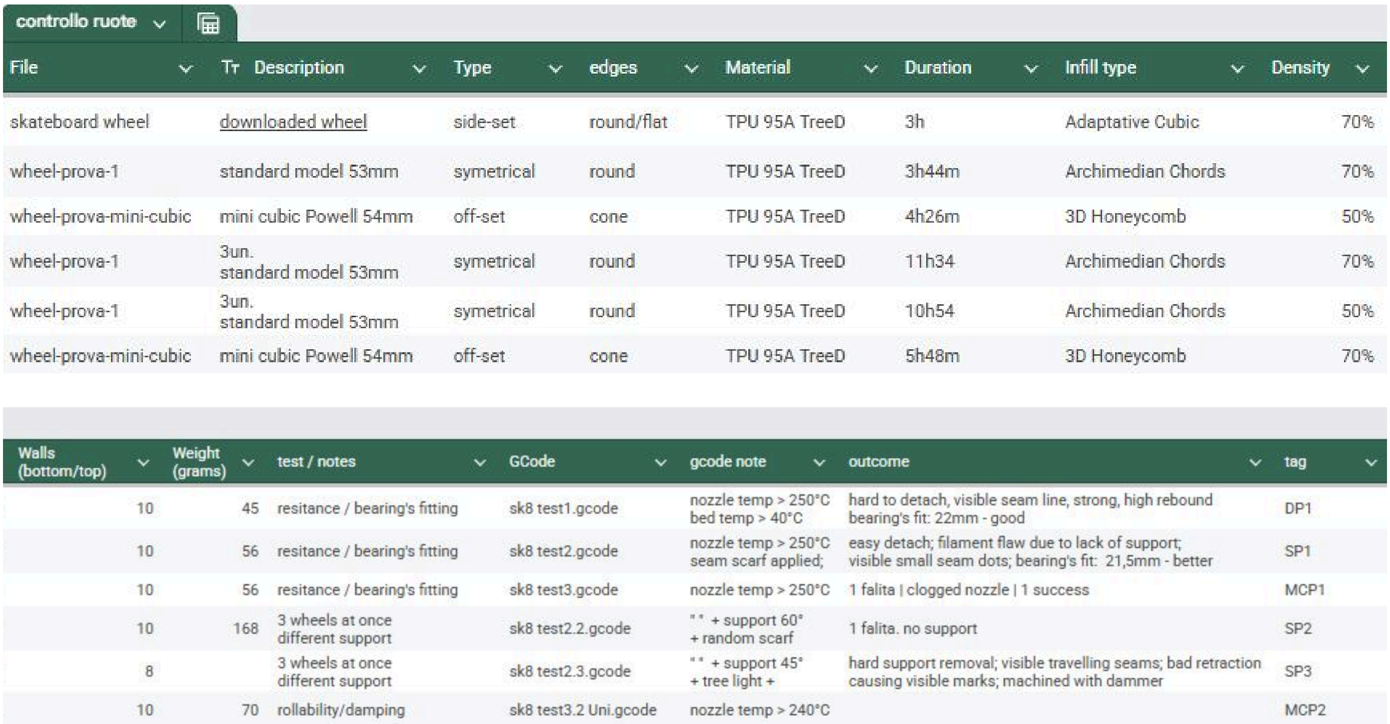
This selection allowed the experimentation to compare not only mechanical performance but also printing feasibility and surface quality differences between geometries.

5.3.2 - Modelling and printing parameters

The modelling workflow involved CAD refinement of scanned geometry, tolerance adjustments for bearing fit, and the preparation of print-ready solids optimized for TPU extrusion. The printing process was structured as a controlled iterative series, where parameters were modified systematically to evaluate their influence on mechanical response.

To ensure traceability and reproducibility, a control table was developed to document each printed sample, including geometry type, filament, print duration, infill type, infill density, wall thickness, observed issues, and final outcome.

This table proved essential in identifying recurring failure modes such as clogging, seam artifacts, excessive softness, and bearing fit instability. It also highlighted key printing thresholds, such as the relationship between high nozzle temperatures (above 240–250°C) and extrusion reliability, as well as the strong influence of support settings on seam quality and surface defects.



File	Description	Type	edges	Material	Duration	Infill type	Density
skateboard wheel	downloaded wheel	side-set	round/flat	TPU 95A TreeD	3h	Adaptative Cubic	70%
wheel-prova-1	standard model 53mm	symetrical	round	TPU 95A TreeD	3h44m	Archimedian Chords	70%
wheel-prova-mini-cubic	mini cubic Powell 54mm	off-set	cone	TPU 95A TreeD	4h26m	3D Honeycomb	50%
wheel-prova-1	3un. standard model 53mm	symetrical	round	TPU 95A TreeD	11h34	Archimedian Chords	70%
wheel-prova-1	3un. standard model 53mm	symetrical	round	TPU 95A TreeD	10h54	Archimedian Chords	50%
wheel-prova-mini-cubic	mini cubic Powell 54mm	off-set	cone	TPU 95A TreeD	5h48m	3D Honeycomb	70%

Walls (bottom/top)	Weight (grams)	test / notes	GCode	gcode note	outcome	tag
10	45	resitance / bearing's fitting	sk8 test1.gcode	nozzle temp > 250°C bed temp > 40°C	hard to detach, visible seam line, strong, high rebound bearing's fit: 22mm - good	DP1
10	56	resitance / bearing's fitting	sk8 test2.gcode	nozzle temp > 250°C seam scarf applied;	easy detach; filament flaw due to lack of support; visible small seam dots; bearing's fit: 21,5mm - better	SP1
10	56	resitance / bearing's fitting	sk8 test3.gcode	nozzle temp > 250°C	1 falita | clogged nozzle | 1 success	MCP1
10	168	3 wheels at once different support	sk8 test2.2.gcode	" " + support 60° + random scarf	1 falita. no support	SP2
8		3 wheels at once different support	sk8 test2.3.gcode	" " + support 45° + tree light +	hard support removal; visible travelling seams; bad retraction causing visible marks; machined with dammer	SP3
10	70	rollability/damping	sk8 test3.2 Uni.gcode	nozzle temp > 240°C		MCP2

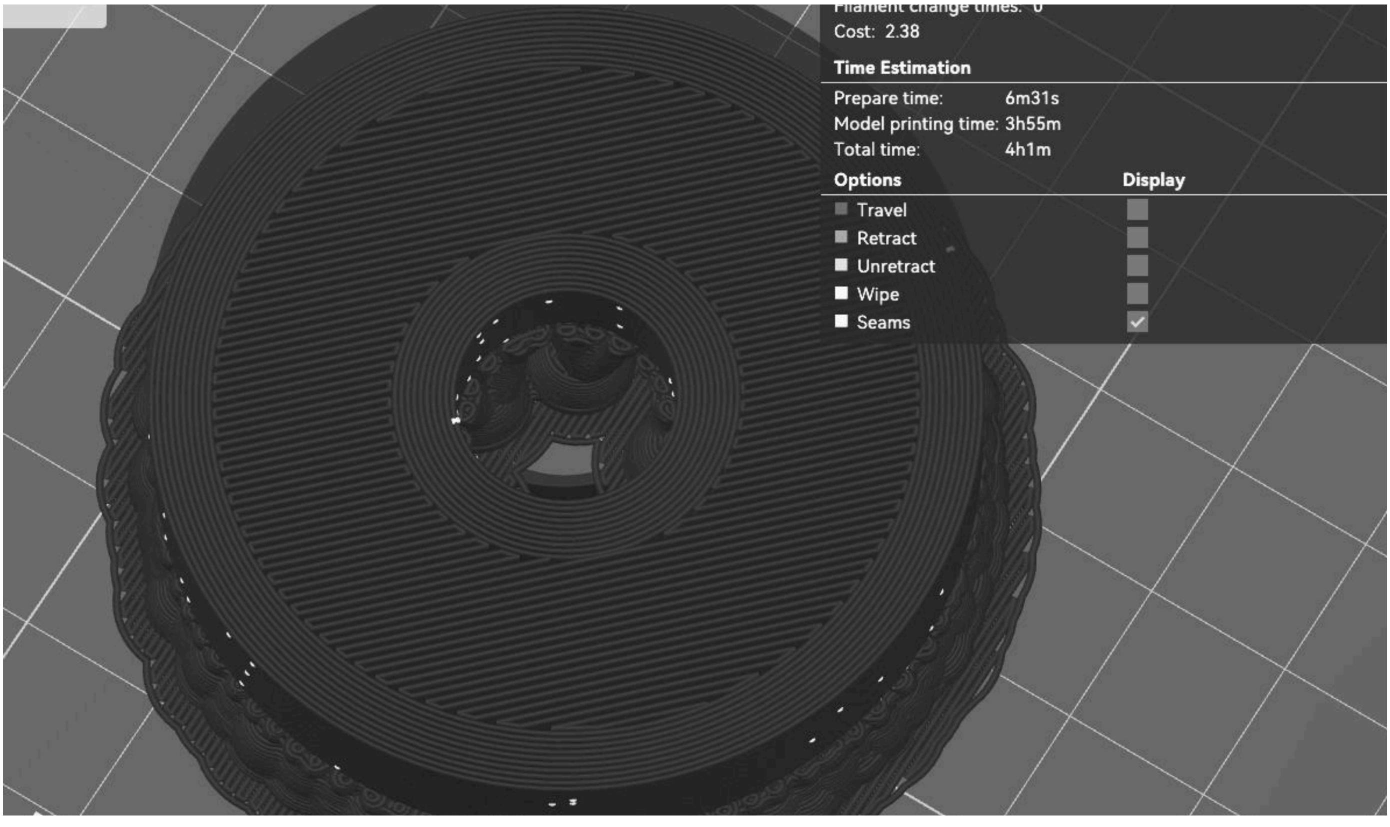
Img. 85 - Table including geometry reference, slicing settings, printer notes, and observed performance results, picture by the author.

5.4 - Parameter Exploration

The experiments demonstrated that the mechanical behavior of printed wheels is strongly dependent on the interaction between internal structure and surface rigidity. While TPU inherently provides elastic deformation, excessive compliance produces negative outcomes such as instability in bearing housing and reduced roll continuity. In this context, infill density and infill topology acted as the primary determinants of structural stiffness and rebound characteristics.

Results confirmed that **low infill densities** produced **highly deformable wheels** with **strong damping effects**. While this behavior may be desirable for absorbing impacts during jumps, drops, or irregular surfaces, it also compromises rolling performance. Excessive deformation caused increased **friction** at the bearing interface, occasionally pressing the bearings and interrupting their rotation. This phenomenon is consistent with studies on elastomeric lattice structures, where internal geometry strongly affects energy absorption and stiffness distribution [2].

Conversely, higher infill densities combined with rigid internal patterns increased rollability while preserving partial damping, producing a hybrid behavior that differs from conventional cast polyurethane wheels.



Filament change times: 0
Cost: 2.38

Time Estimation

Prepare time: 6m31s
Model printing time: 3h55m
Total time: 4h1m

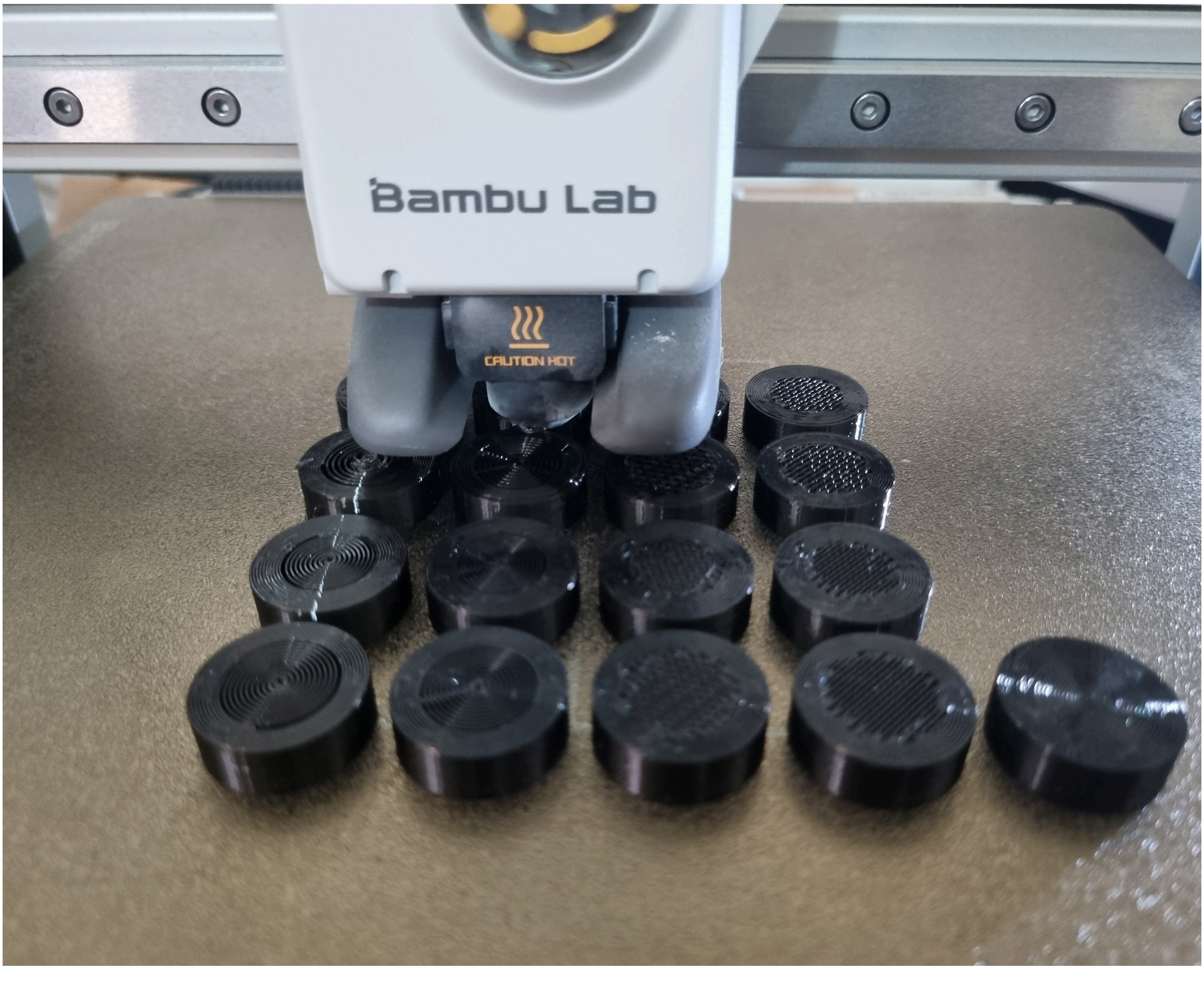
Options	**Display**
Travel	☐
Retract	☐
Unretract	☐
Wipe	☐
Seams	☑

Img. 86 - Infill pattern demonstration on a slicer, picture by the author.

5.4.1 - Infill density and rolling behavior

The first key variable was infill density. Samples printed with densities around 50% exhibited high deformation and a kneadable response, creating strong damping but poor rolling stability. At this range, the wheel behaved more as an elastomeric cushion than a rolling component.

In contrast, wheels printed at approximately 70% infill density achieved a more balanced response. This configuration preserved sufficient stiffness to maintain bearing clearance and rolling momentum while still providing a noticeable damping effect. These results suggest that additive manufacturing enables the creation of wheels with intermediate mechanical behaviors that cannot be achieved through homogeneous casting alone, since casting produces a continuous density rather than a controlled internal lattice.



Img. 87 - 3d printing samples with different infill and wall thickness, picture by the author.

5.4.2 - Infill pattern comparison

The experiments demonstrated that the mechanical behavior of printed wheels is strongly dependent on the interaction between internal structure and surface rigidity. While TPU inherently provides elastic deformation, excessive compliance produces negative outcomes such as instability in bearing housing and reduced roll continuity. In this context, infill density and infill topology acted as the primary determinants of structural stiffness and rebound characteristics.

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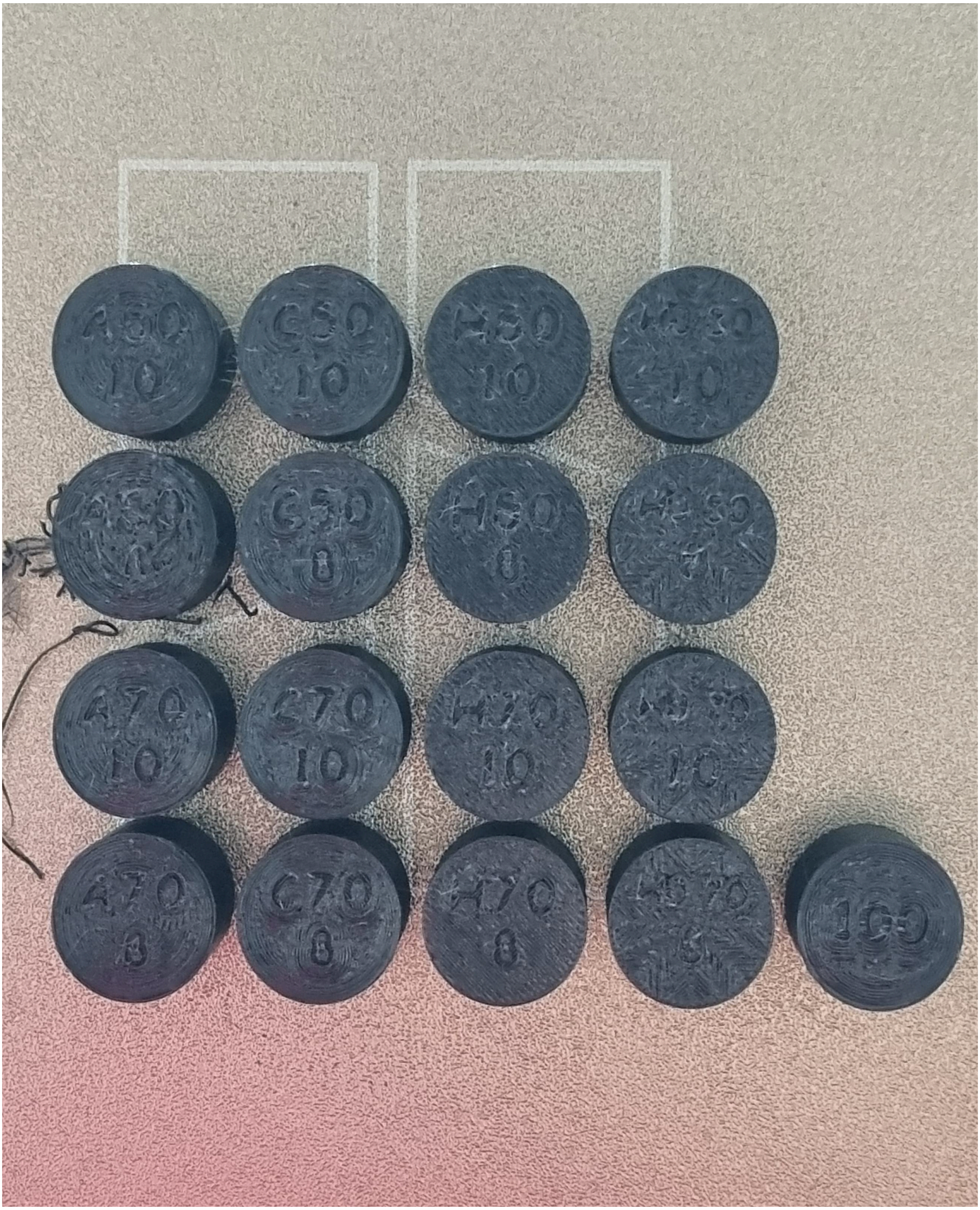
5.4.3 Wall thickness and structural integrity

Wall thickness was identified as a critical factor in maintaining the external geometry of the wheel, particularly at the bearing interface. The experiments indicated that wall thickness values between 3.2mm and 4mm provided a stable configuration.

Lower wall thicknesses increased flexibility but caused visible deformation, seam inconsistencies, and bearing instability. Higher wall thicknesses improved structural rigidity but increased print time and material usage.
The chosen range therefore represented a compromise between structural strength, manufacturing feasibility, and performance response.

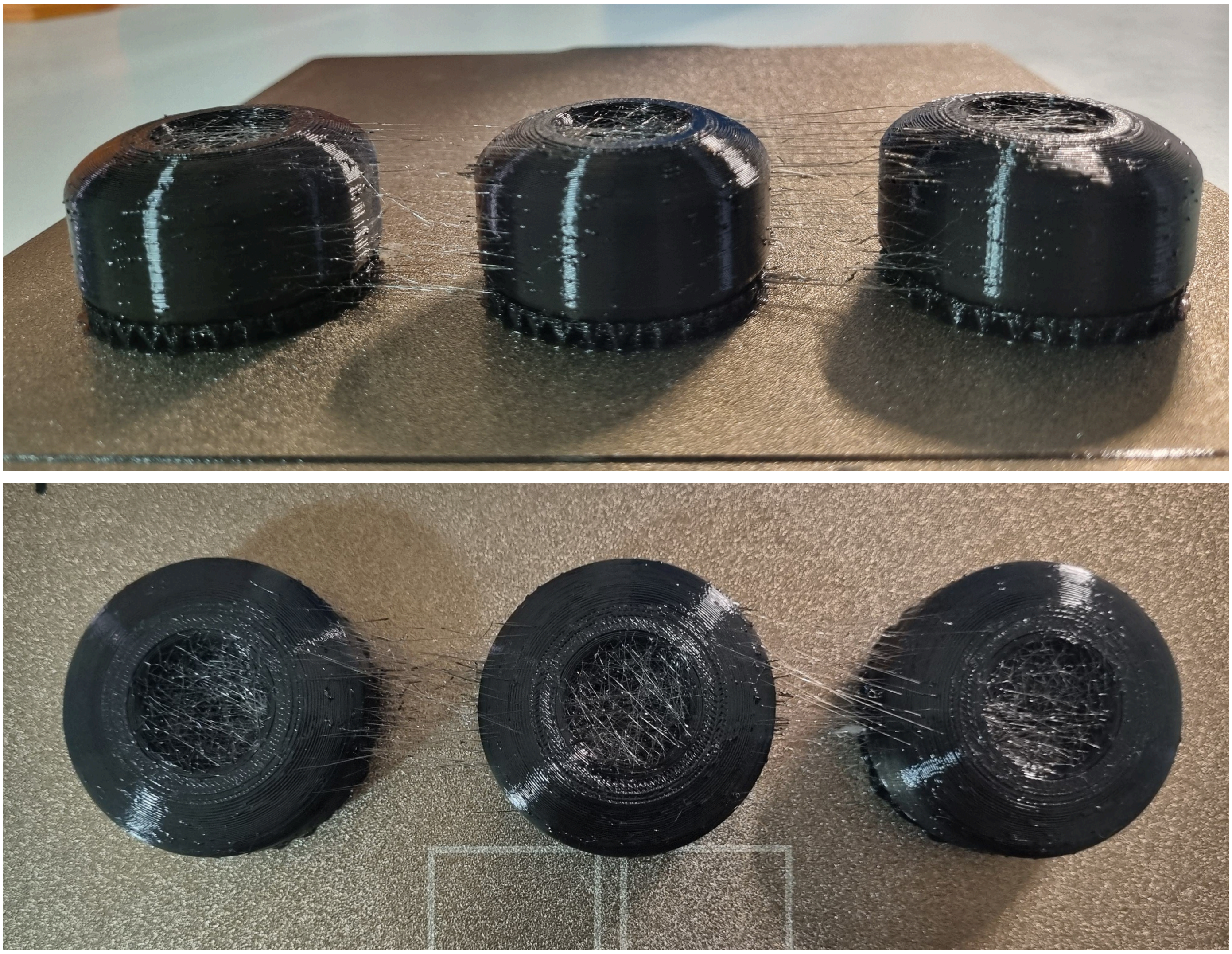


Img. 88 - 3d printed samples with different infill and wall thickness, picture by the author.

5.5 - Results and Material Validation

The experimental campaign provided consistent evidence that TPU-based additive manufacturing can generate functional wheel prototypes with sufficient structural integrity for real skating use. While the analysis did not include standardized laboratory testing (e.g., abrasion loss, rebound coefficient, or Shore hardness measurements), the combination of controlled printing documentation and real riding evaluation supported a semi-empirical validation approach. Each printed configuration was tracked through a control table including material consumption, print duration, wall thickness, infill structure, and qualitative performance outcomes.

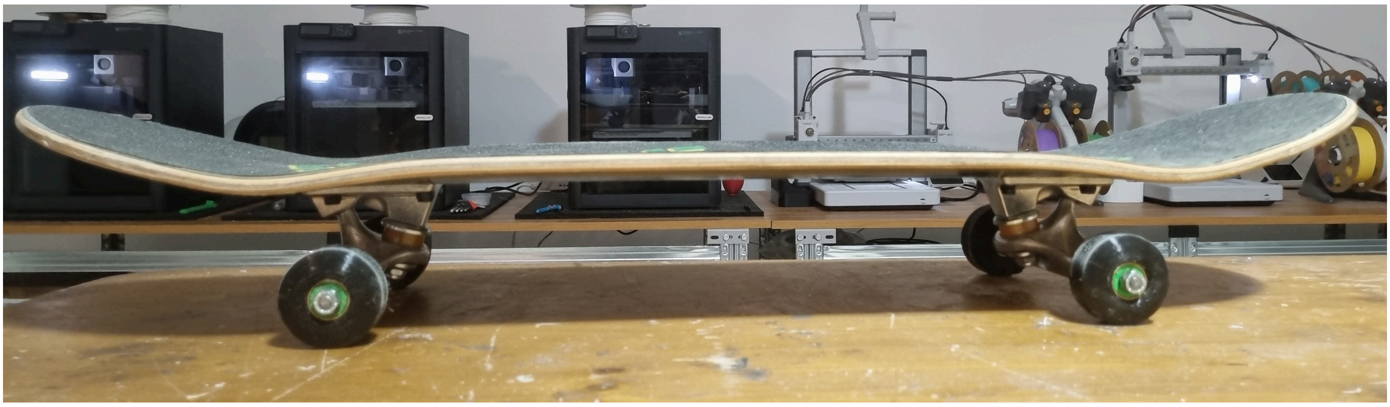
This method enabled the identification of repeatable printing thresholds and failure patterns, while also confirming the viability of the prototypes under real rolling conditions.



Img. 89 - Retraction flaws when printing wheels simultaneously, picture by the author.

Img. 90 - 3D printed centered wheel, picture by the author.

Img. 91 - Support flaw, retraction flaw and support removal, picture by the author.



Img. 92 - Inserted bearing at the centered 3D printed wheel. / Img. 93 - Wheels assembled at the skate, picture by the author.

5.5.1 - Damping versus rollability trade-off

A central result of the experimentation was the identification of a clear mechanical trade-off between damping response and rolling efficiency. Wheels produced with low infill densities exhibited high deformation, creating a cushioning effect that increased vibration absorption and impact comfort. This behavior can be beneficial in street skating conditions, where landing impacts and irregular pavement surfaces are common. However, excessive deformation introduced performance limitations by increasing localized compression around the bearing seat, which may compromise momentum and stability.

Conversely, higher-density configurations improved rolling continuity and stiffness. The results demonstrated that internal lattice configuration strongly influences the mechanical response of flexible polymers, confirming the role of infill as a structural design variable rather than a purely economic slicing parameter. This observation is consistent with literature describing how cellular geometries in polymer additive manufacturing can be tuned to modify stiffness and energy absorption behavior [2].

Img. 94 - Wheel damping, picture by the author.

5.5.2 - Optimal parameter range

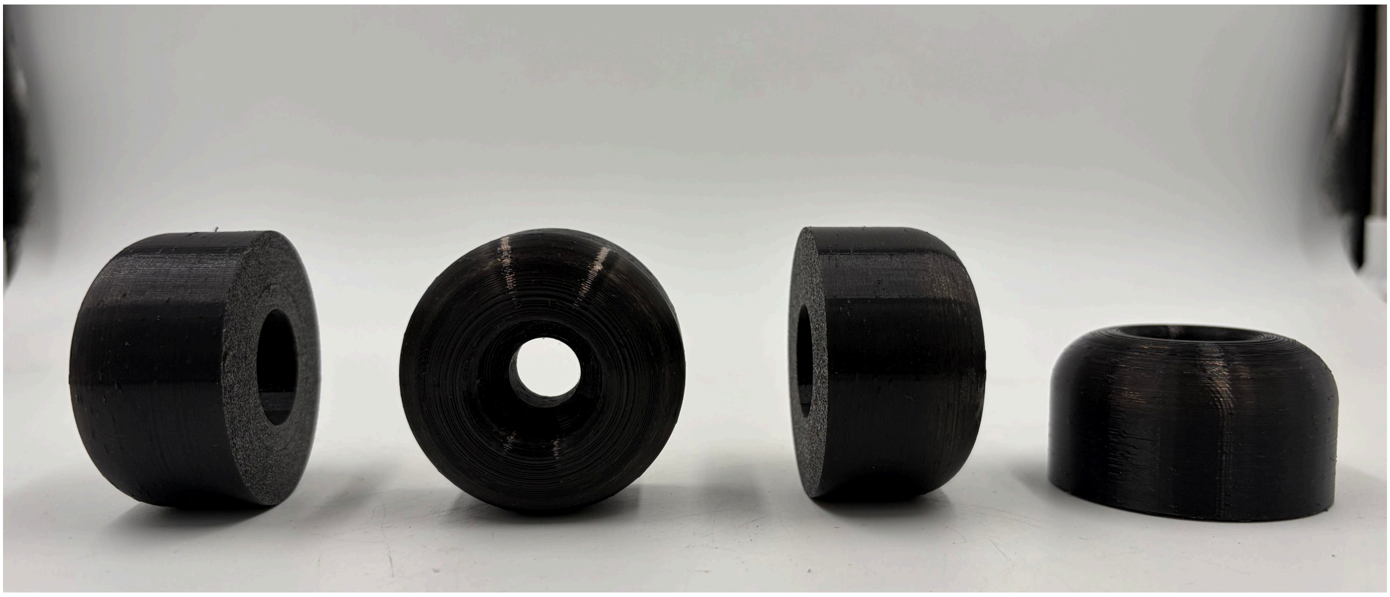
Based on the documented trials, the most consistent functional performance was obtained using an infill density close to 70%, combined with rigid internal patterns such as honeycomb or 3D honeycomb and 10 units of wall (thickness around 4mm). These configurations provided sufficient stiffness to preserve the wheel profile and maintain stable bearing seating, while still allowing controlled damping.

Flexible patterns such as gyroid or Archimedean structures increased energy absorption but required higher density thresholds to avoid excessive softness and loss of mechanical stability. Similarly, wall thickness proved essential in maintaining structural continuity: values between 3.2 mm and 4 mm ensured adequate rigidity without compromising manufacturability.

Print reliability was also strongly dependent on temperature and extrusion stability. Most successful samples were produced with nozzle temperatures above 230°C, reaching up to 240°C depending on flow consistency and seam formation.

All models were sliced and processed using Bambu Studio, ensuring uniform control of printing parameters and comparability across trials.

Img. 95 - Side-set, off-set and centered wheels 3d printed, picture by the author.



Img. 96 - Centered wheel set 3d printed, picture by the author. / Img. 97 - Side-set wheel set 3d printed, picture by the author. / Img. 98 - Off-set wheel set 3d printed, picture by the author.

5.5.3 - Field validation through riding tests

To complement the parametric print evaluation, selected wheel prototypes were tested through real riding conditions. These tests confirmed that the optimized printing configurations allowed effective rolling performance, with stable bearing seating and no significant friction-induced stoppage. The wheels maintained adequate momentum and demonstrated functional rollability comparable to conventional skate wheels in standard street use. This validation was particularly relevant, since one of the main risks identified in early prints was the deformation of the wheel body leading to increased pressure on the bearing interface. The riding tests demonstrated that this issue can be mitigated through controlled infill density and wall thickness, confirming the feasibility of TPU printed wheels as functional prototypes.

Although these results remain empirical, they support the hypothesis that additive manufacturing enables the development of tunable wheel behaviors, where internal lattice geometry can be intentionally designed to achieve hybrid mechanical responses. This finding establishes a reliable foundation for the next project phase, in which freeride and downhill wheels require more complex structures, including rigid cores, modular assembly, and replaceable tread systems.

Img. 99 - Off-set wheel set 3d printed after use, picture by the author.

5.5.4 - Performance implications for further development

The results obtained in this first experimental phase demonstrated that additive manufacturing can generate structurally reliable wheel prototypes while offering design freedom that is not achievable through conventional casting. In particular, the ability to control damping response through internal topology introduces a new approach to wheel tuning, shifting part of the performance design from chemistry (urethane formulation) to geometry (internal architecture).

This outcome is relevant for circular economy strategies, since performance customization may be achieved through adjustable printing parameters rather than the production of multiple chemically distinct compounds. Furthermore, the experimental process highlighted the importance of systematic documentation, as failures such as clogging, seam artifacts, and support-related defects represent key constraints that must be addressed before scaling toward freeride wheels.

The successful validation of TPU in skateboard wheel geometries therefore represents a necessary intermediate step toward the development of modular downhill wheels, where interchangeability, repairability, and part reuse become central design requirements.

Img. 100 - Three sets of wheels 3d printed, picture by the author.

BIBLIOGRAPHY CHAPTER FIVE

[1] Ellen MacArthur Foundation, Towards the Circular Economy: Economic and business rationale for an accelerated transition, EMF Publishing, 2013.

[2] Maskery, I., et al. Mechanical properties of gyroid lattice structures manufactured by additive manufacturing. Materials Science and Engineering A, 670, 264–274, 2016.

[3] Pinshape, “Skateboard Wheels – support-free 3D printable model,” available online: https://pinshape.com/items/22787-skateboard-wheels (accessed 2025).

CHAPTER SIX:

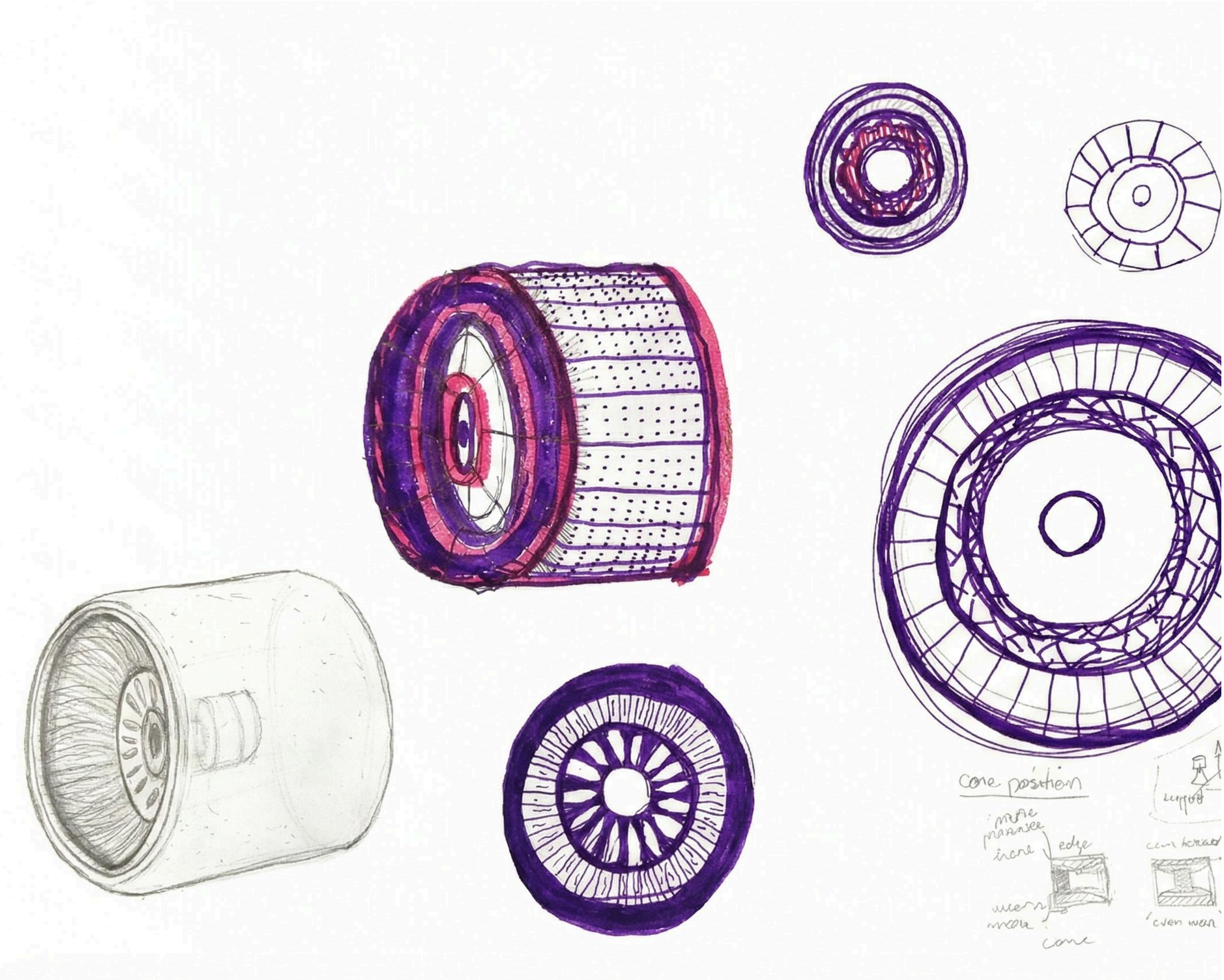
REDESIGNING THE WHEELS

Following the experimental validation of additive manufacturing parameters presented in Chapter 5, this chapter focuses on the design evolution of the freeride wheel system and the transition from early conceptual hypotheses to a functional modular prototype. The chapter documents the redesign process driven by manufacturing constraints, particularly the limitations encountered during multi-material co-printing using TPU and PLA with an AMS system. These constraints prompted a methodological shift toward a separable architecture, where the wheel is divided into a reusable core and a replaceable tread. Through iterative sketching, modelling, and prototyping, the project progressively developed a mechanically reliable assembly strategy based on press-fit tolerances, cantilever locking features, and optional screw reinforcement. The chapter concludes by presenting the final prototype configuration achieved through this redesign process, establishing the technical foundation for the final product validation described in Chapter 7.

Img. 101 - Redesigning a wheel, AI generated.

6.1 - Advanced Sketching

The advanced sketching phase represents the first structured step in translating the findings from the experimentation stage into a feasible freeride wheel design. Rather than serving only as a formal exploration, sketching was used as an analytical tool to evaluate how additive manufacturing constraints, assembly logic, and mechanical requirements could coexist within the same product architecture. This stage focused on defining the relationship between core and tread, identifying critical structural regions (bearing seat, torque transfer areas, contact patch), and testing different modular configurations. By iterating through multiple conceptual alternatives, sketching enabled the identification of key opportunities for a circular design approach, such as replaceability, interchangeability, and the potential separation of functional lifecycles between structural and consumable components.

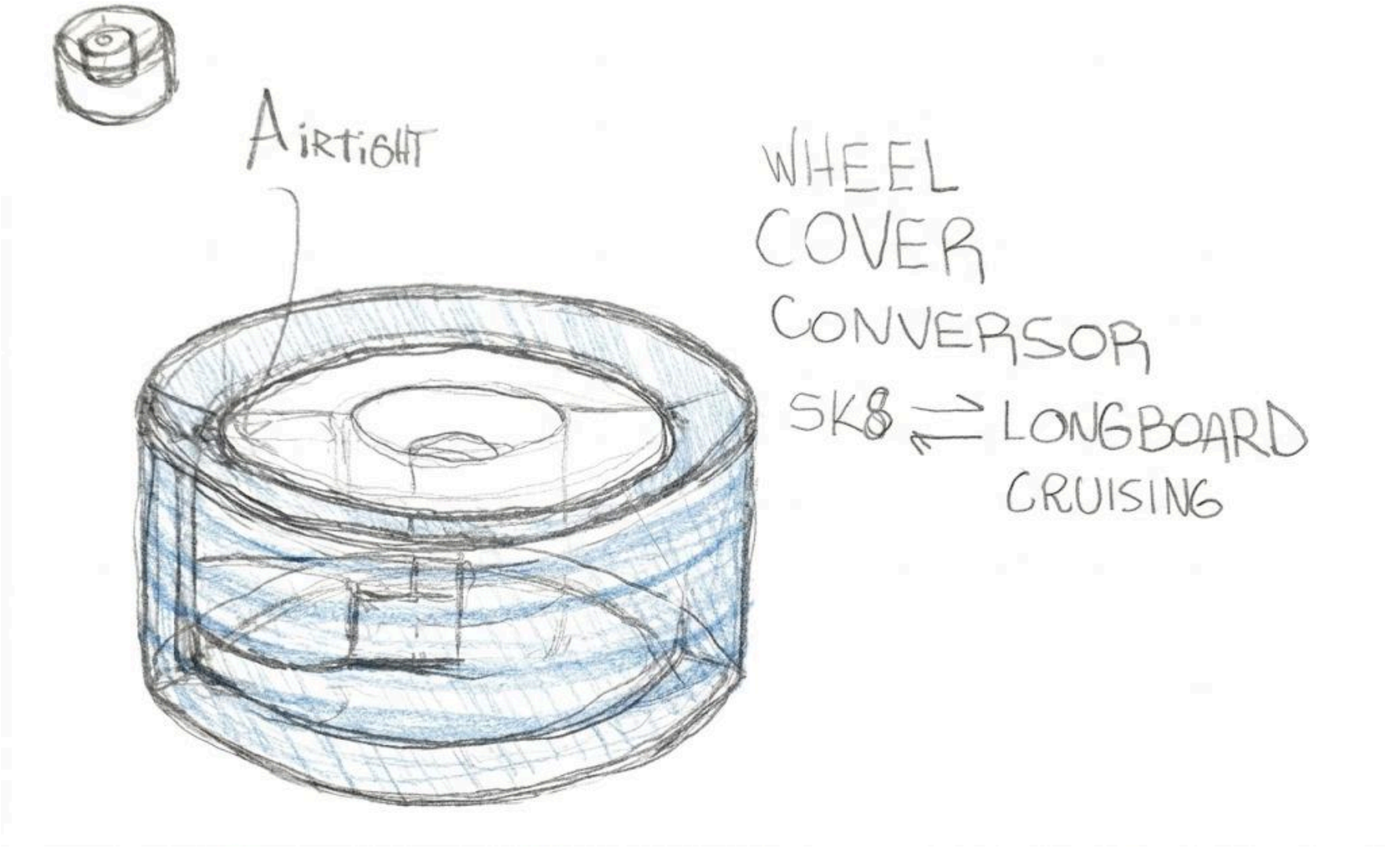


Img. 102 - Primary sketches, picture by the author.

6.1.1 - Sketches linked to productive method

The initial sketching phase was strongly guided by manufacturing hypotheses rather than purely aesthetic exploration. At this stage, the design intent focused on evaluating how additive manufacturing could be leveraged not only as a fabrication method, but also as an enabling condition for modularity and material efficiency. Since freeride wheels require high mechanical resistance under repeated friction and impact stress, the sketches prioritized structural logic and load distribution rather than surface differentiation.

Two distinct conceptual directions emerged: the first based on co-printing a rigid core and flexible tread, and the second based on separated components assembled through press-fit and mechanical locking. This approach is consistent with research on additive manufacturing for functional polymer systems, where geometry often needs to be reformulated in response to print limitations, anisotropic strength, and bonding constraints [2].

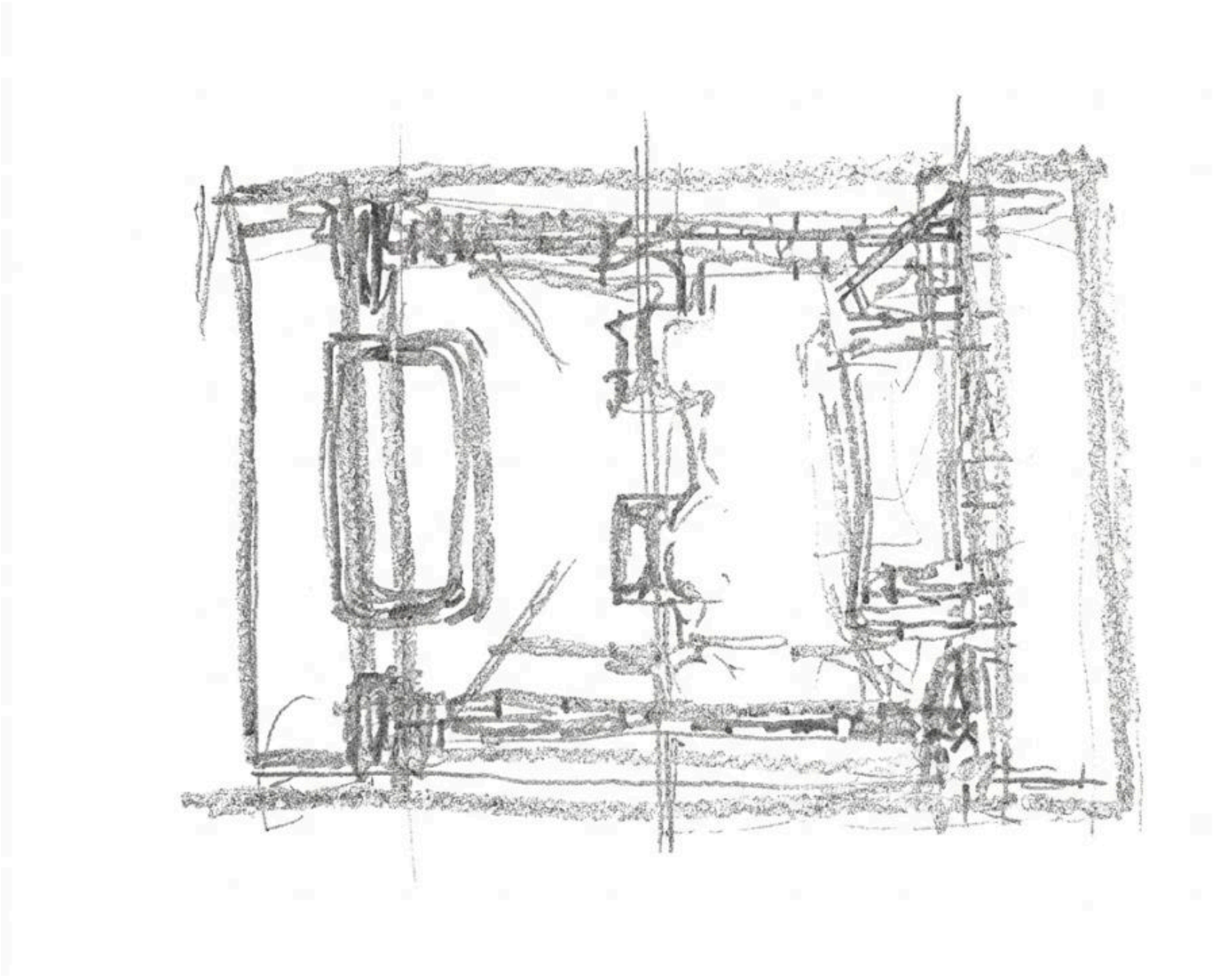


Img. 103 - Sketch of a wheel cover, picture by the author.

6.1.2 - Part and assembly sketches

The assembly sketches were developed to investigate how a wheel could be reconfigured into replaceable components without compromising structural safety. The objective was to achieve a modular system where the tread could be replaced independently from the core, extending lifespan and reducing material disposal.

In the first concept (V1), the core and tread were conceived as one integrated system printed simultaneously, theoretically eliminating the need for post-processing or fasteners. In the second concept (V2), the wheel was divided into a tread and a core formed by two rigid halves assembled with screws. This configuration enabled controlled locking and ensured that the core would not rotate independently from the tread.



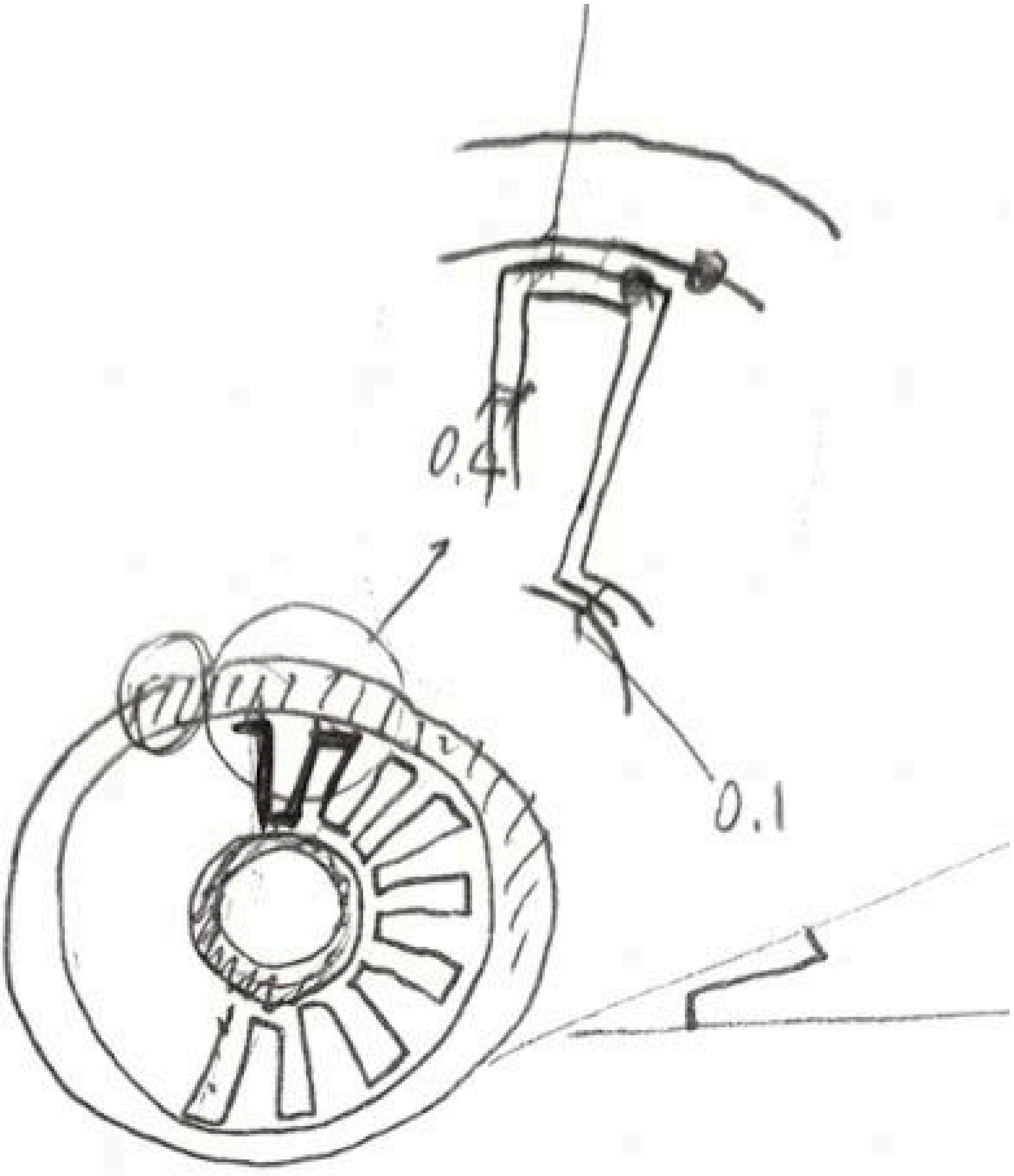
Img. 104 - Sketch of core assembly (V2), picture by the author.

Such design decisions reflect circular economy strategies that support maintenance, repairability, and component reuse as key mechanisms for reducing resource extraction and waste generation [1].

6.1.3 - Representation of final outcomes

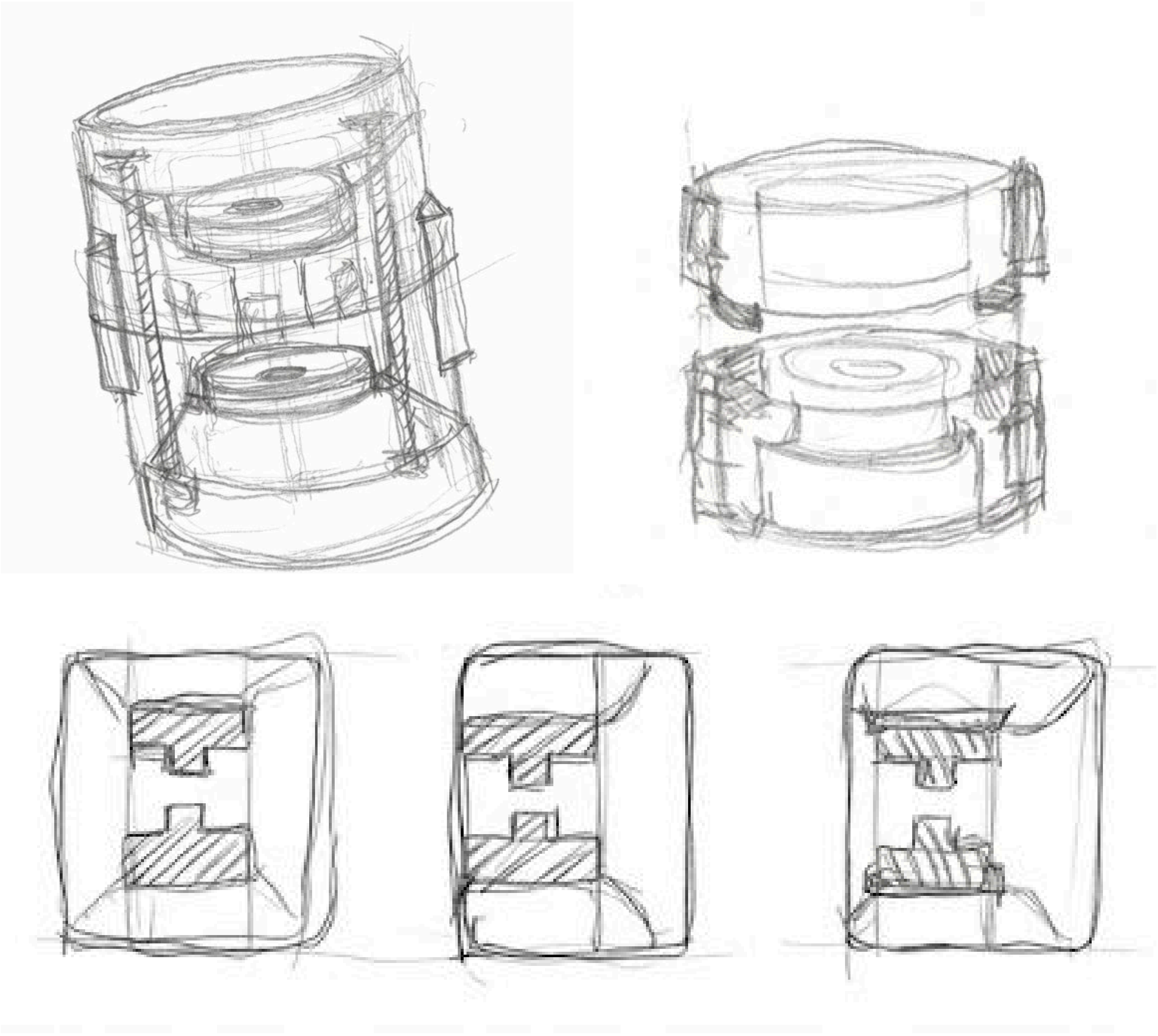
The sketch phase concluded with two defined design outcomes:

1) Freeride Wheel V1, based on multi-material co-printing using TPU + PLA



Img. 105 - Sketch of mechanical bridge (V1), picture by the author.

2) Freeride V2, based on modular assembly of a printed tread and a split core fixed by screws



Img. 106 - Sketch of core assembly (V2), picture by the author.

The V1 solution aimed at reducing assembly complexity, but introduced high risk in print reliability. V2, instead, prioritized repeatability and mechanical control, supporting a design-for-repair logic. These outcomes represent a shift from an idealized manufacturing vision toward a system grounded in feasible fabrication constraints, aligning with additive manufacturing best practices for functional polymer components [2].

6.2 - Final Modelling

Following the conceptual development, CAD modelling was initiated to translate sketches into printable geometries. This stage was critical to evaluate tolerances, assembly logic, and printing feasibility. The modelling phase was structured around two iterations: a first version developed through parametric modelling (V1), and a second version designed through direct modelling (V2), informed by the failure mechanisms identified during co-printing tests.

6.2.1 - Modelling through the experienced methodology

The modelling methodology applied in this project was developed progressively through iterative prototyping. It combined dimensional reference from existing freeride wheels with experimental constraints defined during printing trials in Chapter 5.

Freeride Wheel V1 was modelled using Grasshopper and Rhino, since its geometry required a parametric approach to generate the internal bridging interface between the core and the tread. Freeride Wheel V2 was developed exclusively in Rhino, due to the need for more direct control over mechanical details such as screw channels, press-fit tolerances, and cantilever locking geometries.

This modelling approach is coherent with established design methodologies for additive manufacturing, where iterative CAD refinement becomes inseparable from process testing due to the sensitivity of flexible polymers to print parameters and bonding mechanics [2].

6.2.2 - Reproduction of alternatives

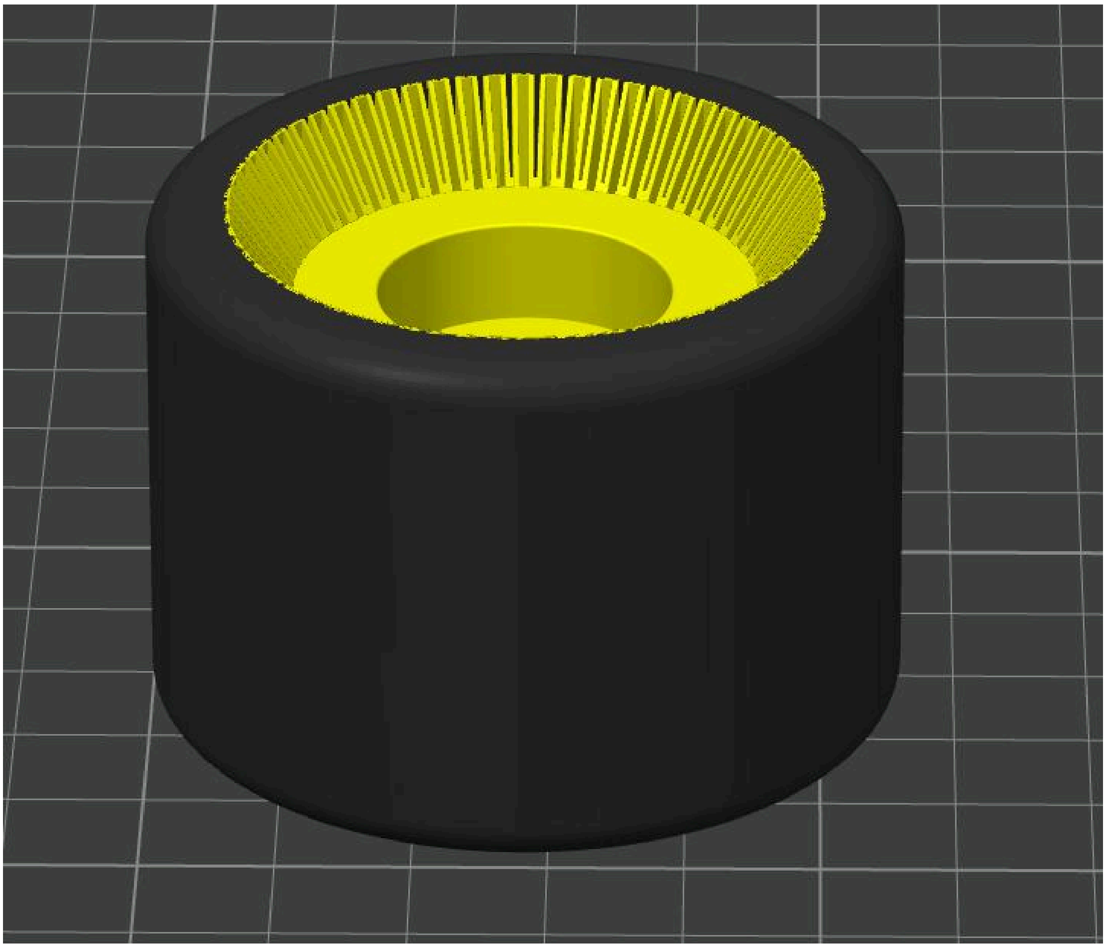
Freeride Wheel V1 — Co-printing hypothesis

Freeride Wheel V1 was designed to be printed as an integrated component combining:

> Rigid core (PLA)

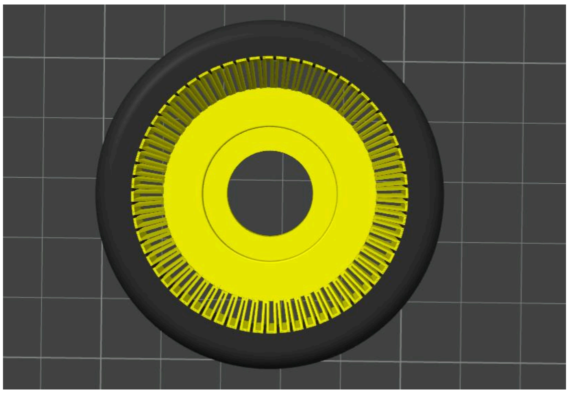
> Flexible tread (TPU 95A)

> Bridge interfacing both materials (PLA)



Img. 107 - V1 model to be 3D printed, picture by the author.

A zig-zag bridging pattern was generated to connect both materials mechanically, since direct adhesion between PLA and TPU is generally weak. The bridging geometry was developed as a transverse structural interface, based on nozzle-width logic and extrusion constraints. The objective was to create a physical “anchor” system, ensuring that the core could not detach from the tread even under torsional stress.



The wheel dimensions for V1 were:

Diameter: **56 mm**

Contact patch: **40 mm**

Core diameter: **44 mm**

This design attempted to replicate the structural advantages of traditional longboard wheel hubs, while reducing assembly steps. However, the complexity of co-printing flexible and rigid polymers using AMS technology introduced significant reliability risks, which directly influenced the redesign path.

Img. 108 - V1 printing attempt, picture by the author.

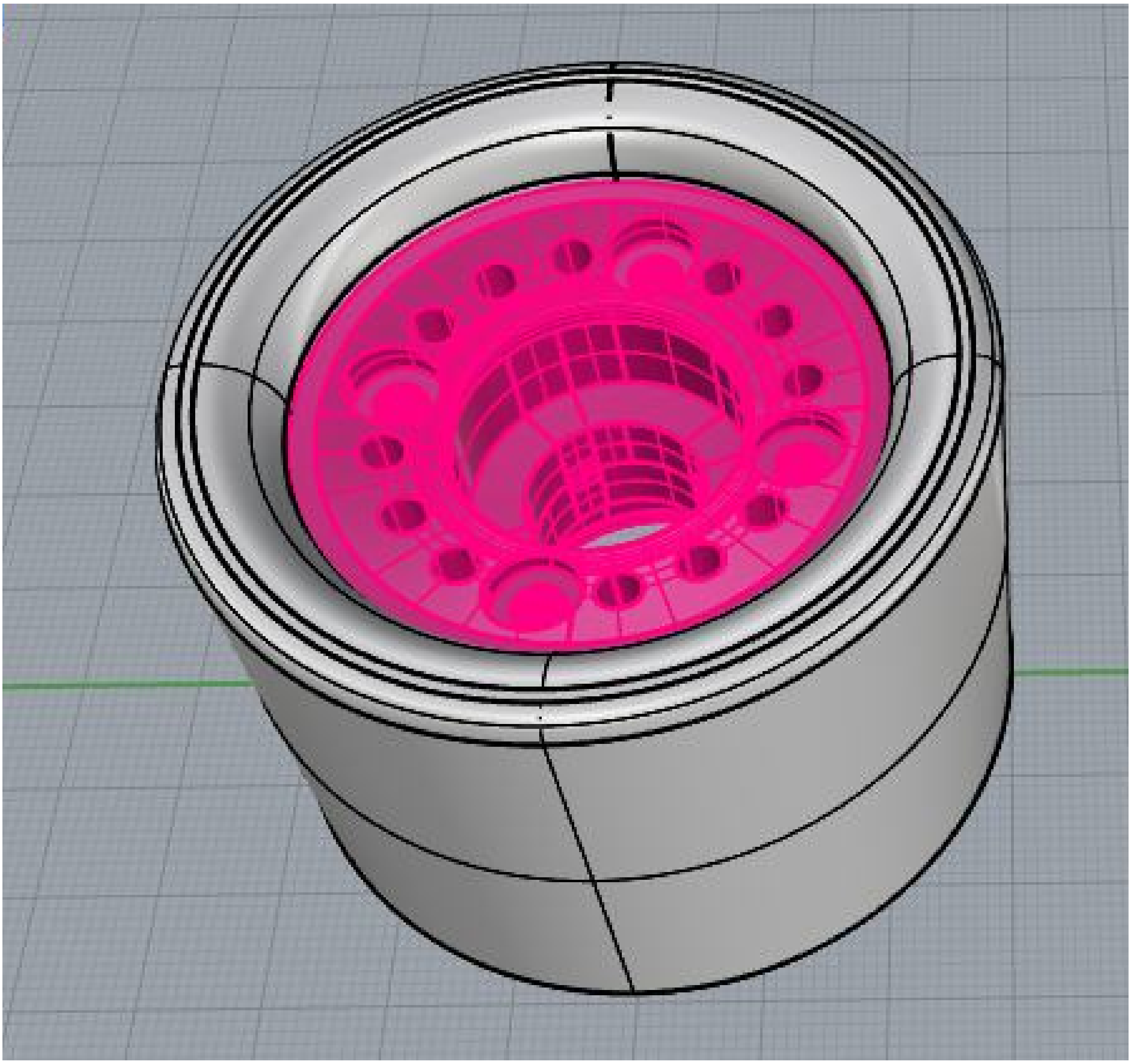
Freeride Wheel V2 — Modular assembly solution

After V1 was discarded, the redesign phase shifted toward separated printing and mechanical assembly. V2 was developed as a modular system composed of:

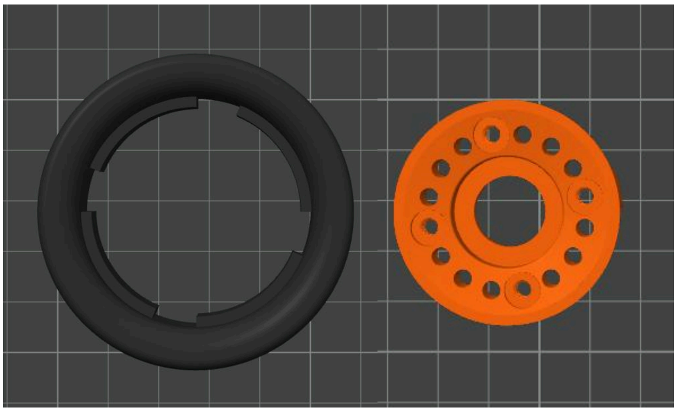
> A fully printed tread (TPU 95A)

> A two-part rigid core (PLA prototype)

> A fastening system using four 30 mm M3 screws and nuts



Img. 109 - Modelling of V2 (assembled), picture by the author.

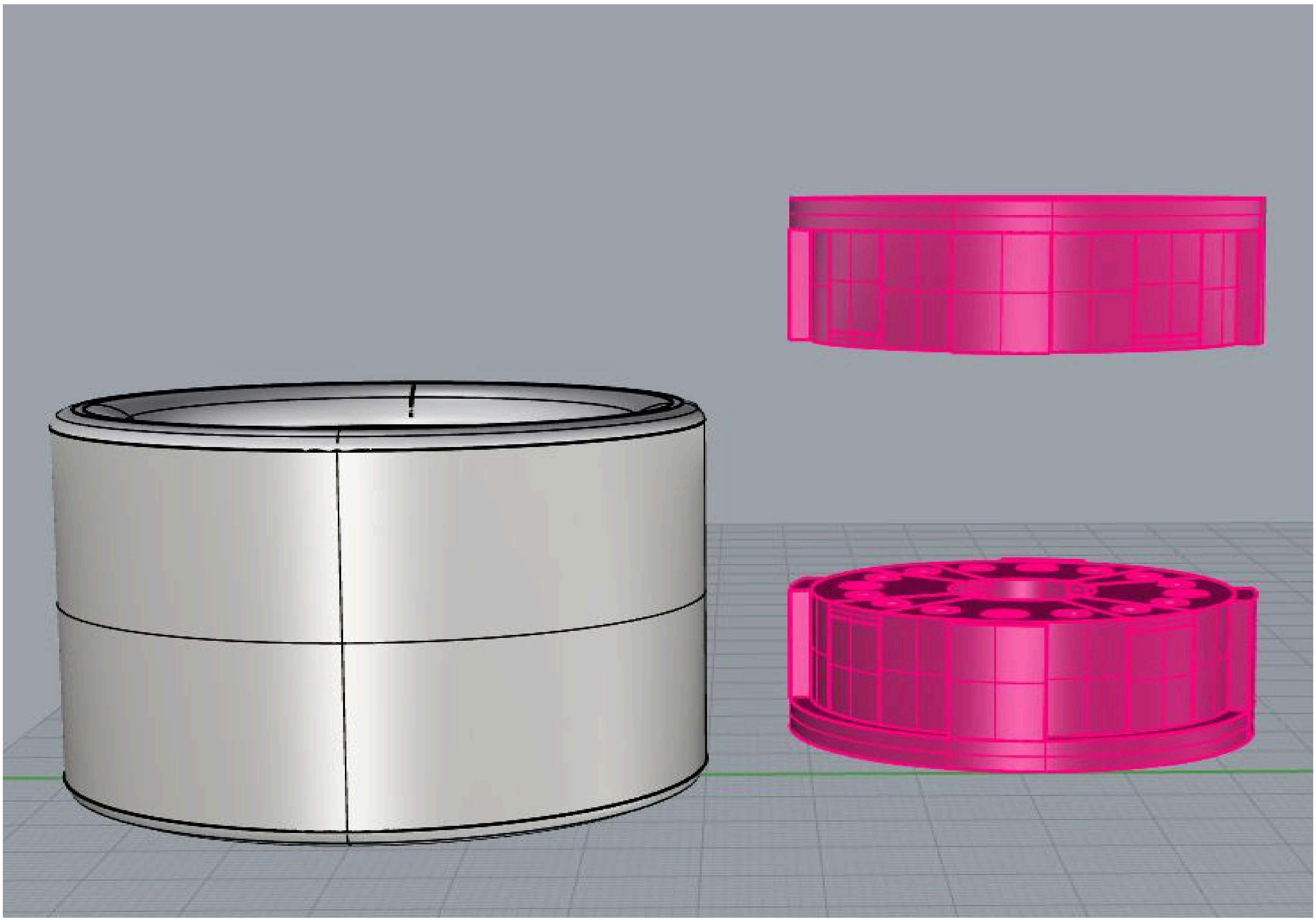


The wheel dimensions for V2 were:

Diameter: **60 mm**

Contact patch: **45 mm**

Core diameter: **44 mm**



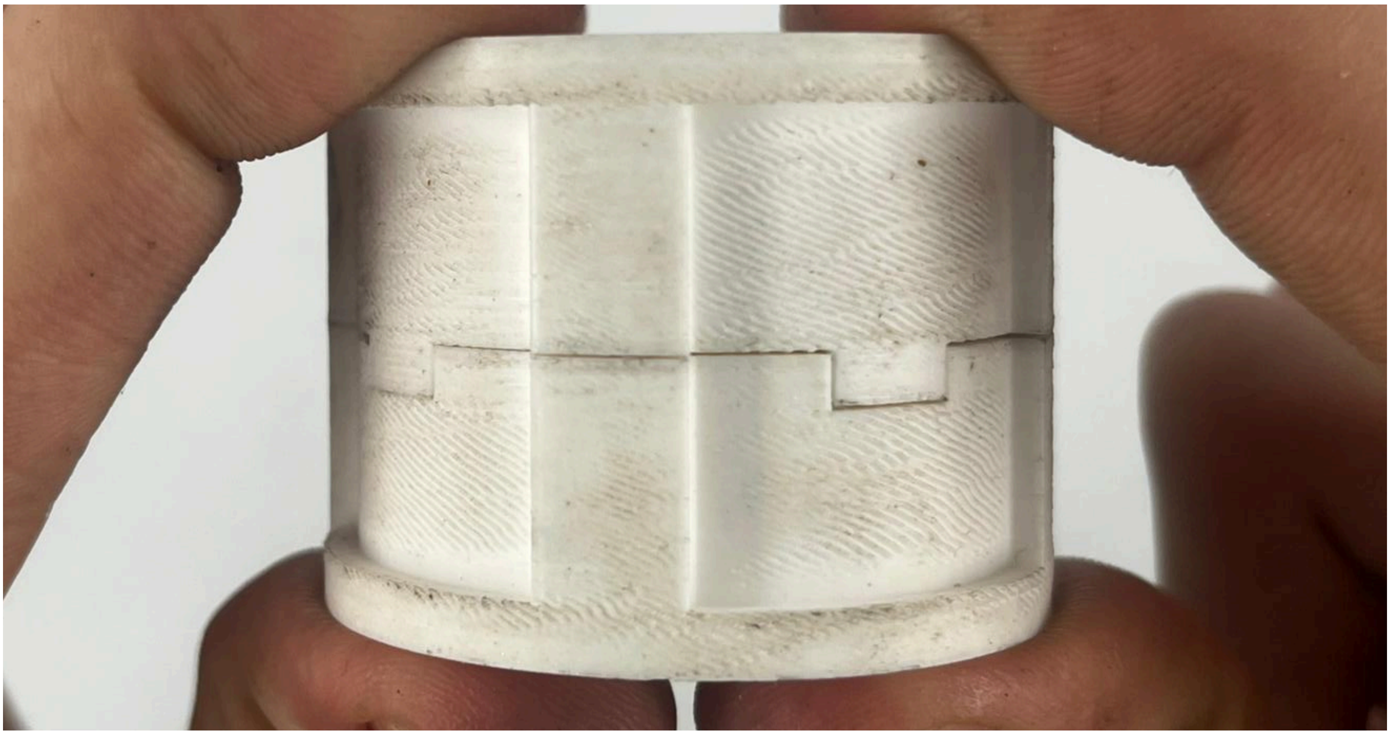
Img. 110 - Modelling of V2 (dissasembled), picture by the author.

The core geometry introduced 16 radial holes, including four aligned screw channels. This layout was designed to reduce weight while maintaining stiffness. The split-core strategy ensured that assembly could be achieved without deforming the tread and without requiring adhesives.
From a circular design perspective, V2 is more aligned with sustainability goals, as it supports repairability, part replacement, and extended use-life through modular maintenance [1].

6.2.3 - Fine detailing of shape

Fine detailing focused on optimizing both performance and printability. The tread was designed with:

> Smooth external surface
> Rounded lips (~1.5 mm)
> No grooves
> Slight chamfer at the core interface (conical surface)



Img. 111 - Joint improvement on V2, picture by the author.

The absence of grooves was intentional: while grooves can reduce rolling friction and improve water dispersal, they can also introduce stress concentration and wear initiation points in polymer wheels. A smooth surface maximizes uniform contact patch and facilitates predictable sliding behavior, which is essential for freeride applications.

For printing performance, the tread was modelled as a vertical cylinder, ensuring that the layer direction followed the wheel circumference and supporting structural continuity. The core was modelled for horizontal printing orientation, improving bearing seat accuracy and screw alignment.

These refinements align with additive manufacturing research that highlights the impact of print orientation and layer anisotropy on polymer mechanical performance [2].

6.3 - Prototyping

The prototyping stage aimed to validate the mechanical feasibility of the assembly-based system and confirm that the modular configuration could withstand basic stress conditions. Prototyping was also essential to evaluate tolerance accuracy, repeatability, and print stability across different printers.

6.3.1 - Cost and process

Prototyping was performed using two Bambu printers:

> Bambu P1S, used primarily for printing the tread
> Bambu A1, used primarily for printing the core (though the P1S could also be used)

The slicing workflow was managed through Bambu Studio, ensuring consistent parameter tracking.

The materials used were:
> Flexmark 9 TPE-U (TPU) TreeD for the tread
> Generic PLA for the core prototypes

At this stage, PLA was adopted exclusively as a prototyping material, due to its low cost and reliable print performance. The objective was not to validate the final mechanical polymer system, but to confirm geometric feasibility, bearing fit, and assembly behavior.

This approach reflects standard iterative development logic in additive manufacturing, where preliminary validation is often conducted with accessible materials before transitioning to performance-grade polymers [2].

6.3.2 - Results

The prototyping outcomes clearly demonstrated that V2 provided superior reliability and repeatability compared to V1. The printed tread, produced with 100% infill and concentric pattern, exhibited high resistance and dimensional stability. The press-fit tolerance between tread and core was designed with 0 mm tolerance, and assembly could be achieved manually without sanding.

The bearing seat was designed with 0.1 mm tolerance, ensuring that rigid bearing insertion remained feasible without causing cracking or deformation.

The core printing settings included:

Infill: 70%
Pattern: honeycomb
Walls: 4 walls (1.6 mm)

The tread printing settings included:

Infill: 100%
Pattern: concentric
Walls: 12 walls (4.8 mm)

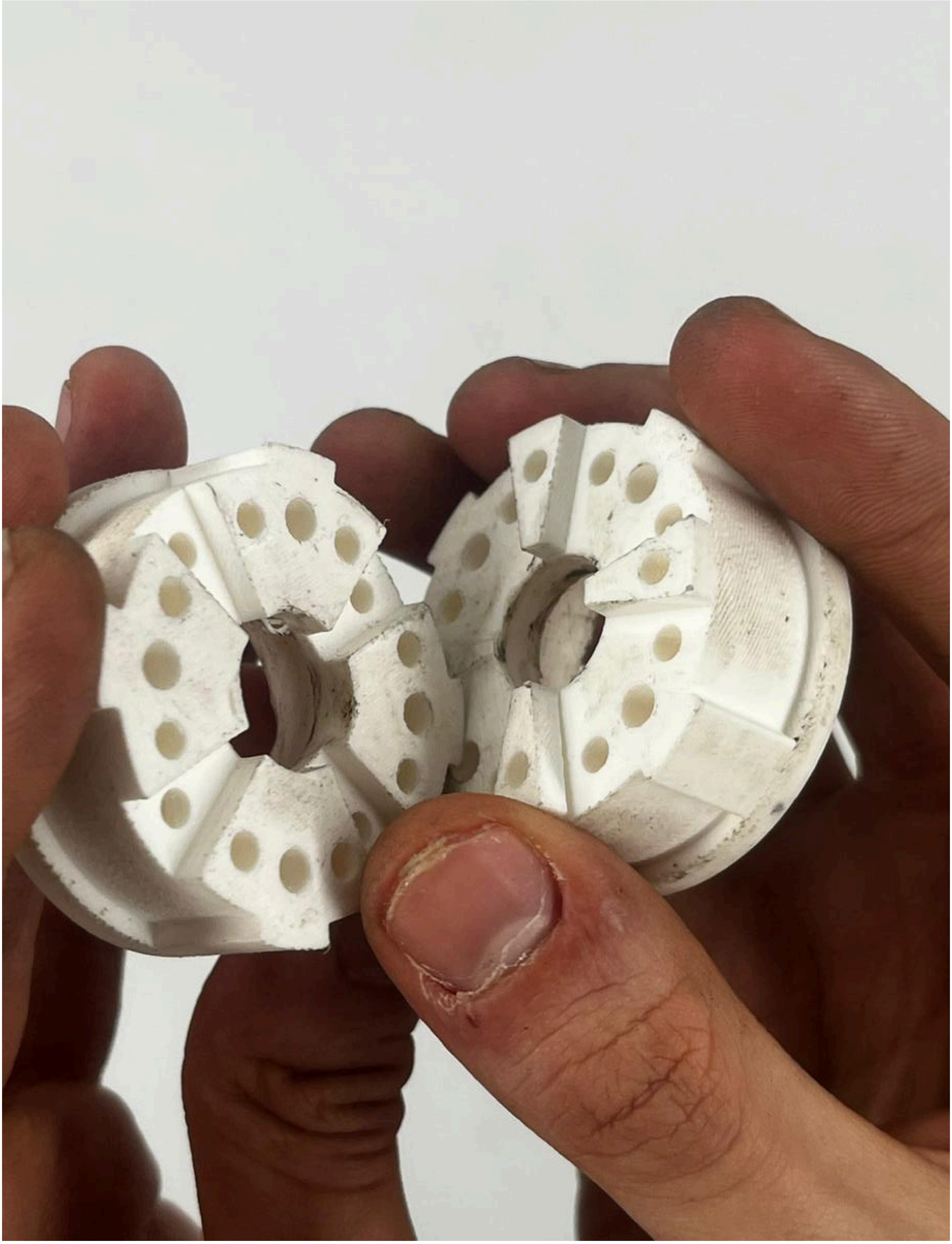
Img. 112 - Prototype of V2, picture by the author.

The layer height used was 0.2 mm, with a 0.4 mm nozzle, and outer wall print speed of 200 mm/s for TPU.

These results confirm that flexible polymer wheels can be manufactured successfully through FDM when geometry and parameters are optimized to avoid collapse and ensure structural continuity, consistent with experimental findings in TPU additive manufacturing literature [2].

Img. 113 - Prototype of V2 (assembly by press-fit), picture by the author.

Img. 114 - Prototype of V2 (internal view), picture by the author.



Img. 115 - Prototype of V2 (separated core), picture by the author.

Img. 116 - Prototype of V2 (TPU tire), picture by the author.

Img. 117 - Prototype of V2, picture by the author.

6.3.3 - CMF

The prototype CMF (Color, Material, Finish) strategy was intentionally minimal, focusing on functional evaluation rather than aesthetic exploration. The tread was printed in black TPU, approximating the visual language of conventional freeride wheels and allowing easier observation of surface defects and layer irregularities. The core was printed in PLA, enabling rapid iteration and visible identification of screw channels and bearing seats.

Although the aesthetic outcome remains secondary in this stage, CMF still supports communication of modular intent: the visible differentiation between rigid hub and flexible tread makes the wheel's assembly logic immediately readable, reinforcing the product-service potential of replaceable components [1].

Img. 118 - Prototype of V2 (front view), picture by the author.

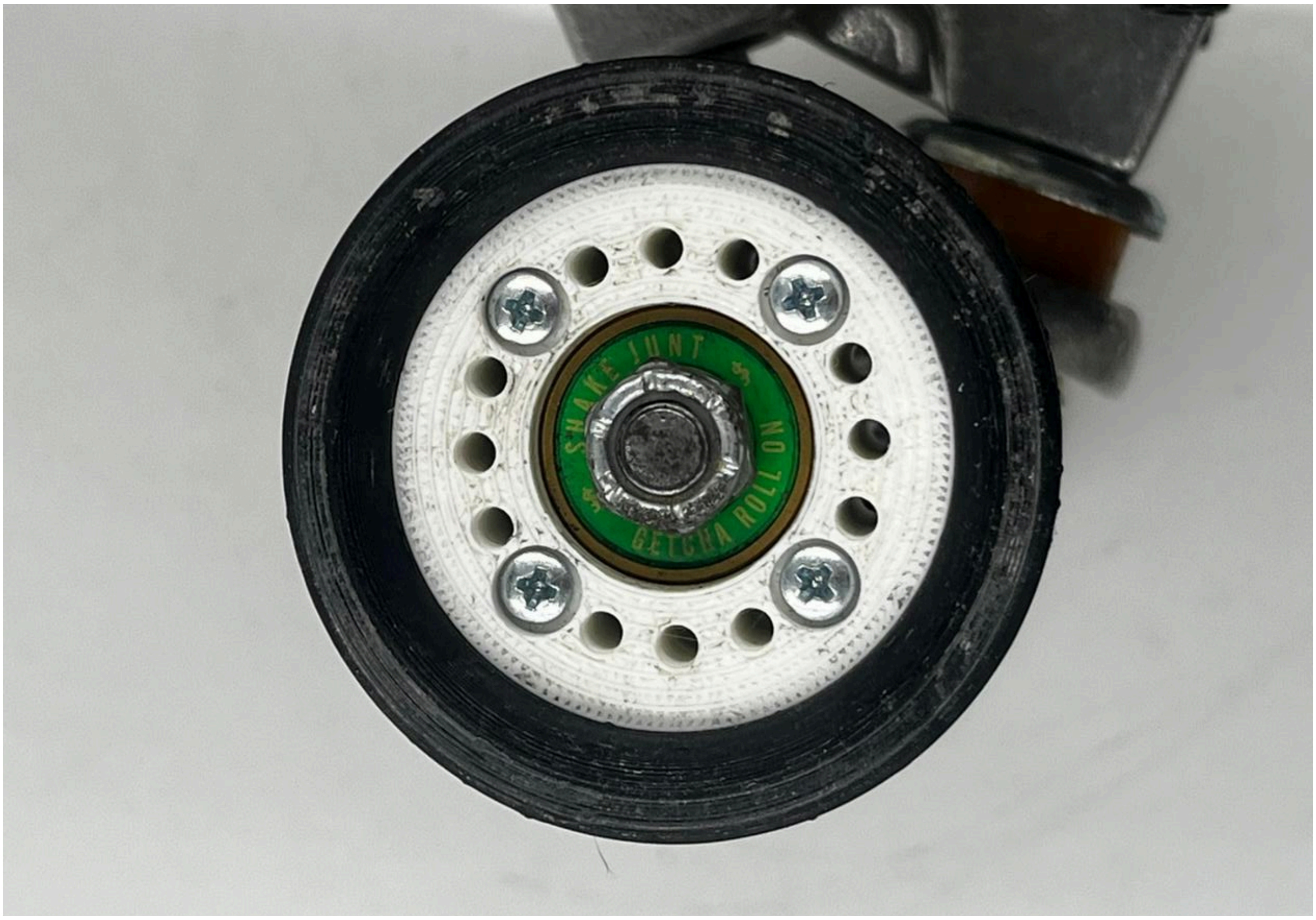
6.4 - Testing

The testing phase conducted in this chapter consisted of preliminary validation procedures. While not yet scientifically comparable to standardized mechanical testing, the procedures were sufficient to verify feasibility and identify critical design weaknesses before advancing to the final product stage.

6.4.1 - Prototype testing

Testing was performed through manual evaluation and functional assembly validation, including:

Hand compression testing of tread deformation
Torsion resistance check between tread and core
Drop test evaluation
Bearing insertion test (608 standard)
Spin test to evaluate rollability and bearing friction



Img. 119 - Bearing insertion test + spin test documentation, picture by the author.

Results indicated that the wheel assembly demonstrated strong structural consistency. The core remained locked within the tread under torsion testing by hand, and bearing insertion was successful without visible cracking. The wheel was also capable of free spinning, suggesting that the design avoided excessive friction or deformation at the bearing interface.

These findings provide a preliminary confirmation that the V2 press-fit assembly can function as a freeride-capable configuration. However, additional riding-based validation is required to confirm real friction behavior and long-term durability.

Img. 120 - Bearing insertion test + spin test documentation, picture by the author.

6.5 - Iterative impressions

The redesign phase documented in this chapter demonstrates how additive manufacturing constraints can actively shape product architecture. The failure of V1 was not merely a technical obstacle, but a design driver that redirected the system toward modular assembly and improved circular potential.

V1 highlighted the limitations of AMS-based co-printing with flexible polymers, particularly in relation to extrusion stability and multi-material workflow. The clogging failure observed after the third layer confirmed that multi-material integration is not always feasible in prototyping environments without specialized hardware or compatible filaments.

Img. 121 - Prototype iteration, picture by the author.

V2, in contrast, established a repeatable and scalable approach. By separating tread and core printing, the design improved manufacturability, reduced risk to equipment, and increased repairability. The modular logic enables the replacement of damaged treads without discarding the full wheel, aligning with circular economy strategies based on maintenance and part substitution [1].

The project also introduced a secondary hypothesis: eliminating screws entirely by implementing a male-female angled joint between the two core halves. This approach would simplify assembly and reduce metal hardware dependency, but remains untested and therefore cannot yet be considered validated.

Img. 122 - Prototype iteration, picture by the author.

Overall, the chapter confirms that the modular freeride wheel system is structurally feasible and operationally coherent for further development. The next stage of the project will transition from prototyping materials toward final sustainable material selection. This includes replacing PLA with a more durable core polymer such as PA11 (nylon) and replacing conventional TPU with Balena.Filaflex, a biodegradable flexible filament, to evaluate performance while strengthening environmental compatibility. These developments will be addressed through the final prototype configuration and performance testing in Chapter 7.

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CHAPTER SEVEN:

SAMSARA WHEELS

CLOSED-LOOP SOLUTION FOR DOWNHILL & FREERIDE SKATE

The final chapter presents the ultimate outcome of the design research, consolidating material, structural, and assembly decisions into a coherent product that aligns with the research question: “How to apply circular economy principles to the development of sports wheels, maximizing durability and minimizing waste through innovative technical solutions?” Building on the development process documented in Chapters 4–6, this chapter details the final wheel system design, its material strategy, prototyping implementation, and preliminary testing outcomes, with a focus on sustainable material selection, assembly logic, and product-service value.

Img. 123 - Samsara Wheels render, picture by the author.

7.1 - Problem Throwback and Design Objective

This chapter consolidates the final outcome of the research and translates the previously defined circular economy principles into a manufacturable and modular freeride wheel system. The initial research question guiding the project was:

How to apply circular economy principles to the development of sports wheels, maximizing durability and minimizing waste through innovative technical solutions?

Within the downhill and freeride longboarding context, wheels represent a consumable component: high friction, abrasion, and repeated sliding progressively remove polyurethane material and lead to frequent replacement. While the market is dominated by performance-driven products, sustainability remains marginal, often limited to partial bio-based formulations rather than systemic circular solutions. Therefore, the final design aims to integrate circular strategies such as component separation, repairability, reuse, and modular replacement, consistent with contemporary circular economy frameworks. In particular, the approach aligns with the principles outlined by Velenturf and Purnell, which emphasize systemic interventions and functional durability rather than isolated material substitution alone [1].

Img. 124 - Prototype tread using Filaflex Foamy, picture by the author.

7.2 - Final Product and Service Outcomes

The final product is a modular freeride wheel designed to combine additive manufacturing feasibility with circular economy intent. This system is based on the separation of wheel components into a reusable structural core and a replaceable tread band. The design is supported by iterative prototyping and validation, as developed in Chapter 6, and refined here into its final specification.

This chapter describes the final system's material selection, assembly logic, and the product-service approach that emerges from the modular design.

Img. 125 - Samsara Wheels, AI generated.

7.2.1 - Sustainable Circular Economy Approach

A circular economy strategy in sports equipment requires addressing the inherent contradiction between performance and wear. Downhill freeride wheels are intentionally designed to lose material through abrasion, which makes their environmental burden strongly tied to consumption rate. Therefore, sustainability must be embedded not only through the selection of alternative materials, but through a redefinition of product architecture.
Velenturf and Purnell argue that a sustainable circular economy must prioritize long-term system redesign, including maintenance and repair pathways, rather than treating circularity as a purely recycling-based objective [1].

Applying this logic to freeride wheels suggests that a meaningful circular intervention must aim to:

- extend product lifespan through replaceable parts,
- reduce waste by minimizing full-component disposal,
- allow repeated use cycles through repair and modular upgrades,
- enable local and on-demand manufacturing through distributed fabrication.

The final wheel system integrates these principles by structurally separating the wheel into independent components and allowing controlled disassembly, thus shifting wheel consumption from “complete replacement” to “partial renewal.”

Img. 126 - Worn wheels (Butterballs and Cannibal), picture by the author.

7.2.2 - Final Material Selection:

Alfanylon CF Core and Ballena Filaflex 82A Tread

The final wheel is defined by a two-material system selected for structural reliability and sustainable potential:

- Core material: Alfanylon CF (Nylon + Carbon Fiber)
- Tread material: Ballena Filaflex 82A (biodegradable TPU-based filament)

Img. 127 - Printing material detail (Nylon in black / biodegradable TPU in beige), picture by the author.

For the core, FILOALFA® Alfanylon CF — a carbon-fiber-reinforced polyamide (PA) filament — was chosen due to its well-documented high mechanical and chemical performance. Alfanylon CF consists of a nylon matrix enriched with carbon fiber, resulting in prints that resist impact, abrasion, and chemical exposure while offering good dimensional stability and mechanical rigidity, qualities that are desirable for load-bearing, structural components such as wheel cores and hubs [turn0search1] [turn0search3]. These attributes are consistent with broader evidence that carbon-fiber-reinforced nylon filaments improve stiffness, heat resistance, and dimensional accuracy relative to unfilled nylons, making them suitable for functional prototypes and end-use parts in demanding applications [turn0search12].

For the tread, Ballena Filaflex 82A was selected as a flexible elastomeric filament intended to provide grip and controlled damping properties. Ballena presents the material as biodegradable and designed for circular material pathways, distinguishing it from conventional TPUs used in additive manufacturing [2]. The manufacturer highlights a sustainability approach based on biodegradation under controlled conditions and circular production logic, positioning the material as a potential alternative for components that inherently degrade by wear [2], [3]. Additionally, existing research supports the growing relevance of bio-based and biodegradable elastomers, including polyurethane-based systems, as a pathway for reducing environmental burden while maintaining mechanical performance [4], [5].

Img. 128 - Balena filaflex representation, by Balena.science.

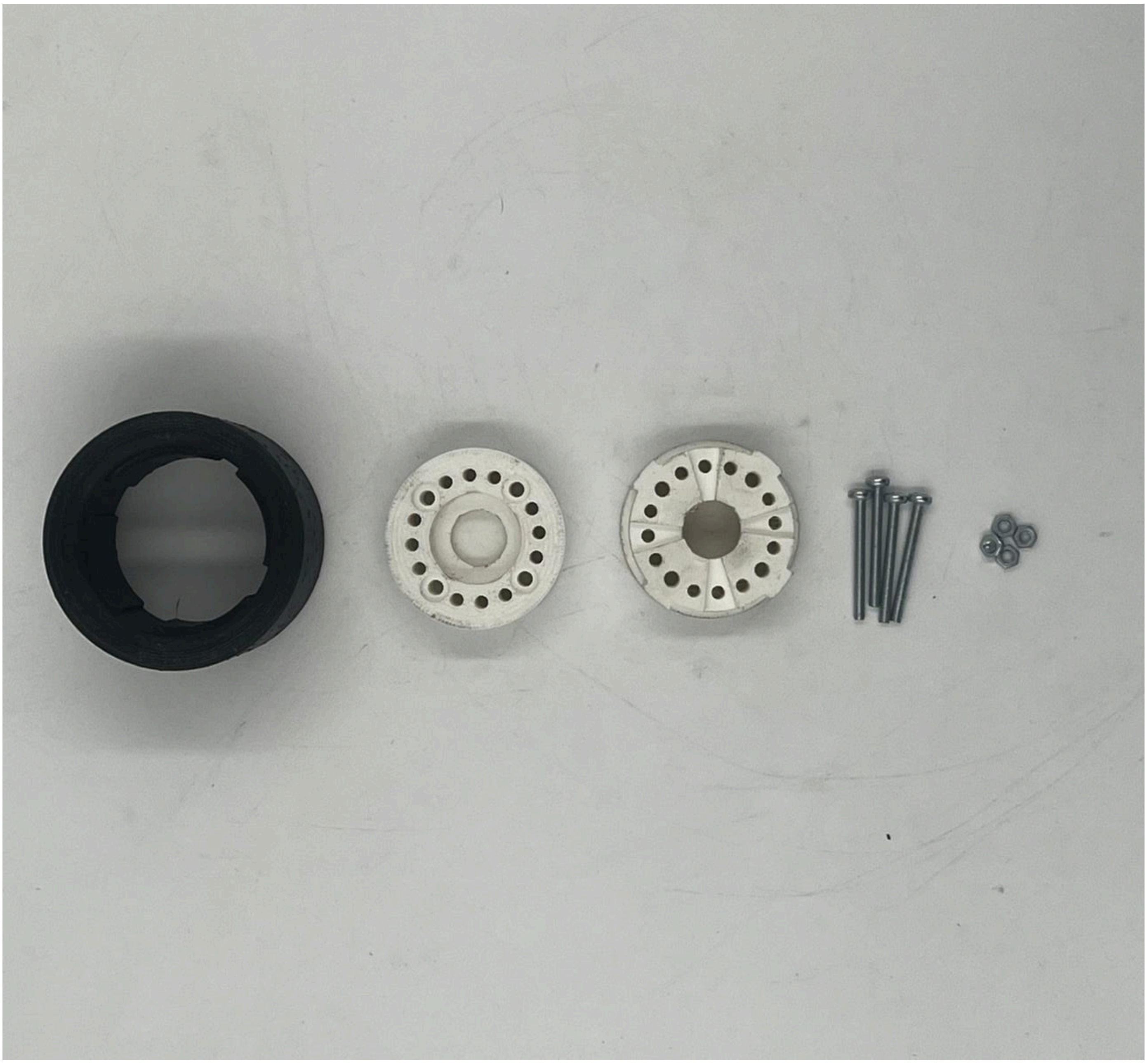
The final material selection therefore reflects a dual objective: ensuring performance-oriented mechanical reliability while reinforcing circularity through bio-based polymer pathways.

7.2.3 - Part and Assembly Logic

The final wheel architecture is composed of two main modules:

1. Reusable structural core (PA11)
2. Replaceable tread band (Ballena Filaflex 82A)

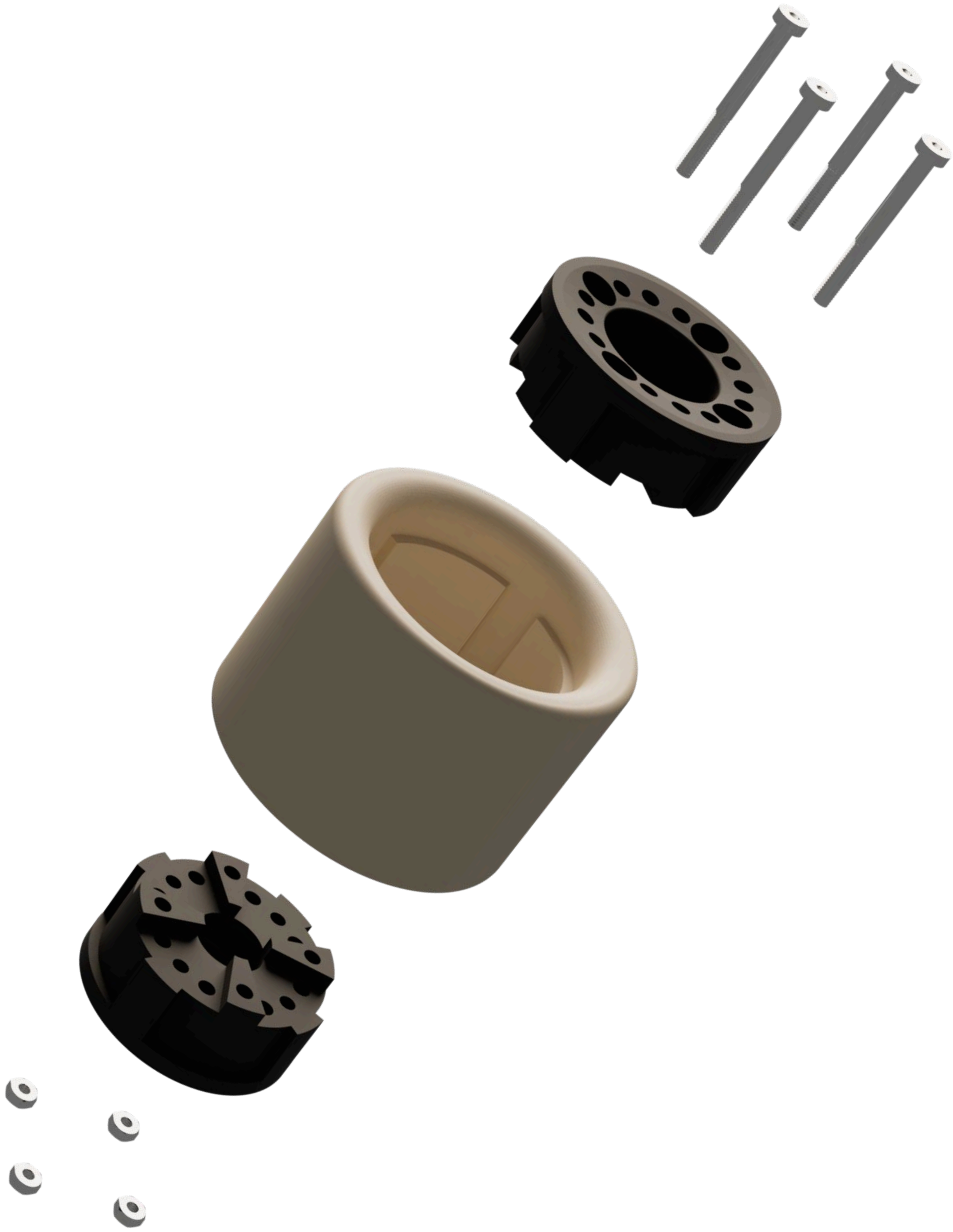
The core is divided into two symmetrical halves, enabling internal insertion into the tread without destructive deformation. Once inserted, the core is locked through a male/female press-fit interface designed with angled walls (24°), improving mechanical stability under radial forces.



Img. 129 - Samsara Wheel components, picture by the author.

A key outcome of the development process is the integration of two possible fixation strategies:

1. Press-fit assembly (screwless configuration)
2. Press-fit + screw reinforcement (optional tightening configuration)



Img. 130 - Samsara wheel exploded render, picture by the author.

Img. 131 - Samsara Wheels render, picture by the author.

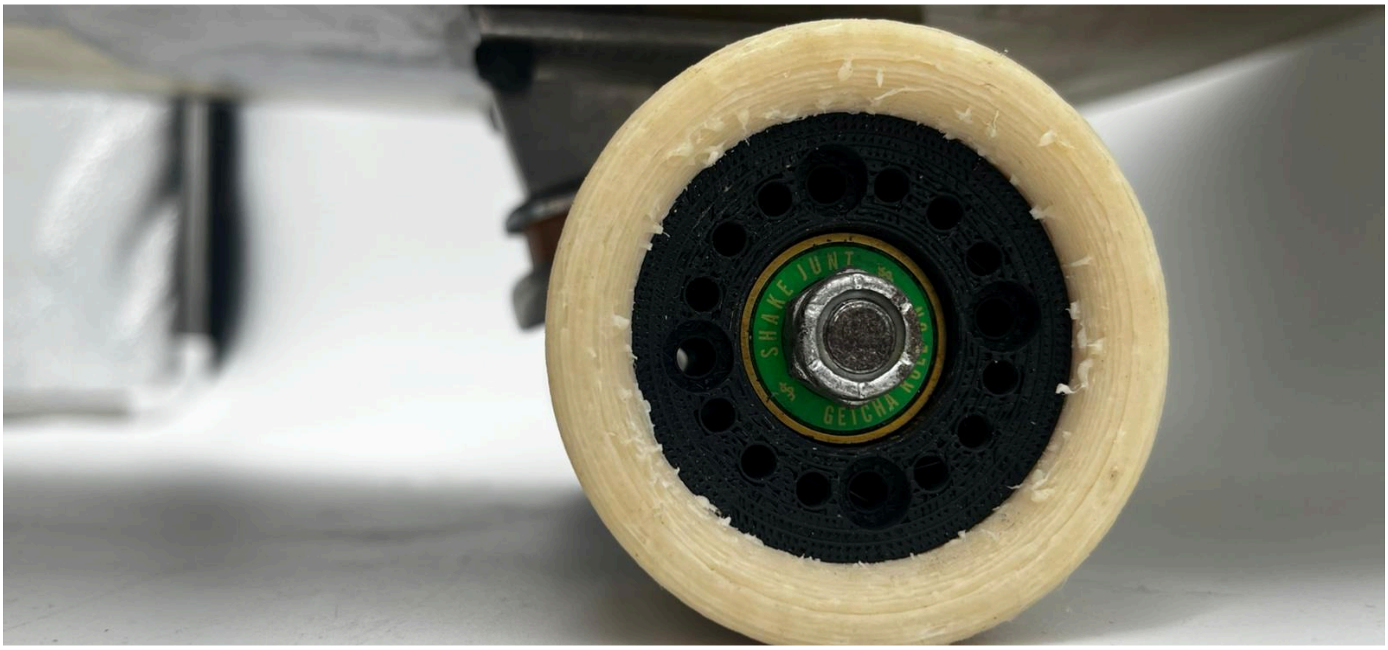
Img. 132 - Samsara Wheels on road render, picture by the author.

7.2.4 - Product and Service Outcomes

The modular design naturally generates a product-service system logic. Instead of replacing a complete wheel, the user can:

- maintain the core as a long-term durable element,
- replace only the worn tread,
- experiment with alternative treads (different hardness or profiles),
- extend product life through maintenance cycles.

The core is divided into two symmetrical halves, enabling internal insertion into the tread without destructive deformation. Once inserted, the core is locked through a male/female press-fit interface designed with angled walls (24°), improving mechanical stability under radial forces.

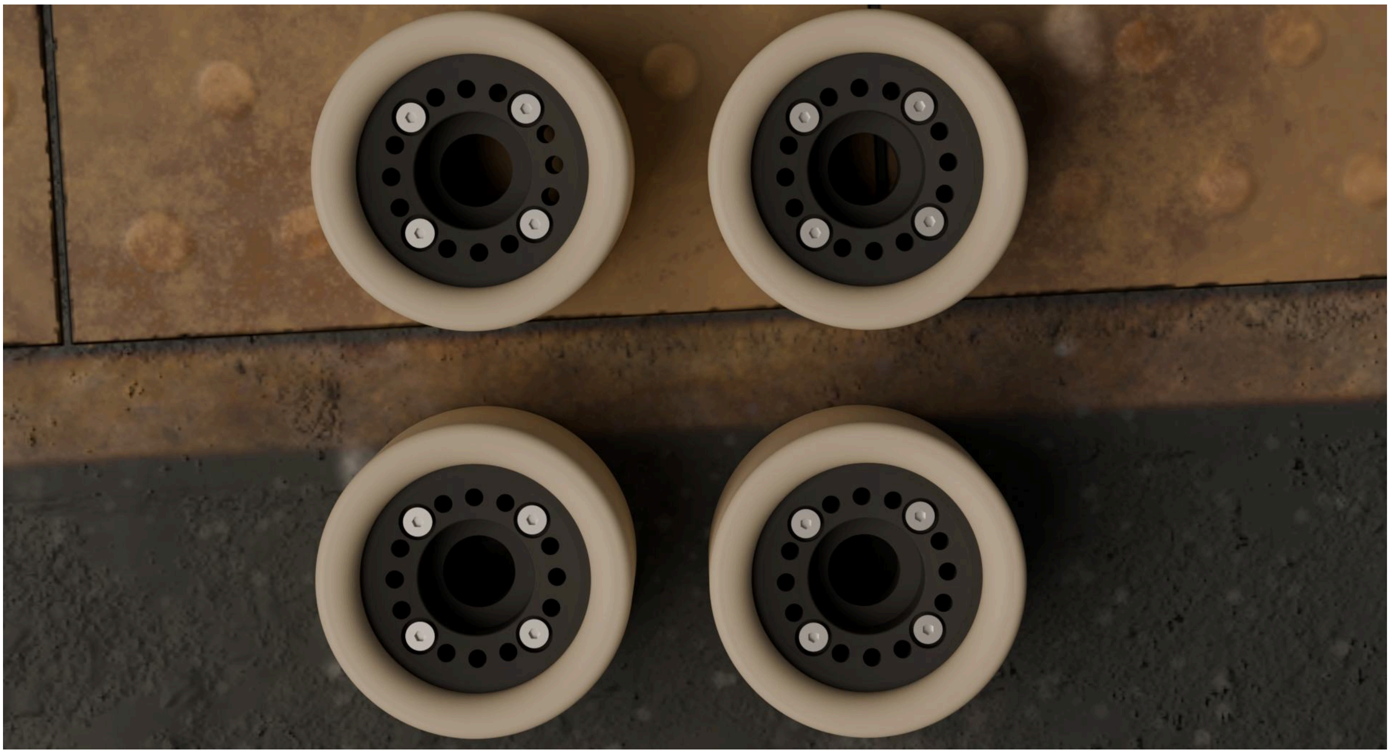


Img. 133 - Samsara Wheel assembled on skate, picture by the author.

This approach aligns with circular economy frameworks that encourage service-based product renewal, emphasizing functional value retention rather than linear consumption [1].

From a market perspective, the system could enable a new distribution model where manufacturers supply tread bands as consumable modules and offer core replacement only when structurally necessary. Additionally, the system is compatible with localized production: treads could be fabricated on-demand in decentralized facilities, potentially reducing transportation emissions and overproduction.

For the tread, Ballena Filaflex 82A was selected as a flexible elastomeric filament intended to provide grip and controlled damping properties. Ballena presents the material as biodegradable and designed for circular material pathways, distinguishing it from conventional TPUs used in additive manufacturing [2]. The manufacturer highlights a sustainability approach based on biodegradation under controlled conditions and circular production logic, positioning the material as a potential alternative for components that inherently degrade by wear [2], [3]. Additionally, existing research supports the growing relevance of bio-based and biodegradable elastomers, including polyurethane-based systems, as a pathway for reducing environmental burden while maintaining mechanical performance [4], [5].



Img. 134 - Samsara Wheels render, picture by the author.

The presence of screw holes is intentionally maintained in the final core design. This ensures adaptability: if tighter mechanical locking is required after long-term riding, screws can be inserted without redesigning the core. This dual strategy enhances reliability while maintaining modularity and user-controlled maintenance.

The tread itself is designed as a continuous cylindrical band with rounded lips and a smooth surface. This configuration supports freeride use by reducing unpredictable catching and enabling controlled sliding behavior, consistent with established wheel geometry strategies discussed in Chapter 2.

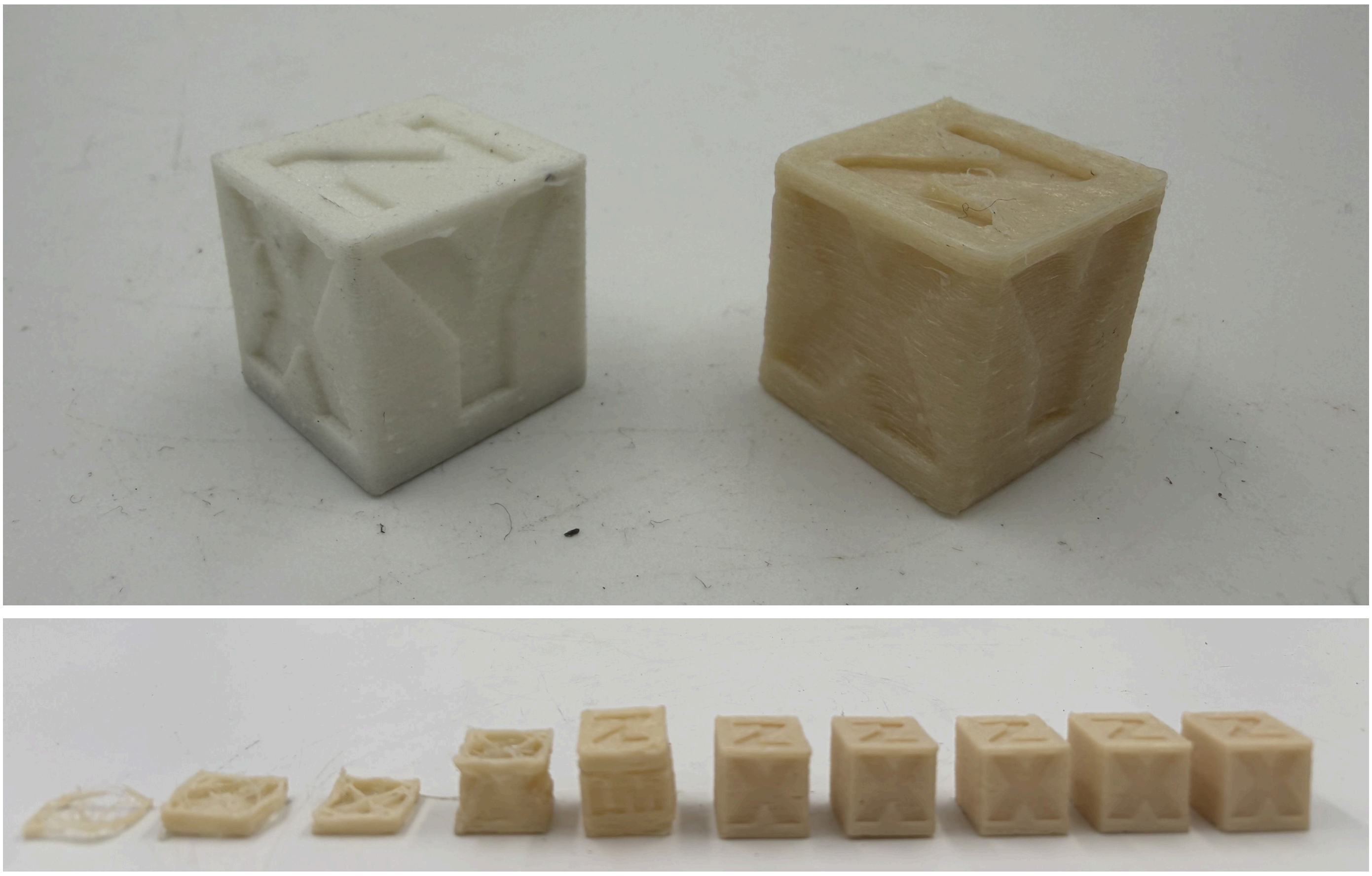
7.3 - Prototyping

This section presents the final prototyping process and defines how additive manufacturing enabled both rapid development and functional refinement of the wheel system.

7.3.1 - Cost and Process

The final prototype was produced using a distributed additive manufacturing workflow:

- Bambu P1S for the tread printing
- Bambu A1 / Bambu P1S for the core printing
- Slicing software: Bambu Studio



Img. 135 - Material (Ballena.filaflex) calibratrion, picture by the author.

The tread was printed in a vertical cylindrical orientation to ensure a continuous circumferential deposition path, supporting surface continuity and abrasion resistance. The core was printed flat on the bed, maximizing dimensional accuracy and structural consistency of the bearing seat region. Print parameters used for functional consistency included:

Print parameters used for functional consistency included:

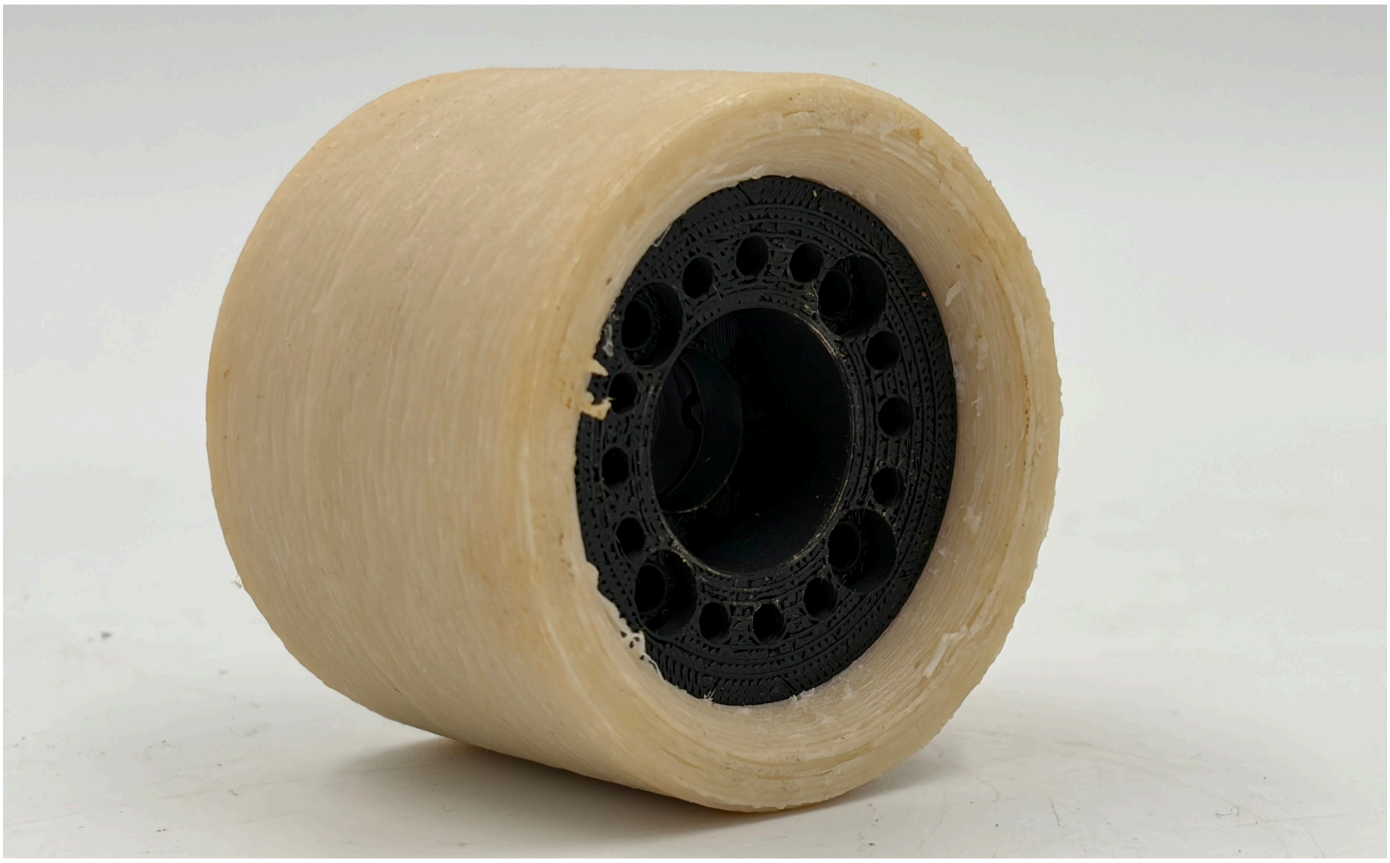
- nozzle diameter: 0.4 mm (core) / 0.8mm (tread)
- layer height: 0.2 mm
- tread infill: 100% concentric
- tread walls: 12 walls (4.8 mm)
- core infill: 70% honeycomb
- core walls: 4 walls (1.6 mm)

Img. 136 - Samsara Wheel, picture by the author.

This configuration was consistent with the validated results of Chapter 5, where high infill and rigid patterns were shown to preserve rollability while avoiding excessive deformation.

7.3.2 - Results

The final prototype resulted in a structurally stable wheel with a clear functional division between the tread and the core. The tread achieved a consistent surface finish and sufficient rigidity to resist manual torsion.
The modular architecture proved effective in assembly: the core could be inserted and locked inside the tread without sanding or tolerance adjustment, confirming that the press-fit system was feasible with 3D printing accuracy.



Img. 137 - Samsara Wheel corner view, picture by the author.

Weight results were recorded as follows:

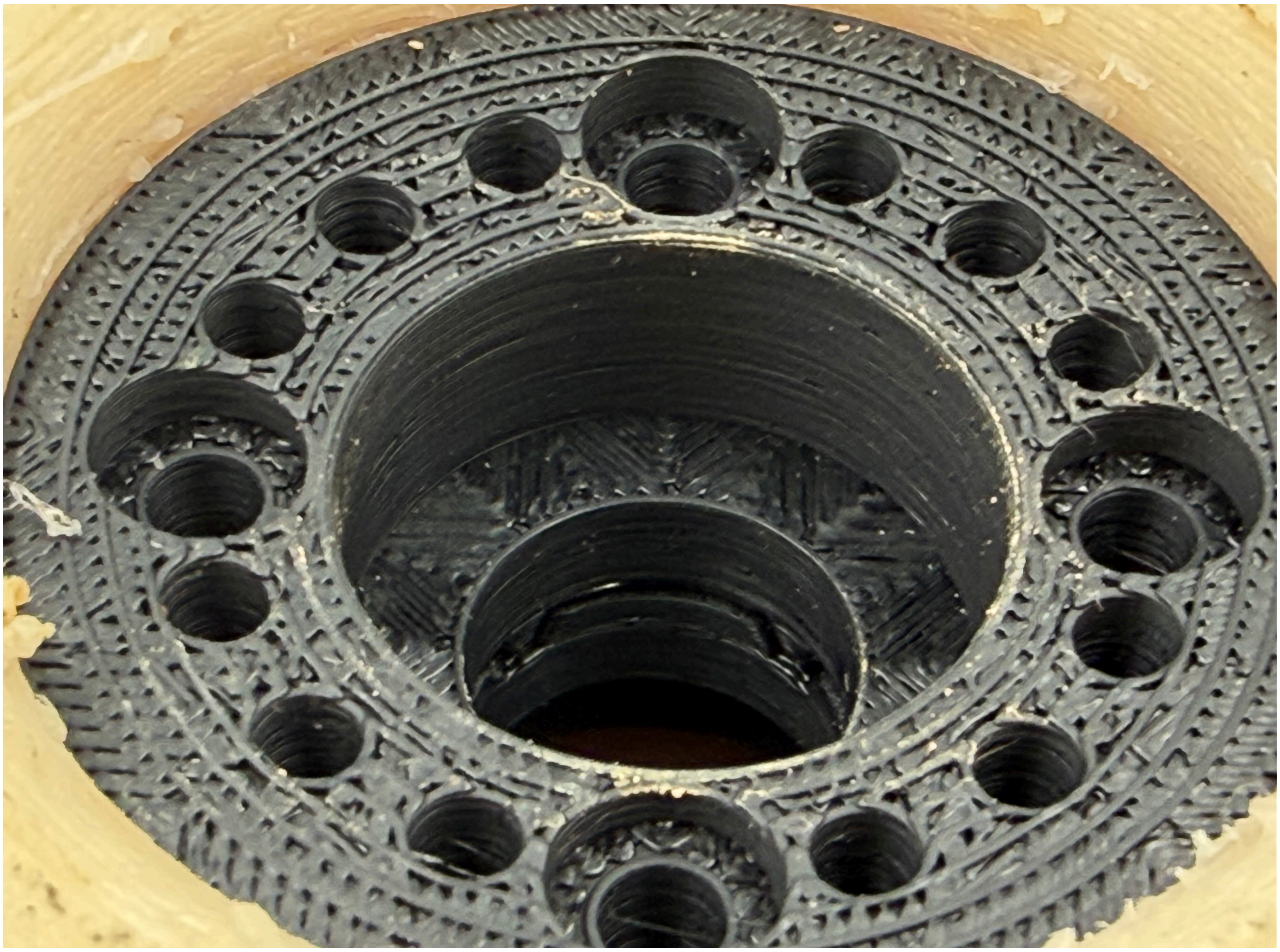
- tread: 60 g
- core: 31 g
- assembled wheel: 91 g
- assembled wheel with screws and nuts: 100 g

This represents a moderate increase compared to conventional freeride wheels, but remains within a feasible range for functional riding. The increased mass is partly explained by the structural thickness required for durability in printed polymers and the modular locking geometry.

7.3.3 - CMF (Color, Material, Finish)

The final CMF strategy reinforces both functional legibility and sustainability intent. The wheel system is composed of:

- Natural beige/grey tread (Ballena Filaflex 82A)
- Opaque black core (PA11)



Img. 138 - Printing details of Samsara Wheels, picture by the author.

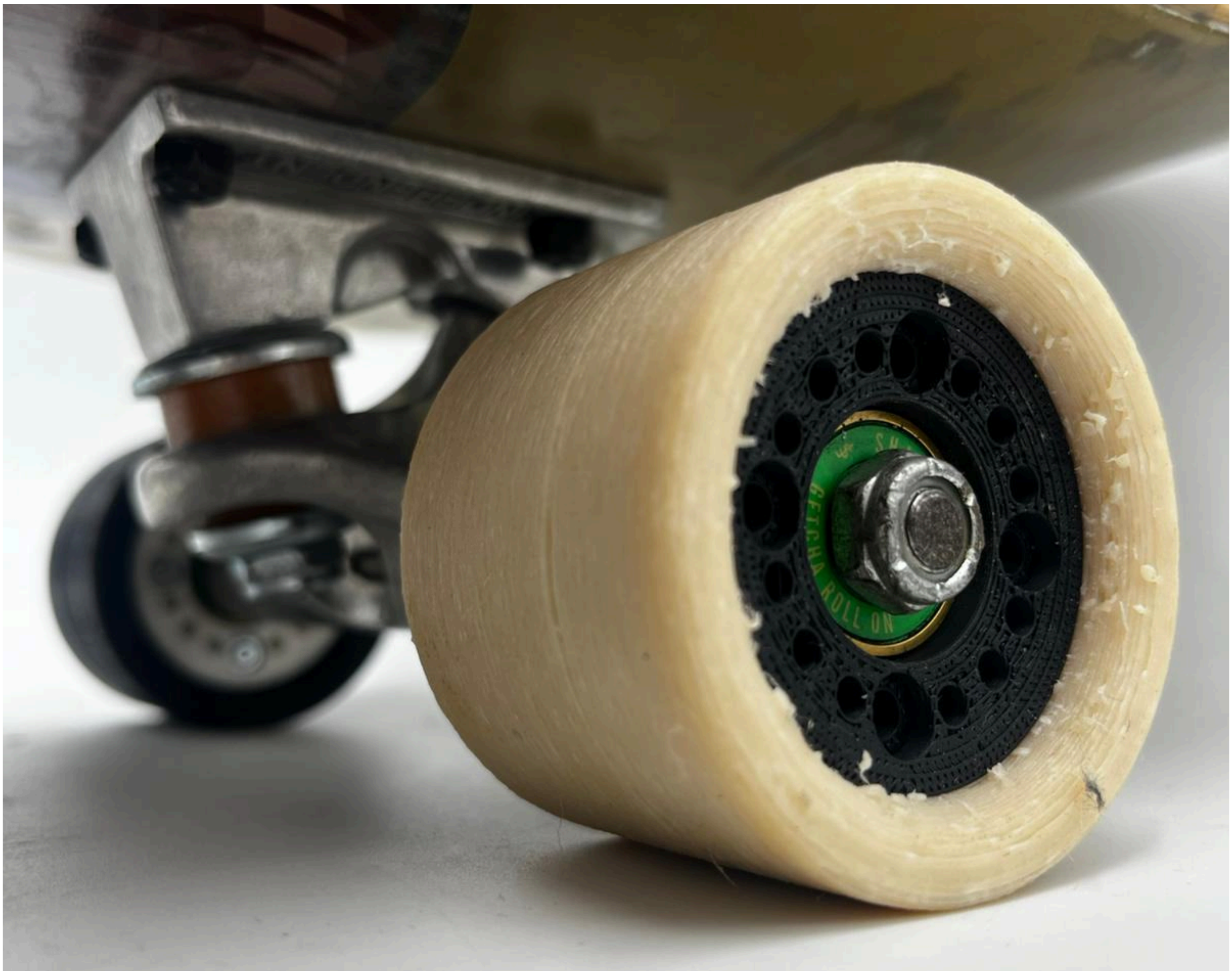
This contrast is not merely aesthetic: it communicates modularity and repair logic. The tread is visually identified as the replaceable wear component, while the core is recognized as the structural long-life element. This separation supports user awareness and reinforces the product’s circular intent.
The surface finish was intentionally maintained smooth, with rounded lips (~1.5 mm radius), avoiding grooves or decorative textures. This choice supports freeride predictability and minimizes localized wear concentration, which can occur in tread patterns with discontinuities.

Img. 139 - V2 prototype front view, picture by the author.

Img. 140 - Samsara Wheel front view, picture by the author.

7.4 - Testing

This section describes the validation process conducted at the final prototype stage. At this stage, testing was primarily focused on assembly reliability, rollability verification, and qualitative structural behavior.



Img. 141 - Samsara Wheel assembled on skate, picture by the author.

7.4.1 Prototype Testing

The prototype underwent multiple functional checks:

- bearing insertion (608 standard)
- spin test and rollability evaluation
- manual compression and deformation observation
- drop testing (impact resistance)
- torsion test (core rotation resistance relative to tread)

Both fixation systems were tested:

1. press-fit only
2. press-fit + screws and nuts

Img. 142 - Removal of the tread from the core, picture by the author.

In both configurations, the wheel maintained structural coherence. Manual torsion did not reveal slippage between the tread and the core. Bearing seating was successful, and the spin test confirmed functional rollability without bearing blockage.

These results confirm that the modular architecture can be assembled reliably and that additive manufacturing tolerances were sufficient to support functional integration. The outcome is particularly relevant given that printed elastomers often introduce dimensional variability; however, the design's tolerance strategy ensured consistent fitting.

7.4.2 - Subjective analysis

Although mechanical performance testing such as abrasion loss measurement, rebound coefficient, or fatigue analysis was not conducted at this stage, the manual validation phase confirms a critical result: the wheel system can be assembled, disassembled, and reassembled while maintaining operational rollability.

The methodology was therefore shown to be reliable and repeatable, exceeding initial expectations for a printed modular wheel system. This does not imply higher precision than industrial manufacturing, but rather demonstrates that additive manufacturing can deliver functional repeatability when geometry and tolerance strategies are designed accordingly.

Furthermore, the modular design introduces a new user interaction: wheel maintenance becomes part of the product lifecycle. This transforms the wheel from a disposable component into a maintainable system, which is a fundamental shift in how wear-based products can be conceived.

Img. 143 - Samsara Wheel and prototype V2 assembled on skate, picture by the author.

7.5 - Reflection about the product

Img. 144 - Assembled 3D printed wheels on skate, picture by the author.

Circular economy literature emphasizes that sustainable circularity must prioritize value retention strategies such as reuse, repair, and modular replacement [1]. The final wheel system embodies these principles through a structural separation between core and tread. Instead of discarding a complete wheel after tread deterioration, the user can replace only the consumable component, maintaining the core for extended periods. This approach reduces waste generation per riding session and decreases the demand for repeated production cycles.

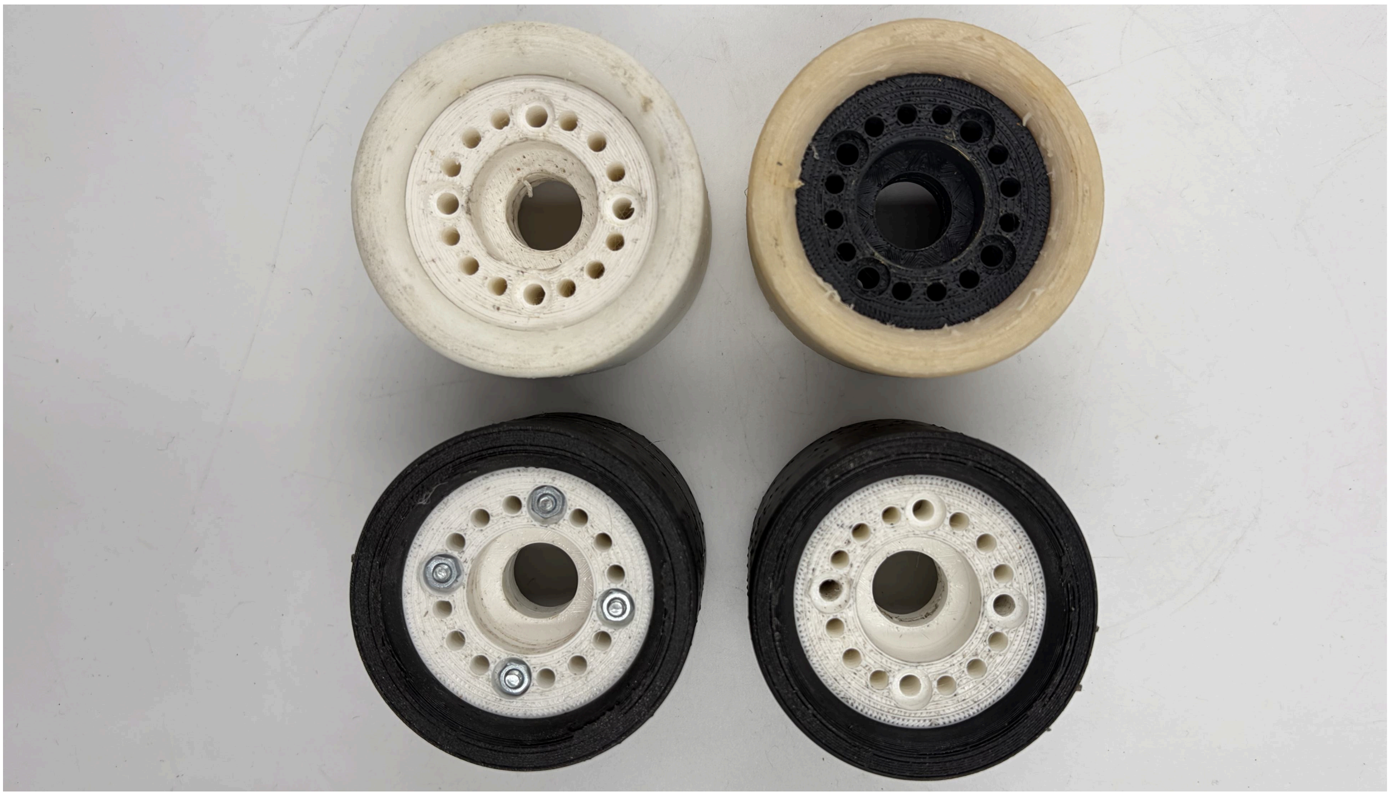
Material selection reinforces this circular logic. PA11 is an engineering polymer with high durability and is derived from renewable sources, making it coherent for a long-life reusable component [7]. Meanwhile, Ballena Filaflex 82A is positioned by its manufacturer as a biodegradable flexible filament designed for circular product pathways [2], [3]. Since wheel tread wear is unavoidable, selecting a material aligned with biodegradable end-of-life scenarios represents a meaningful direction for minimizing long-term residual plastic accumulation.

Academic research further supports the relevance of developing bio-based and biodegradable polyurethane elastomers, particularly as sustainability pressures increase and polymer industries shift toward renewable feedstocks and controlled biodegradation strategies [4], [5]. Although biodegradable polymers require specific disposal infrastructure, the integration of such materials into high-wear applications offers a realistic scenario where biodegradability becomes functionally relevant rather than symbolic.

From a design research perspective, the project demonstrates that failure is a productive stage of development. The collapse of the initial co-printing hypothesis (TPU + PLA) led to a critical methodological shift: instead of forcing polymer adhesion through printing constraints, the system embraced modularity and mechanical locking. This design evolution aligns with contemporary additive manufacturing approaches where geometry becomes a tool to overcome material limitations [8].

The final prototype validates the feasibility of this approach through repeatable assembly and functional rollability. While full-scale downhill testing and abrasion quantification remain necessary to confirm performance equivalence with commercial freeride wheels, the project demonstrates a clear pathway for sustainable innovation in the wheel industry.

In conclusion, the thesis contributes not only a prototype but a design methodology: a modular wheel system developed through additive manufacturing, informed by circular economy principles, and designed for repairability, replaceability, and reduced waste. This final outcome offers a credible framework for future industrial adaptation, especially as distributed manufacturing and sustainable elastomers become increasingly accessible.



Img. 145 - 3D printed freeride wheels, picture by the author.

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SAMSARA WHEELS

CIRCULAR ECONOMY PRINCIPLES APPLIED INTO THE PRODUCTION OF LONGBOARD WHEELS

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