Educational **Cases**

Tailoring tomorrow: Digital Twins for Circularity

Are you ready to tailor tomorrow? Implementing Digital Twins for Circularity in Fashion

How can Digital Twin Technology help fashion businesses to shift and implement circular business models and practices?

This research investigates the role of Digital Twins (DTs) in supporting circular business models and practices within the fashion industry. It demonstrates how businesses can utilize DTs, especially the emerging (European) Digital Product Passport (DPP), to advance towards circularity while maintaining a competitive edge. The findings are based on existing research and interviews with fashion brands, resell platforms, rental providers, industry experts and digital service providers.

The predominantly linear fashion industry has emerged as a major contributor to climate change with severe consequences for the environment and people (Ellen MacArthur Foundation, 2017). Fashion brands, policymakers and other industry stakeholders have recognized the imperative role of adopting circular practices to mitigate waste and reduce the industry's ecological impact.

Key Insights:

-> Digital Twins (DTs) for Circular Fashion: DTs support circular models by enabling virtual prototyping, tracking, and reducing resource use.

-> Digital Product Passport (DPP): The DPP, mandatory in the EU by 2030, will enhance circular practices like reuse and repair through better transparency and consumer engagement.

-> Need for Systemic Change: Effective circularity in fashion requires comprehensive shifts beyond isolated practices, leveraging DTs and DPPs for broader industry transformation.

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Digital Twins have manifold use cases within fashion

- Digital Twins (DTs) are a virtual representation of a physical object that is connected through a flow of data and information.
- The traditional DT definition needs to be broadened for the fashion context.
- We propose a multi-perspective on the DT concept in fashion: DTs for internal use, the Digital Product Passport & future use cases of the concept including real-time data exchange and simulations.
- DTs for digital prototyping, simulation, product tracking and more support existing business models, communication with end-users and offer advantages regarding costs and resource consumption.

Digital Twins can support circularity along the lifecycle of a garment

- DTs offer various opportunities to support circular business models and practices through increased consumer transparency, education and engagement, as well as end-of-life management.
- However, we observe that circular practices are often added to linear core business models, leading to the question of what the true influence on circularity is.

Policy recommendations for the Digital Product Passport (DPP)

- A dynamic DPP at an item level is essential to effectively support circular business models and practices in the fashion industry. We believe that the DPP should be implemented in a dynamic manner, allowing for feeding in post-sale data, and finally granting access rights of DPP information to relevant stakeholders such as repairers, resellers and digital wardrobe providers and/ or their users.

Factbox: Digital Twin Technology

DTs are commonly understood as “digital counterparts of physical objects” (Kritzinger et al., 2018, p.1017).
The DT concept model includes three parts:

- an object in physical space,
- a virtual representation of the physical object
- a bi-directional data and information connection between both (Grieves, 2014).

Although DTs are often seen as a piece of technology themselves, there is rather an interplay of different technologies such as Internet of Things (IoT), Cloud computing and Artificial Intelligence (Mihai et al., 2022, Attaran & Celik, 2023). IoT plays an important role in the textile and clothing industry in connecting items to their digital counterpart in the DT, tracking product data along their value chain (Alves et al., 2022).

DTs can be used to analyze both - the past and current histories of their physical counterparts, as well as to make predictions. A specific form of the DT is the Digital Twin Prototype which is used to develop a product and exists before its physical counterpart (Grieves & Vickers, 2017). DTs allow for virtual design, testing, and simulation, presenting major benefits regarding resource consumption and costs (Grieves & Vickers, 2017). DTs have for long been applied in multiple sectors such as Aerospace and Automotive and Construction throughout different phases of the product life cycle, especially in the manufacturing phase (Attaran & Celik, 2023). DTs within fashion are still rather unmature.

Digital Twins in Fashion

There is no unified definition of DTs where some scholars specifically emphasize the necessity of an automatic real-time data connection with the physical counterpart as a mandatory characteristic for a digital representation to be considered a DT (Jones et al., 2020; S. Singh et al., 2021). However, this traditional definition of DTs does not seem to appropriately fit all use cases within fashion. A manual data flow between a physical garment in physical space and the respective DT in virtual space is partly required as clothes differ from machines. An identifier needs to be applied to garments (e.g. QR codes) that will be scanned by intermediaries such as customers to make information flow between virtual and physical space.

This conceptualisation closely aligns with the upcoming Digital Product Passport for textiles and clothing.

Therefore, the DPP can be seen as a targeted use-case or sub-category of the broader concept of DT technology for promoting the Circular Economy (CE) within the EU.

Based on our research of literature and the analysis of 14 interviews that were conducted with several fashion brands, industry experts, and resale and rental companies, we propose a multi perspective on Digital Twins encompassing current DT usage for internal purposes (1), the DPP (2) and the potential future of DTs (3). Currently, DTs within fashion are mainly used for internal purposes as digital prototyping, simulation, stock tracking and store efficiency (Donmezer et al., 2023; Kuzmichev & Yan, 2022). The DPP will make the application of DTs obligatory from 2030 and enlarges its scope to the post sale phase. In future, automatic real-time data exchange independent from geographic locations can become reality when DTs are used in smart fashion and in the metaverse (Stacchio et al., 2022; Wagner & Kabalska, 2023).

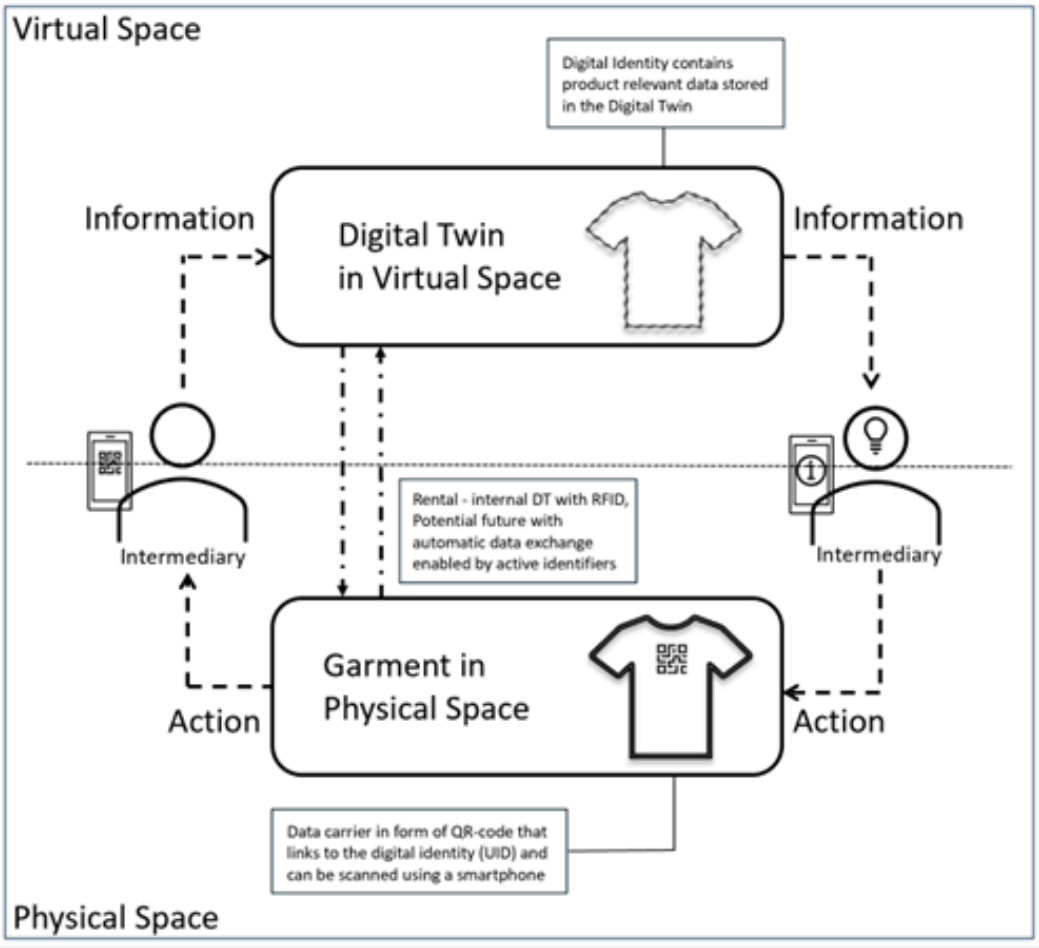

Figure 1: Illustration of DT and physical garment – Information Flow Present and Future (Brügmann & Bieser own illustration based on Jones et al. (2020))

Definition Digital Twin of a Garment

A Digital Twin is a virtual representation of a physical object that is connected through a flow of data and information.

It can be bi-directional or unidirectional and either automated or manual depending on the context.

It encompasses pertinent information potentially relevant to all stages of the object's lifecycle. (Own definition)

Digital Twins for the Circular Economy

The Ecodesign for Sustainable Products Regulation (ESPR) entered into force on 18 July 2024. Responsible economic operators placing products on the European market will soon be required to implement the Digital Product Passport (DPP) outlined in the ESPR, once delegated acts are adopted.

This will particularly impact fashion brands operating in or selling to the EU. While the introduction of a DPP on all product categories may sound like a daunting task for fashion companies, our research highlights the potential of using the concept of DTs and DPPs to support circular economy practices and business models along a garment's lifecycle, from beginning-of-life to end-of-life. (see Figure 2).

While DTs have shown potential in the beginning-of-life phase with use cases in design through simulation and prototyping tools such as CLO3D, the DPP shows its manifold use cases particularly in the retail and during the use and re-use phase of garments. Our research has demonstrated the potential of DPPs to enable a range of activities supporting R-strategies, such as refuse, repair, resale, and recycling (see Table 2; Reike et al., 2018).

In addition to the framework proposed by Reike et al. (2018), we identify three additional specific circular practices that are relevant:

1. designing for emotional and technical durability,
2. providing care instructions,
3. and offering rental services.

Although these practices are not explicitly mentioned in the 10-R framework, they are considered crucial for the fashion industry according to our study.

Table 1 offers a more comprehensive overview of the role of DTs and DPPs in enabling circular business models and practices throughout a garment's lifecycle.

The various circular practices ultimately influence the Circular Economy through cycling, extending, intensifying, and/or dematerializing material and energy loops to reduce resource inputs and waste emissions, as described by Geissdoerfer et al. (2020). Internal DTs play a crucial role in the design stage during the beginning-of-life stage, while DPPs potentially support circular business models and practices in almost all other product life stages throughout the middle- and end-of-life stages.

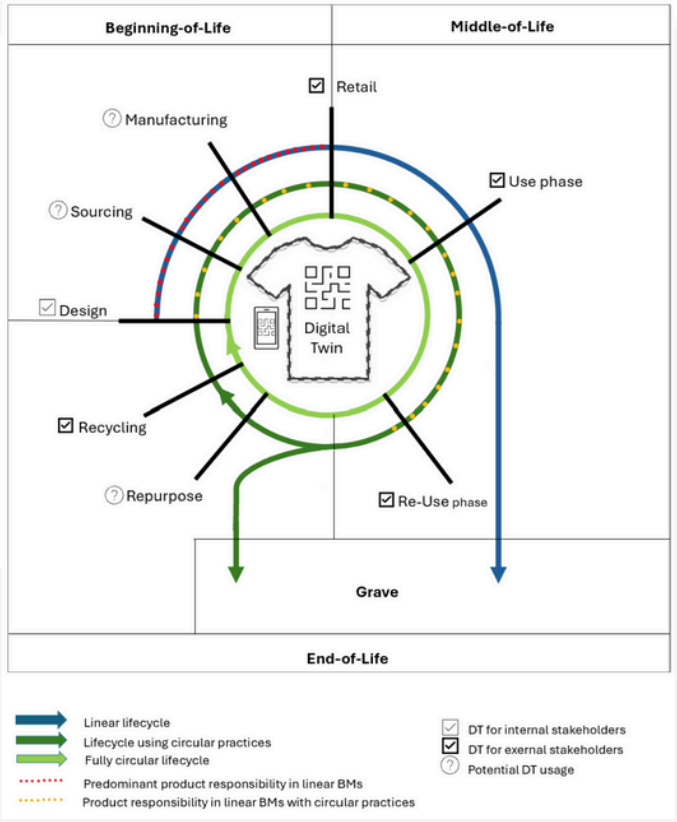

Figure 2: Circular Practices and DTs along the Lifecycle (Brügmann & Bieser own illustration based on Payne, A. (2015) and Mügge et al. (2024))

Considerations:

- The Ecodesign for Sustainable Products Regulation (ESPR) has entered into force, requiring businesses to align with the EU strategy for sustainable and circular textiles. What implications will the introduction of an EU-wide DPP have for your business regarding the legal requirements that must be fulfilled by the expected deadline of 2030?

- The DT concept and the DPP have potential in supporting CE efforts along a garment's lifecycle helping the European transition towards a CE by 2050 – how do you see this possible within your brand?

- Does your brand want to learn more about the post-sale phase of your garments? Implementing DPPs beyond legal requirements can be a potential way to learn more about how garments are being used after the point of sale - an area that is still largely a black box for fashion brands. Moreover, DPPs could offer an additional touch point with customers, potentially increasing brand loyalty and trust.

- Being responsible for the introduction and the management of the DPP, fashion brands should consider keeping this data as open and accessible to other relevant stakeholders and third parties as possible. This way, end-users can make use of DPP information on resale platforms and on digital wardrobe apps, easing the current heavy manual work burden and ultimately benefiting the Circular Economy.

- Hosting the DTs of customers' wardrobes from the first purchase of each garment throughout all product life stages offers new opportunities for both customers and brands, supporting the Circular Economy.

While our research has demonstrated that fashion brands are starting to rethink the way they are doing business, selected r-strategies will not transform the fashion industry to a Circular Economy. A more comprehensive shift towards (fully) circular business models, considering all lifecycle stages of a garment is needed to allow for a greater change towards a Circular Economy.

Key take-aways

Our research concludes that DTs hold significant potential to support circular practices in the fashion industry by enhancing transparency, traceability, and end-of-life management.
The study highlights that the European DPP can be a crucial tool in this transition, provided it is dynamically integrated at the item level with appropriate access rights for stakeholders. While DTs and DPPs can facilitate a shift towards circular business models, the overall impact depends on broader systemic changes and external factors beyond the research's scope.
The need for a holistic approach to circularity in fashion is emphasized, rather than relying on isolated practices.

Table 1: Potential Contribution of DTs to Circularity (own illustration)

***Not identified as individual r-strategy by Reike et al. (2018)**

Lifecycle stage	DT/ DPP	enables...	Specific activity	Circular practice (Reike et al., 2018)	Effect on CE (Geissdoerfer et al., 2020)
Design	DT	Digital prototyping and sampling	Creating a garment in virtual space first	Reduce	Dematerializing
	DPP	Collection & accessing of post-sale data	Use of post-sale data to inform design process	**Design for durability (technical & emotional)*	Extending
Sourcing	*Delimitated from the research*				
Manufacturing	*Delimitated from the research*				
Retail	DPP	Transparency & consumer awareness	Consumer accesses relevant product and sustainability data for purchase decision	Refuse	Intensifying Extending
Use phase	DPP	Consumer awareness, education & engagement	Access & make use of care instructions	**Care*	Extending
	DPP	Consumer awareness	Visibility through digital wardrobes	Refuse	Intensifying Extending
Reuse phase	DPP	Transparency, Consumer awareness, education & engagement	Reduces friction for consumers to engage in resale: see resale options & create automatic listings; increases trust	Resale	Extending
	DPP	Consumer awareness, education & engagement	Access & make use of repair instructions & connect to repair providers	Repair	Extending
	DPP	Repair providers to access product specifications	Information access eases repair processes	Repair	Extending
Repurpose	DPP	?			
Recycling	DPP	Consumer awareness, education & engagement	Informs consumers about proper recycling options	Recycling	Cycling
	DPP	Recycling providers to access product specifications	Information access eases recycling processes	Recycling	Cycling
Throughout the lifecycle	DT	Internal tracking of garments	Allowing personalization, automatization & predictive maintenance	**Rental*	Extending Dematerializing Intensifying

*Not identified as individual r-strategy by Reike et al. (2018)

What are the 10R strategies?

The 10R's are a circular economic framework that examines how materials can be used and reused at their highest value while minimizing waste and environmental destruction.

R-Strategy	Definition
R0 - Refuse	Refuse focuses on avoiding the use of resources altogether and concerns both producers and consumers. In the context of consumers, this can be achieved by preventing products from entering the cycle, by consuming less or buying and preventing the creation of waste. For producers, refuse can be achieved by contributing to a reduction of waste through design choices that avoid virgin materials in the design and production process.
R1 - Reduce	Reduce encompasses the minimization of resource consumption. This can be achieved by optimizing processes, reducing the input of materials, and to optimize efficiency to decrease overall waste generation and predominantly concerns producers, focusing on using less materials in the design and pre-market stages.
R2 - Resell/ Re-Use	Reuse involves the extension of the lifespan of products in the cycle, encouraging products to be used multiple times without leaving the cycle, and thus, reducing the introduction of new products in the cycle. In a consumer context, reuse generally concerns the use of a products through a second consumer without the need to adapt, repair or refurbish the product.
R3 - Repair	Repair emphasizes to mend products that are broken or damaged instead of replacing them by new products. With this strategy, the lifecycle and usability of existing products can be prolonged, conserving resources in the cycle and preventing waste.
R4 - Refurbish	Refurbish involves renewing a product by cleaning, repairing, or upgrading a product such that it is in a condition similar new. However, it generally only includes minor repairs such that they meet a certain quality standard.
R5 - Remanufacture	Remanufacture goes beyond the concept of Refurbish, as it involves a more comprehensive process, disassembling the whole product and replacing broken parts such that the product is brought back to its original condition or beyond.
R6 - Repurpose	Once a product is at its end of their original intended purpose, a product might be Repurposed by finding new use cases for the product or materials, keeping them in the circle, thereby reducing waste generation.
R7 - Recycle	Recycle involves the collection of materials and the extraction of valuable components that can be used for the creation and usage in new products. This strategy helps in minimizing the creation of waste, helps to conserve natural resources and reduces energy consumption.
R8 - Recover	Recover primarily refers to processes such as collecting and processing used products, extracting materials for reuse, and capturing energy from waste.
R9 - Remine	Remine concerns the extraction of valuable materials from landfills where valuable materials are extracted for reuse, though it is often overlooked in policy and practice but holds significant potential for resource recovery.

Table 2: Typology of 10 R-strategies based on Reike et al. (2018), pp. 255-257

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