

Textiles & Biodegradability: Challenges and Opportunities of sustainable textile Futures

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The move towards circular economy seems like a necessity nowadays. Why not apply the processes of nature? Biodegradability is a material characteristic, which is necessary for closing the biological cycle. If biodegradability was a new and invisible criterion for textile and fashion design, how do we design and manufacture such textile products, which are biodegradable? Very few scientific publications are found on biodegradability of textile products. In fact, formerly textiles have been biodegradable but the contemporary textile industry has unlearned how to manufacture them and customers have unlearned how it feels to wear such garments. An applied research collaboration between University and Industry enabled a research team to work in an interdisciplinary setting on developing answers to this novel kind of question.

This paper aims at sharing experiences related to biodegradable textiles along with its scientific testing results as well as the textile design research. The combination of both perspectives allows a multifaceted critical reflection on how the concept of biodegradability could lead to sustainable textile futures.

Keywords: *biodegradability, textile design, sustainable textiles, circular textile future, 4th order of design*

1 Introduction

Biodegradability is a material characteristic, which is necessary for closing the biological cycle. Via composting, biodegradable materials decompose and reintegrate into the natural environment. This urban recycling process is used for plants and food waste. Is it also applicable for textiles? From the point of view of the consumer, composting is a meaningful action, natural wastes are returned to nature and help grow new natural resources – sometimes, this even happens in their own garden. In a cradle to cradle concept, this route represents the biological cycle (Braungart, 2003). Would it be equally meaningful for the customer, to compost their cotton jeans? Yes indeed, was the answer from the Swiss design company Freitag lab.AG, known for their bags made from recycled polypropylene tarpaulin from trucks. In a joint research project with Lucerne University of Applied Sciences and Arts the concept of biodegradability was addressed with a completely new approach for textile and product design as well as the supply chain.

However, during the project, biodegradability became more of a concept for sustainable textile and product design, than just the last step in the life cycle. It was not about the recycling process anymore, but biodegradability became a product design criterion itself. The research question reads: “How do we design and manufacture a textile product, which is biodegradable?” The decision to design for a biological cycle affects the design process: the choice of materials, the composition of materials, the applied dyes, the applied processes, the making-up, the product communication, the use phase and the end-of-life treatment. Other than the design processes, the company wanted to know, if biodegradable textiles are more sustainable than conventional textiles.

2 Motivation

The move towards circular economy (MacArthur, 2013) seems like a necessity nowadays. Especially the textile sector is characterized by over-production, which results in high quantities of waste, by globalized processes, which result in poor communication and lack of transparency. This makes it difficult for all parties involved to know how the textile materials and products are manufactured, processed and designed. Nevertheless, the UN makes clear, that action is required to lower the carbon dioxide production, e.g. by lowering the amount of fossil energy consumed (Global Climate Action Summit, 2018) and ultimately by more efficiency in production and less consumption world-wide. Therefore, and for reasons of resource depletion, research in this field is needed in order to show alternative ways for sustainable production and consumption.

This paper aims to share experiences related to biodegradable textiles from a study along with its scientific testing results as well as the textile design research. The combination of both perspectives allows a multifaceted critical reflection on how the concept of biodegradability could lead to sustainable textile futures.

This includes thoughts on how the concept of biodegradable textiles as a design criterion does reframe the role of a designer and re-distribute the question of responsibility within the value-added chain. This analysis is performed from two perspectives: the one of the natural scientist and the other of the textile designer. The natural scientist analyses and interprets testing data from the biodegradability tests. The designer uses the criteria derived from the interpretation of the tests and applies them as design criteria for the textile product development process. The two perspectives are interlinked by the common vision of a circular economy and, in this case, closing the loop by a biological cycle, and the proof, that the products are biodegradable. Therefore, the end of the product defines the beginning, meaning that the product design has to meet the requirements of the clients as well as fit into nature’s cycles.

2.1 Case-Study F-ABRIC

The FREITAG lab.AG company started several years ago to add to their bag collection under the name of F-ABRIC a range of textile products such as basic garments and bags. The concept for this collection was one of regionalism and biodegradability. Regionalism was provided by defining a certain perimeter around their company location and stating, that all processes and resources should be located within this perimeter, which was defined by 1000 km. Biodegradability was defined as a goal for sustainability and a vision, that the textiles would be readily absorbed by nature after their use phase. The research project was funded by Innosuisse, the Federal commission of technology and innovation in Switzerland. The research project includes several phases: the testing of biodegradability, the scientific

evaluation of the sustainability, material sourcing, material experimentation, user-centered textile and product design.

2.2 Biodegradability of F-ABRIC Textiles

Very few scientific publications are found on biodegradability of textile products. Also, textile materials are not provided with biodegradability data; textile chemicals however include this information in the safety data sheets. The testing of three textile garments from the F-ABRIC collection provided the scientific data on biodegradability for this study. The Hohenstein Institute in Germany offers a standardized biodegradability test for textiles (Din EN ISO 11721-2).

Product	Color	Composition
Bag	dark grey	100% linen, coated
Denim Jeans	blue	81% linen, 19% hemp lining: 51% modal, 49% linen
T-Shirt	black	75% modal, 15% linen, 10% hemp

Table 1: Tested garments for biodegradability.

The experimental design included the testing of three products, see table 1. The experiments are carried out in the environment employing three standardized soil compartments. The textiles are inserted in the compartment and excavated six months later. The test results are the following: weight loss after six months in the ground, indicating how much material has been decomposed; eco-toxicity tests on the soil and living creatures surrounding the objects, indicating if there are toxic or harmful reactions; as well as a visual test to assess the qualitative process of decomposition.

Product	Percentage of weight loss
Bag	61,56 %
Denim Jeans	89,83 %
T-Shirt	87,74%

Table 2: Results of weight loss by biodegradation for the three products (Hohenstein, 2016).

The highest loss of weight results show the denim jeans. This shows that the denim jeans are nearly completely biodegradable within six months. The bag in contrast, is only partly biodegraded within this period of time. The black T-Shirt has also a high biodegradability.

The ecotoxicity tests were carried out with seedling growth test and earthworm toxicity tests. The results lead to the following conclusion: the ecotoxicity is very low. However, slightly elevated values of copper and nickel were found.

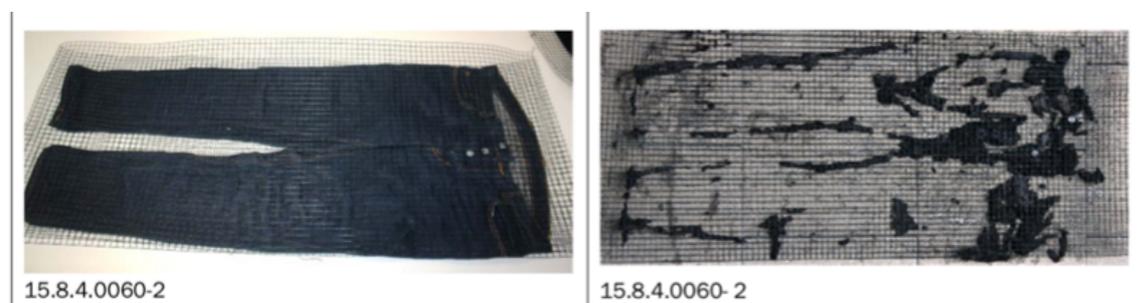


Figure 1: Visual test on denim jeans before and after biodegradability testing (Hohenstein, 2016)

The visual test results for the decomposition process in figure 1 show that the denim jeans is nearly decomposed, as concluded earlier. The remaining material portions are located at the seams.

The results are interpreted and connected to a specific design step, which has to be revised for the design of biodegradable textiles. The textile fibre is biodegradable as expected because natural fibres were used both mixed and non-mixed. Even synthetic fibres originating from natural cellulose material, like modal, do not disturb the biodegradation process.

The textile technique (spinning, weaving, knitting) and the mass per unit area do not seem to have a relevant influence on the decomposition process of the products. It would have seemed logical to conclude, that a tight woven and heavy pair of denim trousers would need more time to degrade than a knitted light T-Shirt. However, the results show that both products biodegrade equally fast in the given testing time.

However, the finishing processes and chemicals are relevant to the biodegradation. The bag, which has the lowest biodegradability value, did have a coating. The heavy metal values of all three products were slightly elevated because of dyes containing heavy metals. It is important to check the safety data sheets for biodegradability and ecotoxicity test results for all chemicals used.

The making-up process is relevant for the biodegrading process. Where double or triple layers are sewn, the biodegrading process is inhibited. The bag had multiple layers for interior bags, which resulted in a slower degradation. In addition, the sewing yarn is not made of natural materials and therefore is not easily biodegradable. The bag had metal buttons, which were not biodegradable.

2.3 Ecological Analysis of biodegradable Textiles

For the evaluation of the ecology of biodegradable textiles, different methods were compared, mainly cradle to cradle, life cycle assessment (LCA) and simplified LCA. The difference between cradle to cradle (C2C, Braungart, 2003) and LCA is analyzed and discussed in the Position Paper of NL Ministry of Infrastructure and the Environment (NL Agency Ministry of Infrastructure and the Environment, 2011). The focus of C2C is on biological and technical cycles. Biodegradable textiles fit into the biological cycle. This product could be certified by EPEA as a C2C product (EPEA, 2013). The certification includes the suppliers in the whole supply chain. This makes it less feasible and very costly for this project. The simplified LCA provided some insight on the matter. However, the LCA does not show any special benefit of biodegrading. This is due to the fact, that the LCA is a cradle to grave analysis and C2C a cradle to cradle analysis. The CO₂ generated by different end of pipe measures (including composting) does not vary; therefore, the LCA results do not show any difference in applying different end-of-pipe technologies. The ecological benefit lies in the production phase, where natural materials and sustainable processes are chosen in order to allow for biodegradability.

The LCA showed, that in production for biological cycle products, there were less chemicals used than in traditional products and therefore fewer emissions to air and water were generated (internal report HSLU, 2016). The production phase only accounts for less than half of the ecological burden in the entire life cycle of a textile. The use phase causes a higher ecological effect through water and energy use as well as detergent use than the

production phase. Considering sustainable textiles and not just biodegradable textiles, the aspect of the use phase has to be included in the considerations.

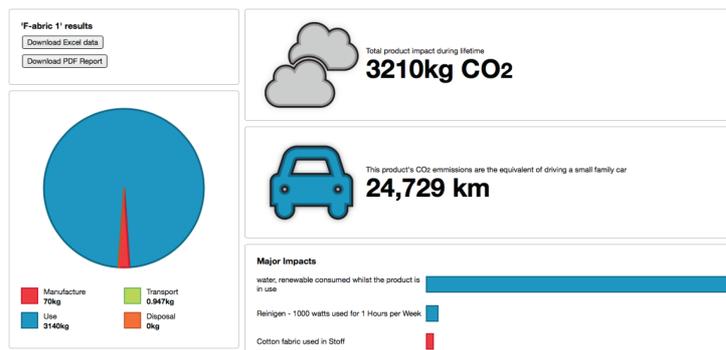


Figure 2: Result of simplified LCA with LCA Calculator of Denim Jeans

2.4 Findings from a scientific Point of View

The biodegradable testing has shown, that biodegradation of textile products is possible under ideal conditions. It has also shown, that decisions on every step in the textile design and in the production process need to be made, in order to foster biodegradation. The most important decision is on the material used: a biological / natural textile raw material. The applied chemicals and the finishing process influence the degrading process and the ecotoxicity to plants and animals. Of high importance is the design of the garment. Multiple layers, which are sewn together and non-degradable accessories inhibit the decomposition of the product. In order to create a biological cycle product, the design phase of the product is the primary issue – it decides, if the product will be biodegradable later.

For the biological cycle to be complete, the composting process needs to be standardized and industrialized in order to foster a fast degradation. However, by focusing design only on biodegradation, important environmental issues are excluded. The process emissions during production as well as the emissions during the use phase need to be taken into account, for they account for more than half of the life cycle emissions of textiles. Therefore, the choice of production processes and the use phase have to be taken into account additionally. In order to be sustainable, the product needs to be designed for a low emission use phase, for instance by giving advice on low emission cleaning, drying processes and on ecological detergents.

3 Research Textile Design Part

In addition to the criteria defined by biodegradability (see section 2), criteria have been formulated with the industry partner, which should be fulfilled within a design context. In terms of comfort, look & feel, the products must be comparable to existing products and meet at least their standards. In addition to that, the products are supposed to embody the circular principle because they are biodegradable.

Therefore, and at any stage of the fabric and product development, both scientific and design criteria need to be considered. Both standards are of equal importance and the goal is to achieve results being satisfactory for both perspectives.

Here the research procedure is described in three phases including development of a design vision, the extensive material experimentation and the user-centered product design process.

3.1 Design Vision Biodegradability

The research process (Weber et al., 2014) was initiated with the description of a design vision which is a framework illustrated in a conceptual and visual way:

The conceptual framework results from workshops between the industry partner and the institutional researchers. The workshop participants identified attributes which provide a garment's wearing comfort and put all of them in an order indicating from top to bottom their priority in favour of the purchase of a garment. On the left side, the framework points out comfort-giving functionalities of garments. On the right side, it lists details of construction and making-up as well as fabric properties, which may be useful to meet the expected performance and fit of the products (Fig. 3).

The visual framework results from a study on how comfort has been achieved in garments and workwear before the invention of the synthetic and elastic fibres. From the 1950s onwards until today, synthetic fibres are blended with natural fibres in order to introduce additional functions in the textile constructions, for instance elasticity. This has influenced fashion development in a way that the silhouettes could become much more body fit while still offering wearing comfort by the help of stretchable fabrics.

Formerly, the need to provide free movement without the use of non-natural synthetic fibres has led to creative solutions. This research provided helpful insights on how this was accomplished: Pleats, folded details or the design of loose silhouettes with integrated mechanical straps or buttons to adjust the fit would lead to elaborately engineered garments. With a collection of selected images illustrating historical and functional features, a variety of such examples could be documented for the use in the design process. This visual research will help to understand how volume can be generated and removed in a garment with an inelastic fabric consisting of 100% natural fibres. In addition, this historic observation is the key to re-introduce natural functionality and comfort to the customer who has unlearned how garments without stretch ability do look and feel (Fig. 4).

DNA F-ABRIC for woven and knitted material	
Functionality → Task	Solution → Job
aesthetics fit silhouette freedom of Movement longevity changeability/ variability modularity thermos control weather protection additional benefits	Construction widen / narrow open / close shorten / lengthen insert / take out Material property course / fine warm / cool plain / structured elastic / stiff heavy / light durable / fragile

Figure 3: conceptual framework design vision of biodegradable textile products



Figure 4: visual framework design vision functionality of biodegradable textile products

3.2 Material & Finishing

The challenge here is to fulfill both scientific and design criteria. From a design point of view, textiles and products should have a specific product expression reflecting the sustainable conceptual framework of biodegradability which was followed in the process. Designers might not be convinced that a single jersey or a plain weave fabric is suitable to convey the sustainability of a range of garments. Therefore, material experiments in weaving, knitting and finishing were conducted to achieve functionality such as softness, pleasing touch along with strength and durability. At the same time, satisfying aesthetic criteria were discovered in terms of complex textile designs including vivid surface constructions and multi-coloured details challenging the future customer.

The results of the experiments were examined and evaluated in expert teams from University and industry in order to identify, which samples would embody both the scientific and design criteria. The selected samples do well balance both objectives including invisible and visible aspects (see Section 4).

To give an example the woven structures are made of yarn-dyed warp and weft and are woven into three dimensional structures, which are mechanically stretchable (Fig. 5). The colours melt into each other as a faux-uni, but seen at close range, they are multicoloured. As a material itself it is just another textile design. But considering it within the larger sustainable conceptual framework of biodegradability, it represents a great depth of design (Huwiler, 2018) with a potential to shift the linear textile industry towards circular economy.



Figure 5: selection of sustainable biodegradable textiles (Knit, Woven)

3.3 Product & Usability

The experience of the FREITAG Lab.AG company in promoting biodegradable clothes clearly indicates that the consumer is not willing to make any compromises in favour of sustainability. This means that the product expectations towards sustainable products are in general remaining the same. Only if a garment is satisfying in terms of the look and feel, the customer will take a purchase into consideration. Customers nowadays are used to narrow silhouettes based on a body fit product. To integrate the expected level of comfort, customers are used to having materials that are stretchable, therefore partially consisting of elastane fibres. The sustainable, conceptual framework of biodegradability is contradictory to the use of additional synthetic fibres to create comfortable fabrics. Therefore, the product design needs to overcome this challenge by finding creative solutions as mentioned before.

The only probable approach to successfully introduce circular textiles and fashion into the market, is to make the invisible aspects explicit. The product communication needs to include all information regarding the circular quality of the product. Moreover, it should point out in which phase of the circle and which stakeholder has the lead in performing circularly in order to activate the sustainable potential of the product.

3.4 Findings from a Textile Design Point of View

For the development of biodegradable textiles, the following criteria are formulated, which integrate scientific and design aspects and represent an integral part of the sustainable conceptual framework of biodegradability:

- Composition: 100% natural fibres or synthetic fibers based on cellulose
- Yarn diameter: there is a limitation to fineness of yarns made of natural fibres which cannot be compared to the same of synthetic fibres
- Fabric weight and Durability: the heavier the fabric the longer the biodegradable process takes, the lighter the fabric weight, the less durable the material and garment will be
- Industrial production in weaving and knitting must take into account that the yarns are of natural strength and flexibility which sometimes requires adjustment of production speed
- Material comfort: Softness has to be achieved through surface construction
- Complex textile design: the enhancement of single jersey and plain weave into more elaborate surface design requires jacquard skills along with the appropriate industrial machinery in production
- Dynamic Colour: in the best case make the weak property, such as the fading out over time due to weak fastness to colour, can be a key topic of the design transforming the ephemeral colour quality into a strength, inviting the customer to discover overtime changing stages of the dynamic colour (Mügglar Zumstein, 2018)
- Colour and Finishing: dyeing and printing can only include biodegradable chemicals
- Plant based finishing: the processing must avoid metal-based chemicals
- Garment pattern making: the inclusion of several layers of fabric is extending the process of biodegrading in terms of time required.
- Garment silhouettes: the more the silhouettes are fitted to the body, the more the non-stretchable character of the fabric needs to be compensated with functional details providing the required width for the body movements
- Communicate to the customer the circular properties of the textile product

- Explain how the user can take responsible action in extending the use of it as long as possible
- Encourage to create a regional network of services, touch points and places where information at any time can be accessed how to close the cycle by initiating the composting process
- Take responsibility as a designer for the on-going change in the market which means that in the transition from linear to circular, all stakeholders involved become partners envisioning the common goal to perform the circle which cannot be an individual mission

4 Critical Discussion referring to Design Theory

The observation that in the last fifty years the textile and fashion industry has become a non-transparent, complex and quite harmful economy for our society and the environment requires a critical reflection on design theory in order to create a better understanding and develop a novel vision.

Reflections on ecological design for sustainable futures have been mentioned almost 40 years ago. This knowledge has led to the movements and results in product design at the end of the last century (Tischner, 2003). Unfortunately, it has not yet conquered and shaped the world of textiles and fashion. More than ever it is therefore crucial, to review those statements from a today's point of view, to finally rediscover their sustainable impact and to substantially learn from it. A closer examination will probably allow to conclude, why it is so difficult to implement ecological aspects into textile industry.

In the seventies, "criteria for a new design" were mentioned (Burckhardt, 1977) and within those Burckhardt was initiating the discussion about the fact that the quality of design cannot only be described by formal and technological aspects but rather by shifts from the product itself to more process-related questions such as: "is [the product] made from raw materials sourced without oppressing anyone? was [the product] manufactured in meaningful, non-rationalized labour processes? is [the product] multi-purpose and is it built-to-last? in what state is it discarded and what becomes of it then?" (Burckhardt, 1977)

These questions redefine the designer's responsibility. In addition, it extends the understanding and definition of design which at that time already had been established. However, let us feature here what Burckhardt in addition in the eighties mentioned (Burckhardt, 1980). He described the invisible aspects of design. As he stated, the so-called invisible design includes today's and tomorrow's worlds, consisting not only of objects but as well as of interpersonal relationships.

If this perception of design is valid today and onwards, it is no longer possible not to include the user in the design process, not to know who has manufactured the product, whose hands have prepared the production machines for the translation of raw-materials into products, etc. By that, the responsibility of a designer and of all stakeholders in the process is redefined. The so far mainly aesthetic approach has shifted to a multifaceted understanding of design quality, which includes ecological, social and economic criteria.

Later on, in the nineties, Jonas (Jonas, 1994) clearly points out key criteria for ecological design such as "longevity, repair-friendliness, the ability to disassemble the product as well as to easily separate materials from each other, reusability and recyclability". Furthermore,

he explains, that these aspects may for the consumer usually be of secondary importance as the products first need to fulfill aesthetic expectations. Nevertheless, the sum of all aspects do make explicit what the values of sustainable products in any case should embody.

To perform sustainable development at the intersection of fashion and textiles, we need to understand the limitations of design (Braungart, 2003), build networks to collaborate and pair with partner disciplines of design (Jonas, 1994), reframe the role of the designer (Hornbuckle, 2018) to be able to overcome the challenges involved. Hornbuckle describes how textile knowledge “can drive and direct innovation towards circularity” (Hornbuckle, 2018). Product communication is becoming increasingly important as invisible aspects such as sustainable impact of textile products, do need further explanation to the customer. Let us give an example here. The sustainable denim product may look similar to ordinary trousers but in comparison the product price of the sustainable one would be slightly higher. In order to highlight the invisible value, a specific communication along with the product is required to reveal the difference between ordinary and sustainably designed textile products.

“Value of textile design knowledge needs to be effectively applied along with a set of non-textile but in general important skills, such as interdisciplinary communication with stakeholders within the process, organization and management skills, creative information visualization tools.” (Hornbuckle, 2018)

5 Reframing of the Designer’s Role

Nevertheless, various approaches have been manifested already suggesting probable solutions to introduce sustainable change within our harmful textile and fashion industry. With the urgency given, the textiles and fashion industry need to be reframed within a larger context. This means that change towards a circular future can only happen if design thinking is prepared to address the complexity of the fourth order of design (Buchanan, 1992). Support is given by more closely and internationally linking research in the field with the entrepreneurial players through consultancy and knowledge sharing (Black, 2008) (Gwilt, Rissanen, 2011). By anachronistically integrating existing knowledge and finally turning thoughts into actions, our environment, health and wellbeing can be affected positively through the sustainable conceptual framework of biodegradability.

Combining the insights from theory together and the outcomes of the research project, the following setting could be developed to answer the research question how to design and manufacture a textile product, which is biodegradable. In general, it has to become a regular design practice to make all invisible aspects in product design and presentation accessible for everybody. In particular, design can therefore be used to enhance our lives and environments if the design process for textile products does include the following criteria together with the criteria mentioned in section 3.2) these conditions represent the so-called sustainable conceptual framework of biodegradability:

- Collaboration of scientists together with designers
- use design skills to make an interdisciplinary setting of work productive
- understand the need to communicate visible and invisible aspects of design
- design user-centered but extend the awareness to all stakeholders involved
- become network partners with a common goal to perform the circle by the help of each other

- think in various dynamic rhythms and interconnecting them while designing in favour of circular textile future

“But equally there are examples of all speeds in the natural world which point towards positive and expansive examples of the full spectrum from fast to slow in other industries, for example food and architecture.” (Goldsworthy, 2018)

6 Conclusion & Outlook

From the natural scientists' perspective, the results of the biodegradation tests can only generate meaning, if they are contextualized with the material properties, the textile and design processes. By contextualizing the biodegrading results with design and technical knowledge, meaningful insights are gained on how certain parameters and decisions influence the sustainability of a product. In fact, by applying a reverse engineering approach and starting at the end-of-life stage of the product, the connection from grave to cradle could be made. If the product characteristics of the product for a specific grave design is understood, the grave can be transformed into the cradle and the circular perspective appears.

From a design perspective an over-all design approach is required to be able to include the various scientific and visible, as well as invisible aspects in the design process. The sustainable conceptual framework of biodegradability can serve as a guideline in a textile product development process. Of course, this concept can be linked with already existing sustainable approaches from pioneers such as for example the idea of reducing waste in production (Rissanen, 2013) or the focus on the dynamic and process-oriented character of product-user relations (Fletcher, 2016).

By connecting design with sustainability, a unique meaning is introduced into the product, which makes it both desirable to the customer and leads to less substitution products and ultimately to less consumption (Walker, 2006).

The concept of shared responsibilities in a circular textile future remains theory, unless the understanding and awareness of the textile cycle including transition of stages from use to composting can be learnt through personal experience. However, it will take common efforts to change the perception not only from the customer but also from all stakeholders involved from linear to circular (Circular Transitions, 2016).

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