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Publication date
2023

Document Version
Final published version

Published in
Proceedings of the 5th Plate 2023 conference

Citation (APA)
van Kuijk, J., & Wever, R. (2023). Spinning Out of Control: reflections on the (non)sense of repurposing as a circular economy loop. In K. Niinimäki, & K. Cura (Eds.), *Proceedings of the 5th Plate 2023 conference: Product Lifetimes And The Environment (PLATE)* (pp. 1115-1121). (Aalto University publication series ART + DESIGN + ARCHITECTURE, 3/2023). Aalto University.

Aalto University
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PLATE
Product Lifetimes
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5th PLATE 2023 Conference
Espoo, Finland - 31 May - 2 June 2023

Spinning out of control – reflections on the (non)sense of repurposing as a circular economy loop

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Keywords: Repurposing; recycling; inner loops; end-of-life; design strategy.

Abstract: Within design for circular economy, the power of the inner loops is frequently stressed. The closer one can stay to the original product, retaining its shape and value, the better it is thought to be from a circular economy perspective. One of those loops, inside of material recycling, is repurposing: re-applying parts and materials with a pre-use history in new and different applications. Showing the history or previous life of the material is then deemed a value-adding aspect.

Repurposing, or upcycling, has worked well in artistic one-off solutions, but presents challenges when scaled to higher volumes, due to fluctuations in material flows and the challenges associated with processing larger volumes of waste streams. However, scaling up of repurposing is required if a meaningful environmental contribution is to be achieved.

By contrasting four cases, analyzing previous design projects, on 1) railway timetables into consumer products, 2) on turbine blades into playgrounds, 3) truck tarps into bags and 4) on dining room chairs into wooden games, we explore when and how repurposing makes sense and when it doesn't.

We explore how well expected material stream volumes match proposed applications. We contrast what would be the alternative, outer-loop process for each material stream, and how future looping is affected by the repurpose loop. We re-assess the 'inner loop'-principle using the concepts of flexibility of application and batch entropy. We argue that in terms of circularity and sustainability, in cases where the waste material can be recycled well, such a route through the outer loop back to inner loops, may be preferable to opting for the tighter 'repurpose loop' if that represents a high change of spinning out of your control and ending-up in incineration.

Introduction

In the frequently referenced butterfly model of the circular economy from the Ellen MacArthur Foundation (e.g. Ellen MacArthur Foundation, 2013, p24), there is no dedicated loop for re-purposing, the recovery of existing products or parts thereof and then re-applying these in a new context and with a new function (Den Hollander et al, 2017; Eike et al, 2020). If it were included in the butterfly model a re-purpose loop would most likely lie between the refurbish/remanufacture loop and the outer loop of material recycling (see Figure 1).

A basic adage of design for a circular economy, is the power of the inner loops (Ellen MacArthur Foundation, 2013, p.30). In general, the closer one can stay to the original product, retaining its shape and value, the better it is thought to be

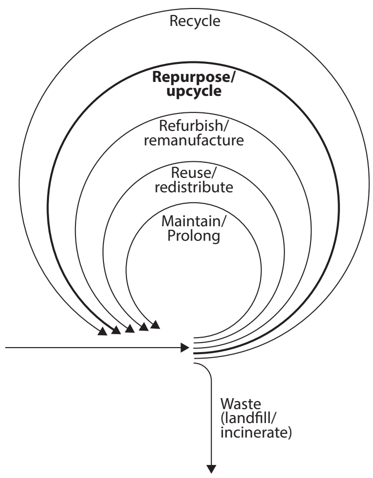

Figure 1. The repurpose loop added to the butterly model of the circular economy by the Ellen MacArthur Foundation.

from a circular economy perspective. Considering this, re-purposing could be considered preferrable to material recycling. This paper aims to reflect under which conditions that is actually true, by reflecting on future potential beyond the initial loop of either re-purposing or recycling.

So far, repurposing, sometimes also referred to as upcycling, has been mainly applied in artistic one-off solutions, where it has worked well. It presents challenges however, when scaled to higher volumes, due to fluctuations in material flows and the challenges associated with processing larger volumes of waste streams. Scaling up of repurposing would be required though, if a meaningful environmental contribution is to be achieved. But then we are automatically talking about diverting relatively large, relatively homogeneous materials streams.

Aim

We therefore explore how well expected material stream volumes match proposed applications. We contrast what would be the alternative, outer-loop process for each material stream, and how future looping is affected by the repurpose loop. We thus re-assess the 'inner loop'-principle using the concepts of flexibility of application and batch entropy and explore when repurposing makes sense and when not.

Methodology

We first discuss the three concepts that we identified as being important for re-evaluating the inner loop principle, namely: re-application bandwidth, waste stream entropy and waste stream volume. We then assess those concepts on four real-world design projects, which serve as scenarios against which the concepts can be matched, and which allow us to explore when and how repurposing makes sense and when it does not or does to a lesser extent. The four projects are: 1) railway timetables into consumer products, 2) turbine blades into playgrounds and street furniture, 3) tarpaulins into bags and 4) dining room chairs into wooden outdoor games.

Central concepts

Below we discuss three concepts that we identified as central for assessing to which extent it is desirable to repurposing a waste stream.

Re-application bandwidth

The first challenge in large-scale repurposing is the (in)flexibility of application of the waste/material stream that is to be reprocessed. Repurposing makes sense from a value-keeping perspective, but it does require quite some design effort to fit an existing element, component or product in a new context (see Figure 2) in a way that sufficient value is offered.

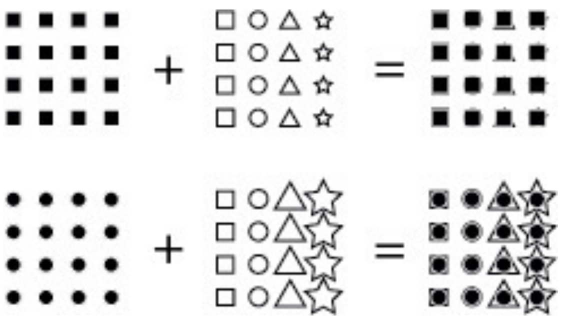

Figure 2. Without altering it, a material/waste stream may not fit many new contexts of use (upper row). Depending on the type of material/waste, and on how many new contexts of use are identified, more matches for contexts where products/elements can be successfully repurposed may be identified (lower row).

To create a successful market for a reclaimed material, one needs to not look at the value that is captured in the current item, but also at in what form the reprocessed item (complete product, construction element or base material) can offer most value on the market. By already taking repurposing into account during the design process of the initial product or component, reapplication bandwidth can be increased, and required efforts and resources for reapplication can be reduced (Schild, 2020).

Waste stream entropy

Entropy is a core concept of thermodynamics, and refers to a measure or disorder, randomness or uncertainty of a system, or in this case, of a waste stream (See Figure 3). Waste stream entropy influences how big and homogenous the batches are of similar products, modules or materials. And thus also the (financial) viability of reprocessing a waste stream, as standardized, high-volume processes are much more efficient than custom, small-scale processes.

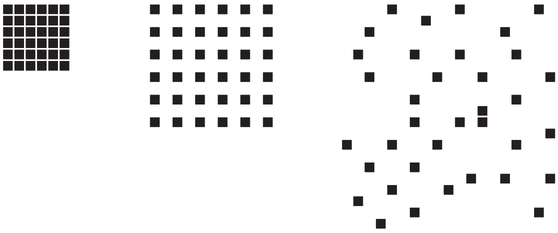

Figure 3. With repurposing, often the waste stream is divided into small unis, and the entropy (distribution, randomness) increases.

The second law of thermodynamics states that: “entropy of isolated systems left to spontaneous evolution cannot decrease with time as they always arrive at a thermodynamic equilibrium.” This implies that once separated, materials and products will not spontaneously reform as a homogenous batch of considerable size. However, just as in thermodynamics, the entropy of a waste stream can be reduced by adding energy (effort). Then the size, density and homogeneity of a waste stream can be increased again (see Figure 4). For example, users can be stimulated to separate waste streams to increase their homogeneity. Or a deposit system can stimulate users to bring back bottles to the supermarket. Another example is a materials passport (Rau, 2022) or distribution logbook, which can help to identify where products or materials are, and what their composition is, thus stimulating recollection.

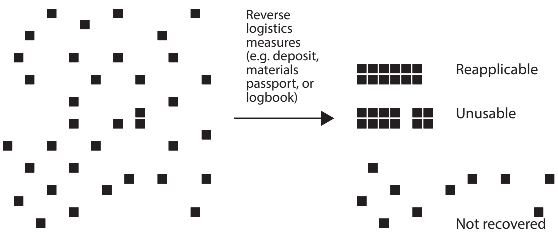

Figure 4. Recollection measures can stimulate entropy (distribution, disorder, randomness) of a waste stream to be decreased again.

Waste stream volume

This concept covers how much of the product, module or material is produced over time and needs to be reprocessed (see Figure 5). Because of the sheer volume of waste, and because the existing shape and structure may limit the possibilities for application, in some cases, it may be preferable to move the waste stream to the more ‘outer loop’ of material recycling, as the flexibility or application bandwidth for raw materials is much higher than for components or complete products.

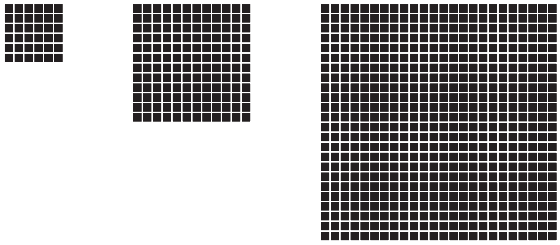

Figure 5. Waste stream volume influences how many components or products need to be reprocessed, and thus how big of a ‘receiving context’ for the repurposed stream needs to be found, or, alternatively how big the reapplication bandwidth of the reprocessed waste stream should be.

Benchmark projects

For each project a qualitative assessment is provided of the waste streams reapplication bandwidth, entropy and volume, and how the chosen loop of the butterfly model (for example, recycling or repurposing) altered this.

Project 1: Railway time-tables

Figure 6. railway time table re-purposed into a service tray.

Old plastic railway timetable signs made from polystyrene were ‘upcycled’ in the form of, among others, book covers and serving trays (see Figure 6). Here the upcycled product gained a higher value than the waste, and possibly even than the original timetables, as consumers highly appreciated the well-known aesthetic of the timetables which was featured on the products.

The reapplication bandwidth of the batch of discarded timetables was considerable, as it is viable to recycle polystyrene and use it for injection molding of new products. However, as a product, the reapplication bandwidth of the timetables is fairly low, as it is harder to find contexts in which time tables can offer the same value. In this case, the value was mostly found in the styling, creating products that still showed the features of the old timetables. This strategy caused batch of considerable size of recyclable material to be cut up into many items, sold to individual, untracked customers. At end-of-life the repurposed products are likely to be incinerated or end as landfill. This is less problematic as the original waste stream size is not so big and there is not a continuous output. However, in terms of circularity in the longer run, in this case material recycling (outer loop) would have been preferable over upcycling of the original timetable (more inner loop).

	Initial waste stream	*Repurposed stream*
Reapplication bandwidth	●●●●○	○○○○○
Entropy	●○○○○	●●●●●
Volume	●○○○○	●○○○○

Table 1. Indicative comparison of the properties of the initial waste stream and the repurposed stream of the raillway time tables

Project 2: Turbine blades into playgrounds and street furniture

Figure 7. One of the playgrounds made out of discarded turbine blades (Photo taken from Medici et al 2020)

In a pilot project wind discarded turbine blades were transformed into children's playgrounds and street furniture (Jensen 2018, Mishnaevsky 2021). Because turbine blades are made of composites of epoxy resins and glass fibers, they are very hard to recycle. However, due to the increasing application of wind energy there is a large and increasing volume of discarded wind turbine blades. Therefore, the idea was to prolong the lifespan of the blades by creating children's playgrounds and street furniture out of them (see Figure 7). Thus, even though the initial waste stream has a limited reapplication potential, because of the highly specific form factor of the turbine blades, through a creative step, a new application was found. It was stated that if 5% of the Netherlands' yearly production of urban furniture was using wind turbine blades, the whole Dutch annual turbine blade waste stream would be absorbed (Jensen 2018).

Although repurposing prolonged the life span of most of the components/material, the repurposed stream subsequently had a limited reapplication bandwidth, which was reduced further by wear and tear (Medici et al, 2020). Also, the entropy of the repurposed stream would increase, as the material would end up in playgrounds in various locations, and there was no system in place to take care of the ultimate end-of-life of the repurposed turbine blades.

In addition, it can be doubted whether the proposed 5% annual market share of new street furniture is feasible considering the highly specific form factor and material properties of the repurposed designs. Although the proposed repurposing could mean a temporary storage of the waste stream and prevent the use of (virgin) materials, absorption of the complete waste stream of turbine blades seems improbable.

Because of the low reapplication bandwidth and the high waste stream volume, in this case it seems that the most preferable option would be to improve recycling processes at the material level for the current turbine blades (outer loop), as well as the development of a new generation of blades, with materials and a design aimed at recycling.

	Initial waste stream	*Repurposed stream*
Reapplication bandwidth	●○○○○	○○○○○
Entropy	●○○○○	●●●○○
Volume	●●●●○	●○○○○

Table 2. Indicative comparison of the properties of the initial waste stream and the repurposed stream of the wind turbine blades

Project 3: Truck tarps into bags

Figure 8. Bag made out of tarpaulin by Freitag

Freitag makes bags from tarpaulins (see Figure 8), and in 2017 the company reported an annual output of 300,000 products and the recycling of 300 tons of tarpaulin per year (Sung et Al, 2022). As with the train tables, the entropy of the waste stream increases highly when it is repurposed, as smaller pieces of tarp will each go with their individual customer. However, in this case that is less problematic, as the reapplication bandwidth of the original material was very low, with landfill/incineration as the likely path. Furthermore, the waste stream is of a large volume, even to the extent that the Freitag products cannot complete absorb the stream. This raises the question of whether in addition to repurposing, a recycling path is needed.

	Inititial waste stream	*Repurposed stream*
Reapplication bandwidth	●○○○○	○○○○○
Entropy	●○○○○	●●●●●
Stream volume	●●●●○	●○○○○

Table 3. Indicative comparison of the properties of the initial waste stream and the repurposed stream of the tarpaulin bags

Project 4: Dining room chairs into games

Figure 9. Kubb game made out of re-purposed dineing room chairs. (Berglund, 2022)

This case was studied as a master thesis project (Berglund, 2022) and is reported more elaborately elsewhere (Berglund et al, 2023). It deals with a Swedish second-hand mall, where donated products come in and are sold (as-is or repaired, re-upholstered, remanufactured, or repurposed) by the entrepreneurs in the mall. This system is operational, but the inflow of dining room chairs is much bigger than can be sold as chairs again. Hence, currently a considerable number of chairs is diverted to waste treatment and energy recovery every week. As one solution direction, re-purposing the wooden chairs into typical Swedish outdoor games was explored (Figure 5).

The current alternative for the chairs is energy-recovery. The repurposed games would, once discarded, likely enter a similar waste treatment.

Batch-size potential of selling games may be limited, but there is aesthetic potential to truly use the pre-use history of the materials (see e.g. Lepelaar et al, 2022) as a value-enhancing feature.

	Original waste stream	*Repurposed stream*
Reapplication bandwidth	●●○○○	●○○○○
Entropy	●○○○○	●●●●●
stream volume	●●○○○	●○○○○

Table 4. Indicative omparison of the properties of the initial and repurposed stream of the kubb games made out of chairs

Discussion and conclusions

Repurposing, as a circular strategy is under-researched in the literature, certainly at larger scales than one-offs. In the common circular economy model, the logical place for a re-purpose loop would be between remanufacturing/reupholstering and recycling. That would also imply that repurposing is less desirable than remanufacturing, but more desirable than material recycling. In this paper, we have critically examined that position. To properly assess the circular and sustainability performance, one needs to look on the one hand at what level of virgin material application has been prevented, but on the other hand also at what future material recycling loops may have been lost or made much more difficult.

A danger of repurposing is that by going to the inner loop, there will be no more subsequent loops. We argue that in terms of circularity and sustainability, in cases where the waste material can be recycled (both technically and economically), that might be preferable to staying in the more inner 'repurpose loop' as there the material might spin out of your control and end-up in incineration at their next end-of-life phase.

We have provided three basic aspects by which designers can analyze both their proposed repurposing scheme, and the paths thus not chosen:

- Re-application bandwidth, for the technical and economic value of the waste stream as a material, component or product,
- Waste stream entropy, for the technical and economic potential of future circular loops after re-purposing,
- Waste stream volume, for assessing how the potential volume of a repurposed stream relates to the volume of the generated waste stream.

Reapplication bandwidth, entropy and waste stream volume seem useful indicators to assess whether upcycling is sensible.

With one-offs or limited volumes, it might be possible to find an acceptable or suitable repurpose-context, but if the volume of to-be-repurposed items goes up, it becomes harder to find niches for which the repurpose item is suitable.
Repurposing does seem to make sense if the reapplication bandwidth is limited and volume is low.

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