Computational Structural Reuse for Circular Design

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Abstract

Circular design aims at expanding the lifespan of industrial products through repair and reuse. But mainstream computer-aided-design tools have been developed to support the creation of new products rather than the reuse of existing ones. The goal of this project is to revisit one of the core tasks of computer-aided-design – shape creation – under the new constraint of reusing parts of existing shapes. We will formulate shape reuse as a combinatorial optimization problem and we will explore potential strategies to cope with the resulting computational complexity in a scalable manner.

1 Project Description

1.1 Context and objective

Our economy is facing a pressing need to replace the dominant "take-make-use-dispose" linear model of production and consumption by a more sustainable, circular model where products undergo a longer lifespan through reuse, repair, and high-quality recycling [2]. But while more than 80% of the environmental impact of a product is determined at the design stage [3], Computer-Aided Design (CAD) remains dominated by legacy software developed for the outdated, unsustainable production model. Our goal in this project is to rethink the foundations of CAD to better assist designers in creating products for a circular economy.

Circular economy aims at reducing waste by retaining resources in the production chain. Importantly, while several strategies exist to recover resources from end-of-life products, repair and reuse are preferred over recycling as these strategies better preserve the value of products and their materials [6]. For this reason, our project focuses on so-called *structural reuse*, where parts of a product are reused to make new products. Figure 1 illustrates two real-world structural reuse scenarios where hard-to-recycle products are re-purposed by cutting and/or reassembling. Designing products via structural reuse raises significant new challenges for designers, as they not only need to think about the shape and functionality of the product they want to create, but also about how they could achieve these design goals by reusing parts of existing products, and eventually also think about how parts of their product might be reused in the future [1, 4].

To assist designers in performing the new, challenging tasks of circular design, we plan to study two underlying computational design problems:

1. Given a stock of existing shapes and a new, target shape, how should we segment the stock into parts and assemble them to form a good approximation of the target? This problem amounts to *projecting* the target shape onto the space of shapes feasible from the stock.

2. Given a stock of existing shapes, how can we guide designers in creating a new shape that can be well approximated with parts from the stock? This problem amounts to *navigating* into the space of shapes feasible from the stock.

Figure 1: Real-world structural reuse scenarios. *Left:* Windturbine blades are composed of layers of fiber glass, resin and balsa wood that cannot be recycled, and as such are either incinerated or landfilled. With a service life of 20 to 25 years, recent studies estimate that windturbine blades will result in a combined waste of tens of million tons by 2050 [7]. Yet, the light weight and structural strength of windturbine blades make them a valuable source of construction material for freeform architecture (source: `https://re-use.eu/blade-made/`). *Right:* Ikea Hacking aims at re-purposing classical Ikea furniture to create new products [9]. In addition to offering opportunities for augmenting the lifespan of the original products, Ikea Hacking fosters the reuse of highly standardized parts, making the new product easy to assemble and repair (source: `https://www.platform21.nl/page/3293/en.html`).

The two problems are related, as the ability to project an arbitrary shape onto the space of feasible shapes is a necessary ingredient to constrain the designer to stay in that space during design exploration. Importantly, both problems entail expressing shapes as an assemblage of existing pieces, akin to solving a jigsaw puzzle. We will formalize these problems, which are combinatorial in nature. We will propose both geometry-driven and data-driven strategies to solve these problems efficiently, which is critical to allow fast design iterations.

1.2 Applications

We will ground our research into real-world practice by focusing on the structural reuse of windturbine blades for architectural design (Figure 1, left). We have initiated a collaboration on this topic with Jelle Jousta[1] and Mariana Popescu[2] from TU Delft. Jelle Jousta studied the reuse of windturbine blades as part of his Ph.D. on circular design [5], and as such brings a unique expertise on the challenges and opportunities of working with the composite materials that make such blades. Mariana Popescu does research on computational architecture and sustainable design, including the use of innovative materials in freeform concrete shells [8]. Her expertise will be critical to define the physical properties that the assembly of blade segments should fulfill to form a usable structure. Together, we aim at demonstrating a complete reuse cycle of a decommissioned windturbine blade, from the initial design of an architectural structure all the way to its fabrication.

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