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Evaluating Circular Packaging in Online Retail: A Case Study-Based Design Approach

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Abstract

The growing environmental concerns associated with plastic packaging in online retail necessitate the development of sustainable alternatives. This study explores an innovative approach to e-commerce packaging by designing and testing an alternative cushioning material using biodegradable and recyclable components. The experiment utilized paper straws, cut into small segments, to create sturdy rings, which were adhered to sheets of parchment or recycled paper. This structure aimed to replace conventional plastic air pillows and bubble wrap while maintaining protective performance. The study evaluated the durability, shock absorption, and feasibility of these paper-based alternatives in packaging applications. Results indicated that the designed packaging components provided adequate cushioning and structural integrity, offering a viable and eco-friendly solution for online retailers, including Amazon. The findings highlight the potential of biodegradable materials in reducing plastic waste and promoting circular design in e-commerce packaging.

Keywords
Circular, Design, materials, Packaging, Paper

1. Introduction
The growth of e-commerce has significantly increased the demand for packaging materials in retail online shopping. Amazon, as one of the largest global e-commerce platforms, has implemented various packaging strategies to enhance sustainability. This case study examines Amazon's packaging practices, its life cycle analysis, and the gaps in its sustainability efforts. Amazon's packaging primarily consists of corrugated cardboard, plastic mailers, air pillows, and paper-based alternatives. The life cycle analysis (LCA) of these packaging materials involves the following stages:

1.1 Raw Material Extraction
Amazon's packaging materials primarily consist of corrugated cardboard, plastic mailers, air pillows, and paper-based alternatives, each with distinct environmental impacts. Corrugated cardboard is sourced from both virgin and recycled wood pulp, contributing to deforestation and significant water consumption (Villanueva & Eder 2014). However, sustainable forestry practices and certification programs such as the Forest Stewardship Council (FSC) aim to mitigate these adverse effects by promoting responsible sourcing (World Wildlife Fund 2021). In contrast, plastic mailers and air pillows are derived from petroleum-based polymers, leading to carbon emissions and continued reliance on fossil fuels (Hopewell et al. 2009). While the integration of recycled content in plastic packaging has increased, challenges in recyclability persist, particularly due to the complexity of material separation and contamination (Geyer et al. 2017). Paper-based packaging has gained traction as a sustainable alternative, with an increasing reliance on FSC-certified and recycled paper materials. Research indicates that using recycled paper significantly reduces water and energy consumption compared to virgin paper production, making it a more environmentally responsible choice (Klemm et al. 2020). Amazon has implemented several initiatives to enhance packaging sustainability. In 2023, the company reported that 12% of its global shipments were sent without additional Amazon packaging, and approximately 12 million products qualified for the "Ships in Product Packaging" program (Amazon 2023).

Additionally, Amazon avoided more than 446,000 metric tons of packaging in 2023 and has reduced the average per-shipment packaging weight by 43% since 2015, cumulatively preventing over 3 million metric tons of packaging (Amazon 2023; Supply Chain Dive 2023). The company also reported a 9% reduction in the average single-use plastic packaging weight per shipment between 2022 and 2023 (Amazon 2023). Despite these efforts, Amazon's plastic packaging waste remains significant. In 2022, the company generated approximately 208 million pounds (94.3 million kilograms) of plastic packaging waste in the United States, marking a 9.6% increase from 2021 (PIRG 2023). Globally, it is estimated that up to 22 million pounds (10 million kilograms) of Amazon's plastic packaging waste in 2022 could enter aquatic ecosystems, contributing to pollution in rivers, lakes, and oceans (Oceana 2023).

1.2 Manufacturing & Processing

The manufacturing process for Amazon's packaging materials is energy-intensive, involving paper pulping, plastic extrusion, and ink printing, all of which contribute to emissions and resource depletion (Hischier et al. 2005b). To address these concerns, Amazon introduced its Frustration-Free Packaging (FFP) initiative, which aims to reduce material complexity and optimize recyclability (Amazon 2023). Research suggests that simplified packaging structures lead to increased recycling rates and lower overall environmental impact, as they eliminate unnecessary components and facilitate easier disposal (Van Eygen et al. 2018).

1.3 Distribution & Logistics

The distribution and logistics phase of packaging plays a crucial role in determining the overall carbon footprint. The weight and volume of packaging materials directly influence transportation emissions, as heavier and bulkier materials require more fuel consumption (Weber & Matthews 2008). To counteract this, Amazon implemented its "Ship in Own Container" (SIOC) program, which minimizes secondary packaging and reduces material waste (Amazon, 2023). Studies highlight that right-sizing packaging can significantly lower carbon footprints by eliminating excess material and reducing shipment volume (Accorsi et al. 2014b).

1.4 Usage & Consumer Handling

Consumer behaviour plays a key role in determining the end-of-life outcomes of Amazon's packaging. While many consumers attempt to reuse or recycle packaging materials (Singh, 2025), disposal behaviours vary depending on local recycling infrastructure and awareness levels (Singh et al. 2014). Amazon's emphasis on minimal packaging and right-sized boxes aims to optimize material use while also encouraging more sustainable consumer habits (Packaging Europe 2022). However, gaps remain in ensuring that consumers properly recycle or repurpose packaging, as accessibility to recycling programs is inconsistent across regions.

1.5 End-of-Life (Recycling & Waste Management)

Recycling and waste management remain critical concerns in Amazon's packaging sustainability efforts. Corrugated cardboard boasts high recovery rates, particularly in developed economies where recycling infrastructure is well-established (Smith et al.2019). However, plastic mailers and air pillows often end up in landfills due to the limitations of municipal recycling programs, as flexible plastics require specialized facilities that are not widely available (Jambeck et al. 2015). While compostable and biodegradable alternatives exist, their adoption remains limited due to the lack of industrial composting facilities and insufficient consumer awareness regarding proper disposal methods (Song et al., 2009). Addressing these challenges requires a multi-faceted approach, including improved recycling technologies, expanded access to sustainable disposal options, and enhanced consumer education initiatives.

2. Gaps in Amazon's Packaging Sustainability

Despite Amazon's sustainability initiatives, several challenges persist in achieving fully sustainable packaging. One significant gap is the continued reliance on plastic packaging. Although Amazon has increased the use of paper-based alternatives, plastic mailers and air pillows remain prevalent in its packaging systems. Many consumers lack access to plastic recycling facilities, leading to a high volume of plastic waste ending up in landfills rather than being properly recycled. Another major issue is the limitation in recycling infrastructure. While cardboard recycling is widely accessible, flexible plastic packaging requires specialized recycling facilities, which are not available in many regions. Additionally, consumer education on proper recycling and disposal practices remains inadequate, resulting in improper waste management and increased environmental impact.

The complexity of Amazon's global supply chain also poses challenges in sustainable packaging efforts. Packaging materials are sourced from various locations worldwide, contributing to a higher carbon footprint due to transportation emissions. Furthermore, differences in packaging regulations and sustainability policies across regions impact the consistency and effectiveness of Amazon's eco-friendly packaging strategies. Consumer

participation in reuse programs is another area that requires improvement. While companies like TerraCycle's Loop have introduced large-scale reusable packaging solutions, Amazon has yet to implement such systems at scale. Moreover, there are limited incentives for consumers to return or reuse packaging, which could otherwise significantly reduce single-use waste.

3. Future Directions and Recommendations

To address these gaps, Amazon can increase the use of recyclable and compostable materials by expanding biodegradable and mono-material packaging to simplify the recycling process. Additionally, improving consumer education through enhanced packaging labeling and detailed recycling guidance can help boost participation in responsible waste management. Another critical step is the development of reusable packaging systems. Introducing returnable packaging models similar to Loop could significantly reduce single-use waste and encourage sustainable consumer behavior. Lastly, enhancing supply chain transparency by improving tracking and reporting of packaging sustainability efforts would allow Amazon to monitor progress and optimize its environmental impact more effectively.

4. Amazon packaging – a case study

Amazon has made significant strides in sustainable packaging through initiatives like Frustration-Free Packaging and Ship in Own Container. However, challenges remain in plastic reduction, recycling accessibility, and consumer engagement. Addressing these gaps requires industry collaboration, policy interventions, and innovations in material science to achieve a fully circular packaging economy. Following (Figure 1) is a curated unboxing of a package that was delivered in August 2024 in Virginia. The experiment employed jugaad (Singh et al, 2017 a) technique. However, the practical implementation can be easily adopted with robust manufacturing detailing

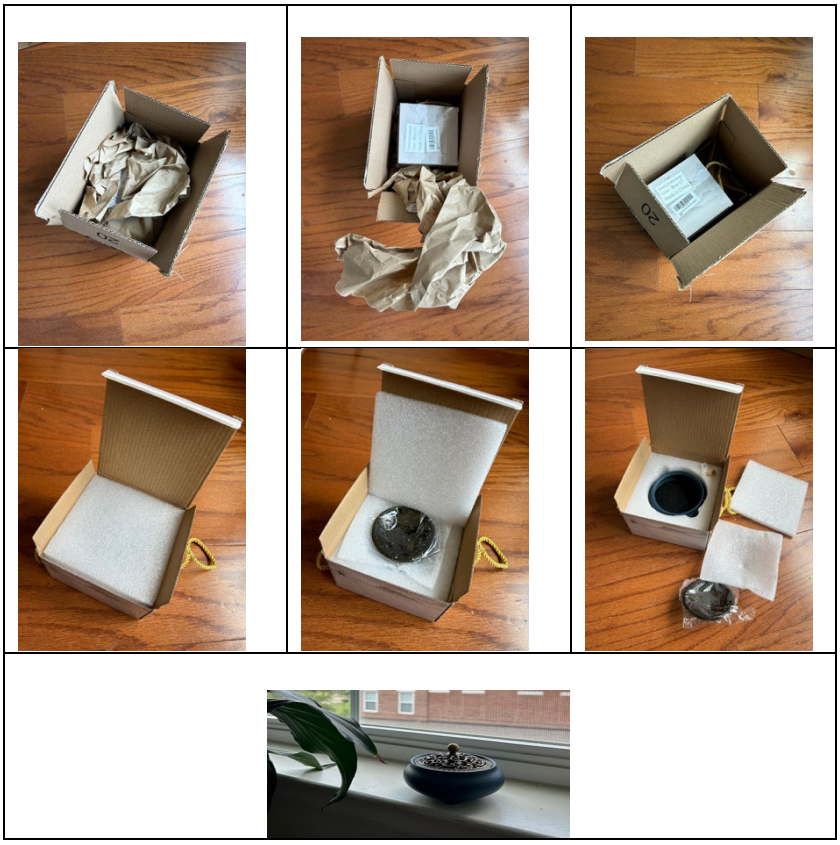

Figure 1. Unboxing of an Amazon package which consisted of corrugated box, Polyethylene foam sheets and crumpled paper filler.

5. Experimental Study on Alternative Packaging for Online Retail

To explore sustainable packaging alternatives for online retail, including Amazon, an experimental study was conducted to design innovative packaging components using biodegradable and recyclable materials. The study

focused on utilizing paper and paper straws as structural elements. Paper straws were cut into small segments to create sturdy rings, which were then adhered to sheets of parchment or recycled paper, forming a cushioning layer (figure 2). This approach aimed to replace traditional plastic air pillows and bubble wrap with a compostable alternative. Additionally, layered paper structures were tested for their ability to provide shock absorption and durability during transit. The findings demonstrated that paper-based solutions could offer effective protection while significantly reducing reliance on plastic packaging, making them a viable option for enhancing sustainability in e-commerce logistics.

Figure 2. Alternative to bubble wrap sheet – an experiment of firm rings placed at a uniform distance on a recycled paper.

6. Testing of the alternative packaging

The experimental packaging design presents a novel and eco-friendly alternative to traditional plastic-based cushioning materials, such as bubble wrap and air pillows, which contribute significantly to plastic waste and environmental pollution. This approach utilizes biodegradable and recyclable components, primarily paper and paper straws, to create a sustainable yet effective protective layer for packaged goods.The design process begins with cutting paper straws into small, uniform segments, which are then arranged to form sturdy rings. These rings serve as impact-absorbing elements, reducing shock and vibration during transportation. To ensure stability and ease of application, the segmented rings are adhered to a sheet of parchment or recycled paper. This layer functions similarly to conventional plastic cushioning by providing a protective buffer between the product and external forces while maintaining flexibility and adaptability to different package sizes.

The structured nature of this design offers multiple benefits. First, the paper straw rings create air pockets that distribute impact force evenly, preventing damage to fragile items. This mimics the efficiency of bubble wrap while offering a more sustainable disposal option. Unlike plastic-based materials that persist in the environment for decades, the biodegradable nature of the components allows for easier decomposition and recyclability. The images (figure 3) illustrate various stages of this innovative packaging system, from the initial preparation of cushioning materials to their application in securing a fragile product within a shipping box. The process ensures that the item is well-protected without the need for synthetic padding, making it an excellent solution for online retailers aiming to reduce their carbon footprint.

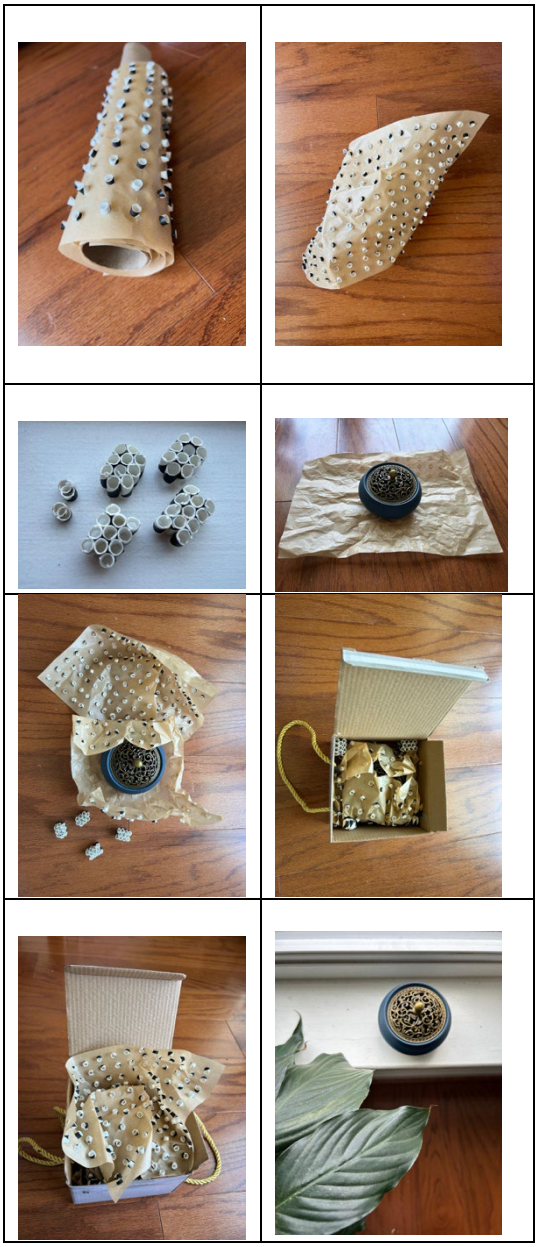

Figure 3. Testing of the new packaging components.

7. Comparison between the packaging materials

Reducing Amazon's packaging size by 20% could significantly improve supply chain logistics, energy consumption, and carbon footprint. With smaller packaging, more products can fit in the same shipment, leading to fewer shipments and reduced fuel consumption. If Amazon's global packaging reductions (446,000 metric tons in 2023) are proportional to packaging size, a 20% reduction in packaging could avoid an additional 89,200 metric tons of packaging. A 10% reduction in transportation requirements from better space utilization could result in a 10-15% decrease in fuel use and emissions, which equates to a potential reduction of 44,600 metric tons in CO2 emissions (based on Amazon's reported metrics). Reducing packaging size could also prevent the need for air freight in some cases, cutting its high carbon footprint (more than 4.5 times that of ground transport per mile, depending on the distance and type of cargo). The reduction in single-use plastic packaging by 9% in 2023 further suggests the company's ability to scale similar initiatives for other types of packaging (Amazon Sustainability, 2023). While Amazon has made efforts to enhance packaging by introducing paper fillers, customer experiences regarding package damage vary.

Table 1. List of materials used in the Amazon and the proposed packaging

Items	Amazon packaging	Proposed design
Packaging material	Polyethylene foam (3mm th.) size: 4”/4”	Recycled paper with firm hollow bumps
Internal casing	Polyethylene foam (1” th.) size: 4”/4”	Hollow nuggets made of paper tubes.
Filling material o	Loose twisted recycled paper. Size: 10”/20” (Amazon)	Firm hollow nuggets filling the gaps between the packaging walls and the product box, limiting any internal displacement of the product inside the amazon packaging in transport and handling.
Package size	Packaging box size: 5”/9”	Packaging box size: 6”/6”
Space efficiency	Material wastage in Amazon packaging:20%	With compact and well-padded packaging, the space wastage can be substantially reduced ensuring energy and space efficiency in the warehouse, delivery vans.
Total weight	16 ounces (paper carton) +.6 ounce (Polystyrene foam packing)-16.6 ounces	16 ounces (paper carton)+1.2 ounce (paper packing (.04 (weight of 3 paper straws)+2.85ounces(10”/10” butter paper)))=18.89 ounces. Paper weight calculation source: https://www.omnicalculator.com/everyday-life/paper-weight

In a Reddit discussion, a user noted that despite minimal packaging, approximately 80% of items arrived undamaged, suggesting that packaging quality might influence damage rates. Another user reported that about half of the books ordered arrived damaged, attributing this to inadequate packaging. Additionally, a Reddit thread highlighted that inadequate packaging, such as insufficient padding, leads to a significant percentage of items arriving damaged. However, these observations are based on individual experiences (Reddit users) and may not accurately represent the overall damage rate. Amazon does not publicly disclose specific statistics on delivery item damages, and as factors such as product fragility, shipping conditions, and handling practices can influence damage occurrences.

7. Discussion

A systematic sustainable manufacturing process for the proposed alternative packaging solution requires a holistic approach that prioritizes eco-friendly materials, energy-efficient production, optimized logistics, and responsible end-of-life management. The use of FSC-certified or recycled paper helps reduce deforestation and water consumption (Villanueva & Ede 2014), while biodegradable, non-toxic adhesives ensure the packaging remains compostable. Manufacturing should focus on low-impact processing, minimizing energy-intensive steps such as excessive heating or chemical treatments (Hischier et al. 2005a), and leveraging renewable energy sources to lower emissions. Process optimization through lean manufacturing techniques can further enhance efficiency and minimize waste. In logistics, lightweight and right-sized packaging reduces transportation emissions, aligning with studies highlighting the impact of packaging weight on fuel consumption (Weber & Matthews 2008). Furthermore, designing for biodegradability and recyclability ensures proper disposal, addressing the challenges of waste management in existing recycling infrastructures (Smith et al. 2019).

Consumer awareness also plays a critical role, as studies suggest that clear disposal instructions improve recycling behaviors.. Additionally, ergonomic considerations in production are essential, as worker-friendly design interventions can minimize physical strain, particularly in tasks requiring repetitive manual handling (Singh et al. 2016, 2017 b, 2018, 2022 a, 2022 b & 2024 b). User-centered design approach (Singh et al, 2025) will help ensure the gaps in waste disposal and recycling challenges are met with suitable design solutions (Singh et al. 2024 a,c) .Compliance with sustainability certifications such as ISO 14001 and Cradle-to-Cradle enhances credibility and ensures adherence to international environmental standards. Life Cycle Assessment (LCA) studies can further support continuous improvements by evaluating environmental impact at each stage of the manufacturing process (Accorsi et al., 2014a). By integrating these principles, the proposed eco-friendly packaging system presents a viable alternative to conventional plastic-based cushioning materials, reducing environmental footprint while maintaining functional efficiency.

8. Conclusion

Adopting compact, sustainable packaging strategies offers significant environmental and operational benefits. For example, reducing package dimensions by just 10% can decrease material usage and cut shipping costs by up to 20% by minimizing wasted space and reducing the need for extra fillers (Creative Logistics Solutions 2022). Similarly, switching from plastic-based cushioning to biodegradable paper alternatives has been linked to diverting millions of tons of plastic waste from landfills—as demonstrated by Amazon's move to paper filler, which eliminated nearly 15 billion plastic air pillows annually (ESG Today, 2024). Moreover, right-sized packaging solutions that eliminate unnecessary void space can reduce shipment volume by approximately 30% and cut fuel consumption by at least 15% (Ranpak, 2021). Increasing the recycled content in packaging by 25% has also been shown to save thousands of gallons of water and lower energy consumption during production, contributing further to resource conservation (U.S. Plastics Pact, n.d.). Finally, reusable packaging systems can often replace up to 100 single-use packages over their lifespan, reinforcing a shift toward a circular, environmentally responsible supply chain (Reusable Packaging Association, n.d.)

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