

CHAPTER 1 POLYMER COMPOSITES: DESIGN AND APPLICATIONS

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1.1 DESIGN PROCESS IN PRODUCT DEVELOPMENT

Engineers are trained to develop environmentally friendly products using a concurrent engineering approach. Effective design is essential to produce high-performance products that are both durable and reliable. The concurrent engineering process typically involves concept generation, concept clarification, concept development, and concept selection. Conceptual design is a critical early phase of product development that aims to fulfil the design intent by offering improved performance and environmentally responsible solutions.

The product design development process generally focuses on four key areas: idea generation, idea refinement, concept development, and concept selection. Designers and engineers can adopt various systematic methods within these areas. One crucial tool is the product design specification (PDS), a document that outlines essential requirements to ensure the project aligns with intended product goals. PDS can include up to 32 different aspects relevant to conceptual design development (Pugh, 1991).

Design typically begins with a basic framework incorporating fundamental design data to guide the entire development process. PDS is vital for product success, as it provides key information related to

performance expectations. Boundary conditions must be realistic to avoid inaccurate predictions. Therefore, all relevant factors must be included to meet customer requirements effectively.

Several systematic methods, such as the Theory of Inventive Problem Solving (TRIZ) and brainstorming, are employed to generate ideas and resolve design challenges. For example, Cascini et al. (2011) applied the TRIZ method to develop a conceptual design for sheet metal snips, improving idea generation through contradiction analysis. The resulting concept was further enhanced using Computer-Aided Design (CAD) software. Other studies suggest that TRIZ can be complemented with morphological charts for even better outcomes.

Concept selection is a vital stage in finalising the design for development. Methods such as the Analytic Network Process (ANP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are often used. These tools provide valuable support in selecting the optimal design from multiple alternatives by evaluating them against defined criteria. This stage is also useful in collaborative decision-making during the conceptual phase.

1.2 DESIGN FOR SUSTAINABILITY

Design for Sustainability (DfS) links sustainable consumption and production with the four main pillars of sustainability: economic, ecological, institutional, and social (Spangenberg et al., 2010), as illustrated in Figure 1.1. To ensure responsible resource management from production to product disposal, designers must incorporate all four pillars. Key factors include consumption patterns, production methods, and the use of suitable technologies and materials that reduce emissions and non-renewable resource use while prioritising human well-being.

Consumer culture frequently drives mass production of personalised goods and services. Organisations can address this through strategic design and marketing, often leading to the emergence of pseudo-satisfiers or inhibitors. DfS offers a way to replace these with lasting satisfiers, thereby increasing long-term value (Spangenberg et al., 2010).



Figure 1.1 The Prism of Sustainability model and their critical linkages

Unlike eco-design, which focuses mainly on economic and environmental aspects through life cycle analysis (LCA) and costing, DfS considers the entire production and consumption system. It guides decision-making in terms of materials, processes, and user interactions to create sustainable products.

In the context of green polymer composites, DfS helps designers develop products that are both effective and environmentally friendly (Zhang et al., 2024). These composites, made from natural fibres and biodegradable or bio-based polymers, support sustainable development by emphasising renewable resources, waste reduction, product longevity, and end-of-life recyclability (Val & Lambán, 2025). This lifecycle approach ensures minimal environmental impact from raw material extraction to disposal.

Integrating DfS into biocomposite product development fosters innovation by challenging conventional practices. It promotes the use of new material combinations, advanced manufacturing techniques, and multifunctional designs (Apel et al., 2024). The innovation lies not only in materials but also in how products interact with users and ecosystems, contributing to a circular economy. DfS thus enables the creation of environmentally responsible, economically viable, and socially beneficial solutions.