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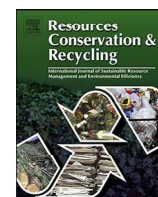
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Sustainable product design and development: A review of tools, applications and research prospects

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ABSTRACT

Due to increasing pressure for achieving sustainability objectives, the concept of sustainable product design and development is gaining more attention in recent research. In the past, a plethora of eco-design tools that address only the environmental aspect have been developed. Hence, previous review articles focused mainly on eco-design tools, such as life cycle assessment (LCA) and others. Unlike previous studies, the main contribution of this article was to review and analyze the recent and emerging product design tools (published from 2007 to 2017) which considered other dimensions of sustainability along with the environment. Based on the criteria of sustainability dimensions, this paper proposed a generic and broader classification scheme to enhance the understanding of these recent tools. Those which included two aspects of sustainability were categorized as partial sustainable product design (P-SPD) tools, and those which covered three aspects of sustainability were classified as sustainable product design (SPD) tools. The analysis revealed that SPD tools were less mature and standard as compared to P-SPD tools. The majority of both P-SPD and SPD tools were based on a life cycle perspective. However, P-SPD tools were found to be more useful at early design stages. In addition, this paper presented the case studies of the tools to decipher their practical utility. It also discussed the hurdles and problems associated with the methodological development and practical utility of the tools. Founded on these difficulties, future research directions were presented. In essence, a coordinated and responsible effort among practitioners, governments, societies and researchers is needed to ensure the successful implementation of the tools.

1. Introduction

Sustainability or sustainable development has become a significant and major research area these days (Zhen et al., 2015). The challenge of realigning the present path of development on a sustainable trajectory concerns all sectors of society, including engineering and manufacturing (Rosen and Kishawy, 2012). Manufactured products impact all three facets of sustainability; economy, environment and society throughout their entire life cycle; material extraction, manufacturing, transportation, use and disposal (Tarne et al., 2017). It was found that about 80% of sustainability impacts are decided at the product design stage (Keoleian and Menerey, 1993; Kulatunga et al., 2015; Lewis and Gertsakis, 2001). To address this issue in the manufacturing sector, designing and production of sustainable products was found to be an important strategy to achieve sustainability (Moreno et al., 2011; Ameli et al., 2016) and cleaner production objectives. Thus, considering the triple-bottom line concept (Hacking and Guthrie, 2008; Hall, 2011) in

product design, sustainability can be defined as the ability of a product to work continuously while ensuring lowest environmental impacts and providing economic and social benefits to the stakeholders.

A sustainable product design solution deals effectively with a product's functional attributes and also balances the three dimensions of sustainability appropriately (Bereketli and Genevois, 2013; Hosseinpour et al., 2015). All three sustainability aspects must be considered as an integral part of sustainable design (Gennari, 2000; Jia et al., 2017). However, initially, environment was the only concern for product design. So, developing an environmentally friendly or ecological (eco)-design was practiced during the first wave of sustainability (Lofthouse and Bhamra, 2012). Since then, an abundance of tools called eco-design or Design for Environment (DfE) tools were developed to provide support during the product design phase (Navarro et al., 2005; Shi et al., 2017).

Because of the fact that previously, many studies focused on developing eco-designs, most of the review articles were also based on

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