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Chapter 1 Introduction and Sustainable Product Development

Daizhong Su
Advanced Design and Manufacturing Engineering Centre,
School of Architecture, Design and the Built Environment,
Nottingham Trent University, UK
E-mail: Daizhong.su@ntu.ac.uk

Contents

Abstract This book consists of 16 chapters which are grouped into four parts including tools, methods, LCA case studies and integrated approach for sustainable product development. Overview of this book is given with brief information of the 16 chapters. The scope of sustainable product development is presented. The sustainable product development process is detailed with explanation of the sustainable product development through the product lifecycle and its objective, as well as a three-tiers approach for sustainable product design. The integration of methods and tools through the product development process is described, and all the tools and methods presented in other chapters of this book are relevant to this integrated approach. At the end, the novel contributions of this book are highlighted.

Keywords Sustainability, Product design, Life cycle impact assessment, Life cycle analysis, Integrated process

Abbreviation

EoL, End of product life
GA, genetic algorithm
GUI, Graphical user interface
ICT, information communication technologies
LCA, life cycle analysis
LCI, life cycle inventory
LCIA, life cycle impact assessment
PDS, Product design specification
S-LCA, social life cycle assessment
XML, Extensible Markup Language

1.1 Overview of the book

Nowadays, sustainability has been receiving great attention globally. Sustainable product development through its lifecycle stages (material attraction, design, manufacture, use, recycling/reuse, etc) considerably contribute to this issue, and, hence, there is a demand to up-date the knowledge of sustainable product development. To meet such a demand, this book is proposed.

This book consists of 16 chapters. Apart from this chapter which is an introduction of this book, the rest 15 chapters are grouped in four parts, of which Part I and Part II are about the tools and methods, while Part III and Part VI are examples to illustrate how the tools and methods were applied in industrial cases.

Part I presents the tools related to sustainable product development, including directives, regulations, standards, life cycle impact assessment (LCIA) methods and software packages, and life cycle inventory (LCI) databases, which are presented in three chapters:

After brief definitions of the three terms 'directives', 'regulations' and 'standards', Chapter 2 reviews nine directives, two regulations and 26 standards which are related to the design and manufacture of sustainable products.

In Chapter 3, 13 LCIA methods such as CML and ReCiPe, and 10 LCI databases such as Ecoinvent and EXIOBASE, are reviewed. The new initiatives for reducing emissions and improving resource efficiency, Product Environmental Footprint, and the environmental product declaration are introduced. And then how to select the LCIA methods and LCI databases are given. The data formats of the Ecoinvent databases are also examined.

Chapter 4 reviews 10 popular LCIA software packages, such as SimaPro, Gabi and openLCA. They are then analysed against three criteria regarding the function to define the product and its lifecycle, databases, and assessment categories and available LCIA methods. Based on the review and analysis results, guidelines for selection of the tools are proposed.

Part II is about the methods for sustainable product development, which are presented in Chapters 5 – 9:

Chapter 5 introduces the concept '***eco-point***' which is a reference of the ecological impact values of products, and then the eco-point approach is presented, including 'eco-debit' to show the customer's negative impact resulted from the products purchased, 'eco-credit' to credit customers' positive behaviour of recycling end-of-life products, 'eco-shopping' for consumers to gain the ecological information of the products to be purchased, and 'consumer eco-account' to record consumers' ecological footprints. The application of the eco-point approach in sustainable production, eco-shopping, recycle/reuse and consumer eco-accounts are also presented.

In the eco-accounting, large amounts of dynamic data are handled for the calculation of eco-points, and, hence, various information communication technologies (ICT) have to be utilised, which are presented in Chapter 6, including distributed computing, Web-based services, security and privacy, data bridging for online Life Cycle Analysis (LCA), and necessary NFC, RFID and mobile communication technologies. The design of the software structure is also presented.

In Chapter 7, after a brief literature review, the social life cycle assessment (S-LCA) technology is introduced, including fundamental terminologies, steps for Implementing an S-LCA, and seven major assessment methods.

Chapter 8 presents an approach to convert ecoinvent data format, EcoSpold, to SQL format for LCI inventory data management and Web based applications. It employs the data extraction programming script and applies extracted data values and information in an SQL database management client. An XML parsing library is used to implement the automated EcoSpold files search and extraction function invoked by a Python script. A Java based graphical user interface (GUI) application is also developed, to help select feasible LCI datasets and automated data file to import into LCIA software.

Chapter 9 starts with the introduction of genetic algorithm (GA) and the GA tool embedded in software package MATLAB. The approach of sustainable product design optimisation using GA is then presented, including the LCIA method/toll selection, a three-tier structure for product LCA, and the sustainable product design optimisation procedure.

Part III deals with the LCA case studies, which consists of five chapters, and each chapter presents an LCA case study in a particular industrial application, including industrial gearbox, petroleum products, vegetable farming, lighting products and flooring products.

Part VI illustrates the integrated approach for sustainable product development with two case studies, one chapter for each, in the areas of eco-lighting product and sustainable flooring product respectively.

1.2 Scope of sustainable product development

The World Commission on Environment and Development (1987) defined sustainable development as the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' This is also the ultimate aim of sustainable product development. It comprises three dimensions: environment, economy and social aspects which have to be properly assessed and balanced if a new product is to be designed or an existing one is to be improved (Klöpffer, 2003).

In the literature about sustainable product development, both words 'sustainable' and 'ecological (or eco for short)' are used regarding the sustainability of products. Although they are different in wording, their scopes in sustainable product development are more or less the same. Taking the definition of sustainable design and eco-design as an example, in its basic definition, eco-design is an approach to designing products with special consideration for the environmental impacts of the product during its whole lifecycle (Wikipedia, n.d.). On the other hand, it was stated that Eco-design concepts, must evolve by taking environmental issues and all three dimensions of sustainability into equal consideration (Byggeth et. al., 2007). The three dimensions of sustainability, which are stated in the paragraph above, are the scope of sustainable design. Taking eco-point as another example, as presented in Chapter 5 of this book, the eco-point is calculated using ReCiPe method with three end-points: resource availability, ecosystems, and human health. The third point is out the scope in the basic definition of ecology, but is the issue within the scope of sustainability.

In this book, both words 'sustainable' and 'ecological (or eco)'are used with similar meaning, but which one is to use in the context depends on its usage in common practices. For example, 'eco-cost' is used in the EU supported myEcoCost project (myEcoCost, n.d.), and following the same usage of 'eco', eco-point, eco-credit, eco-debit and eco-accounting are used in Chapters 5 and 6 of this book.

1.3 Sustainable Product Development process

Figure 1.1 shows the sustainable product development process, which covers the whole product life cycle. The middle part shows the product life cycle, from the product design until the end of life; the left part shows the input to the product life cycle, including materials, energy and human labour, while the right part shows the output from the product life cycle, which mainly includes harmful emission and waste. The whole product development process is supported by utilisation of relevant sustainability methods and tools.

Figure 1.1 Sustainable product development process

1.3.1 Sustainable product development through product life cycle

As shown in the middle of Figure 1.1, the product life cycle consists several phases, including product design, prototyping and test, production, transportation and retail, and end of life, which are further detailed below with related sustainability issues.

Product design phase is initiated by the clients' demands, and based on the demands, the product design specification (PDS) has to be formulated. With the PDS, designer may propose several concepts. The design concepts are then evaluated with the evaluation criteria derived from the PDS and after evaluation, the best concept is selected. With the best concept selected, the detail design is carried out. It has to be aware that in most cases, the design is an iterative procedure, and re-design may happen at any stage of the design process.

Design is the most important for reducing the product's impact on environment, because 'over 80% of all product-related environmental impacts can be influenced during the design phase' (European Commission, 2018). Similar statements can be found in many resources in the literature, for example, Church (2014), Donato (n. d.), McAloone and Bey (2009), Murray (2013) and more, indicating that it is a common understanding in the product development field.

Many sustainable product design methods have been developed, such as design for environment (Telenko, 2016) and 'Design Products for Sustainability' (Donato, n.d.) which introduces a set of methods including design for embedded carbon, design for recyclability, design for recycled content, design for bio-degradability or compost ability, design for transport efficiency, design for concentration, design for longevity, and design for energy efficiency.

Prototyping and test are to validate the design. With the final design, a prototype is made. The prototype is then tested to confirm the expected functions and sustainable features of the product. If the prototype passed the test, then the production starts; if not, the design has to be modified until it passes the test.

Production phase normally includes production process planning, material selection, manufacture, assembly and packaging. This is the most important part for calculation of the ecological impact of the product, because it transfers the design into the product. This phase makes the most ecological impact in the product life cycle, as illustrated in the examples of LCA of all the products shown in this book. Therefore, sustainable production has attracted considerable attention and resulted in many literatures regarding the methods in this area, for example, sustainable manufacture (Moldavska and Welo, 2017), cleaner production (Klemes, Varbanov and Huisingh, 2012) and lean manufacture (Bhamu and Sangwan, 2014).

Distribution and retail. There are two routes for products to reach at their consumers: (1) factories – retailers (shops/supermarkets) – consumers, i.e., the products are delivered from the manufacturer to the retailers first, then consumers make their shopping at the shops/supermarkets and take the products home; (2) the products are delivered to the consumers directly. The second route is achieved via e-commerce Websites, such as Amazon and eBay, or catalogue shopping stores such as Agors in the UK where the consumers order the products according to what they see from the product catalogue or samples exhibited, then the products are delivered from the factory to the consumer's home.

The major sustainability issues involved in this phase are the energy consumption and carbon emission during the transportation of the products. It is obvious that the second route is preferable form the sustainability point of view, because it reduces the energy consumption and carbon emission.

Consumption. This is the phase of product in service. It is important for the consumers to be encouraged to use the product in a proper way for energy saving and enabling the product in service with its designed life or even longer life. When the product reaches its end of life, the consumer should recycle it, not to throw it to landfill. As presented in Chapters 5 and 6 of this book, an eco-credit method is developed to encourage the consumer for recycling and an eco-account is established to record the consumer's ecological footprints due to their daily purchasing and recycling products.

End of product life (EoL). In this phase, the product's service life terminates. If possible, the EoL product should be disassembled. After disassembling, the EoL product goes in three routes including material for recycling, components for reuse, and disposal. The material for recycling goes back to the manufacture stage and components for reuse goes back to the assembly stage in production phase. The disposal section makes up of landfill, physical, chemical, biological and sustainable treatment, and incineration. Incineration and treatments can produce energy for the whole life cycle to reuse.

1.3.2 Objectives of the sustainable product development

To achieve the sustainability through the product development process, both the inputs and outputs, as shown in Figure 1.1, should be reduced and various sustainable methods should be applied within the product development process.

The outputs from the whole product life cycle are emission and waste. The emission includes CO2, SO2, etc. The waste represents any sort of unrecyclable waste.

The inputs to the whole product life cycle include materials, energy, human labour and other resources. To reduce the inputs, the energy and materials have been paid considerable attention in the existing literature; however, the human labour's impact has not been given enough consideration. Because the human labours also produce considerable negative impact, their impact should be considered. To deal with this issue, Su and Ren (2011) developed a method to calculate the human labour's eco-impact, which includes three parts: input (food and drink), output (urine, faeces and respiration) and transportation from home to work place.

1.3.3 A three-tiers approach to assess product's eco-impact

In this approach, a product is broken into three tiers: components, subassembly and assembly. Within the production process of a product, related components are assembled together to form a sub-assembly, and then all the sub-assemblies are assembled to form the final product (assembly). The eco-impact elements associated with the production process are relevant to the component and sub-assembly tiers, including impacts of materials used, manufacturing process, packaging, and transportation, as well as human labour and overhead eco-cost. In the assembly tier, the eco-impact elements considered include transportation, packaging, product service life, design for disassembly, product re-use, recycling, and disposal. This approach is further detailed in (Su and Ren, 2011), and it has been utilised in the optimisation of sustainable gearbox design presented in section 9.4.1.1 of Chapter 9.

1.4 The Integration of sustainability methods and tools for Sustainable Product Development

Fig. 1.2 The integrated approach for sustainable product development through product life cycle.

The approach is illustrated in Fig. 1.2. Within the approach there are three types of integrations:

Integration of Methods. This is to integrate relevant methods into the whole product development process. The methods include the sustainable product design methods presented in Section 1.3 above, life cycle impact assessment methods reviewed in Chapter 3, eco-point method detailed in Chapter 5, ICT for eco-accounting infrastructure detailed in Chapter 6, social life cycle assessment presented in Chapter 7, life cycle inventory management methods presented in Chapter 8 and genetic algorithm for sustainable design optimisation presented in Chapter 9. In addition, other existing methods are also included, such as PDS with eco-constrains, LCA procedure, design for X (design for environment, design for reuse, design for recycling, design for assembly/disassembly, etc), modular design, finite element analysis and sustainable manufacture.

Integration of Tools. This is to Integrate of relevant tools into the whole product development process. The tools include the regulations, directives and standards related to sustainable product development reviewed in Chapter 2, inventory database reviewed in Chapter 3, and life cycle impact assessment software tools reviewed in Chapter 4. Other existing tools related to product development are also considered, such as the tools/equipment for testing the lighting quality of the luminaire mentioned in Chapter 15.

Integration through Product Life Cycle. Within the product development process, the product's sustainability is considered throughout the whole product life cycle, including elaboration of product design specification (PDS), conceptual design, detail design, prototyping and test, manufacture (material acquisition, manufacturing process, packaging, etc), transportation, retail, use (product in service), and end-of-life product treatment (recycle, reuse, disposal, etc.)

In the *PDS elaboration phase*, the eco-constrains are derived from various sources such as relevant directives, regulations, eco-design guidelines, standards, etc. These eco-constrains are then integrated into the PDS.

In the *conceptual design phase*, to meet the PDS derived in the previous phase, several design concepts are generated, and then are evaluated against the PDS evaluation criteria. Relevant standards are used to set-up the evaluation criteria. Life Cycle Assessment (LCA) will be conducted during the concept design stage, and, in order to do so, relevant LCIA methods, such as carbon footprint calculation, will be utilized. Because in the conceptual design phase, the product information is not very detailed, unlike the detail design phase, a quick estimation is performed. The eco-points obtained (see Chapter 5 for more information) are used for evaluation of the product concepts. LCIA software for simple and fast analysis, such as Sustainable Minds or SolidWorks (see Chapter 4 for more information), could be more suitable to be used for the analysis.

In the *detail design phase*, the product is further developed from the concept obtained in the conceptual design phase. The major tasks conducted include the selection of components (elementary input, elementary output, process flow, etc.), material selection, and the product system configuration. With further detailed information obtained in detail design, the product's more accurate eco-point score (see Chapter 5 for more information) can be obtained. With the eco-point, the product can be then further optimised to further reduce the product's negative eco-impact. Several software tools are utilized to help select the components and conduct the detail design task. Relevant standards are also referred during this stage of the process to ensure the product quality and to meet the eco-specifications. Relevant sustainable design methods are employed to conduct the detailed design, such as application of genetic algorithm design optimisation, modular design, and design for reuse/recycling.

In the *prototyping and testing phase*, the prototype of the product is produced and tested; and the eco-accounting for the product's eco-impact, is conducted and its results are analysed in order to ensure the product to meet the required eco-constrains and the product quality according to the referred standards. Proper testing equipment will be utilized to test the product quality. Unlike the simple/quick LCA conducted in conceptual design phase, a more comprehensive LCA is conducted at this stage. The LCA method and related software tools are utilized to conduct detailed analysis and validation. This is because, in this phase of the product development, the product prototype is completed and hence more detailed information about the product is available. To validate the product's performance, software tool such as finite element analysis package, and hardware tool such as Goniophoto meter for lighting test will be applied in this phase.

In the *production phase*, relevant eco-manufacturing and eco-packaging methods will be applied to reduce waste, material, energy consumption, and impact on the environment. Relevant standards are also followed at this stage to ensure the product quality.

In the *retail phase*, the methods related to eco-shopping, such as eco-account, eco-debits and eco-credits as detailed in Chapter 5 will be utilised to encourage the consumers to reduce their footprints on the environments due to the purchasing.

The data related to the *product in service* phase and treatment of product at the *product end-of-life* phase will be used in the LCA, eco-accounting conducted to assess the product's sustainability.

It has to be pointed out that the tools and methods shown in Figure 1.2 and discussed above may not all be applied in a particular application. The selection of the tools and methods are depending on the individual cases. The integrated approach for the sustainable product development are illustrated in Chapter 15 and Chapter 16.

1.5 Novel contributions of this book

This book has the following novel contributions to sustainable product development:

- With an increasing demand for sustainable products, the product designers and manufacturers must comply with the sustainability related directives, regulation and standards, and they need appropriate tools and methods to conduct sustainable product development tasks. However, it is a challenge for them to achieve those. The tools presented in Part I and the methods presented in Part II of this book provide valuable support for the product designers and manufacturers to overcome the challenge.
- The eco-point method presented in this book is a novel contribution to encourage the users to reduce their impact on the environment. The consumer eco-account with eco-debits/credits and eco-balance, and its combination with eco-shopping have not been seen in the literature, and, hence, it is a new and valuable attempt to alert the consumers with their eco-footprints. This method can also be further developed for manufacturers to record their eco-footprints, enabling them to achieve sustainable production.
- The eco-accounting framework enables the implementation of the eco-point approach throughout the process of data collection and processing into the sustainable production assessment, eco-shopping, consumer eco-accounting and recycling/reuse. This a valuable means for both industry and consumers.
- This book also provides several valuable technical contributions, such as
  - The method of integrating multiple tools and methods into the sustainable product development process, which is presented in Section 3.3 and illustrated in Chapters 15 and 16.
  - A novel dynamic data management method, which is presented in Chapter to track data and monitor each stage of product life cycle, which overcomes the problem of massive data acquisition throughout product supply chain;
  - There have been a large number of sustainable product designs, but how to systematically optimise sustainable designs is a still challenge task. The proposed sustainable product design optimisation approach presented in Chapter 8 is a valuable contribution to this subject area.
- The descriptions of each sustainability tool and method are accompanied by easy-to-understand guidelines and examples. The seven case studies presented in this book are real industrial applications, which are valuable illustration for successful application of the sustainability tools and methods into industrial practice.

1.6 Concluding remarks

This chapter gives an overview of this book and highlights the book's novel contributions in the area of sustainable product development.

The scope of sustainable product development is specified, and, in particular, the meanings of the wording 'sustainable' and 'ecological', or 'eco' in short, are discussed and stated that the two words have a similar meaning in this book.

This chapter gives particular attention to two sub-sections '*Sustainable Product Development process'* and '*Integration of sustainability methods and tools',* which are important issues in sustainable product development. The former details with relevant sustainable technologies to be addressed at each stage of a product lifecycle, the objectives to be achieved, and a three-tiers approach; the latter details with various tools and methods, which are presented in the other chapters of this book, could be integrated into the product development process.

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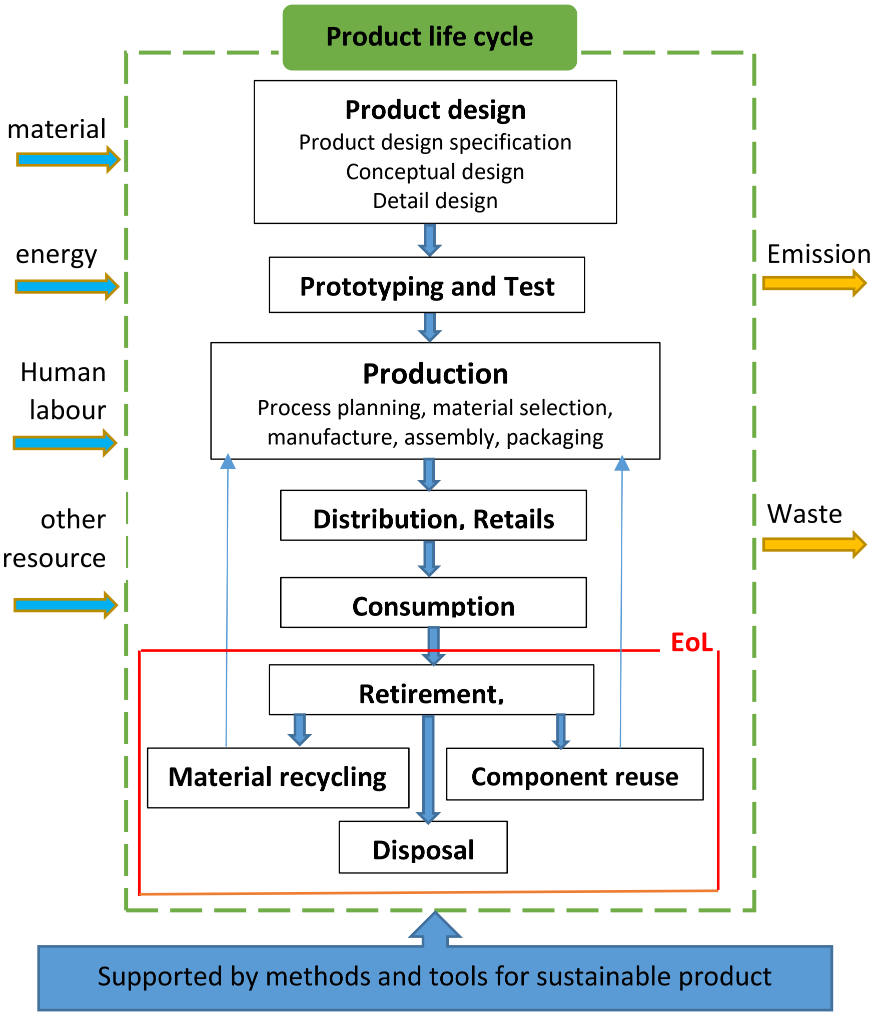
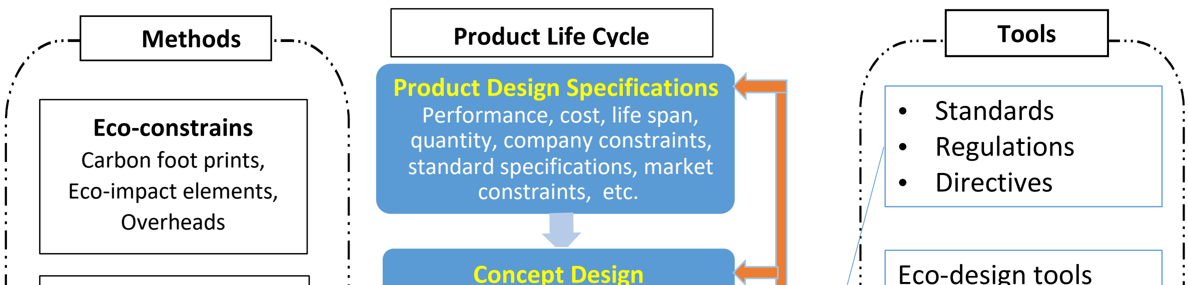


Figure 1.1 Sustainable product development process



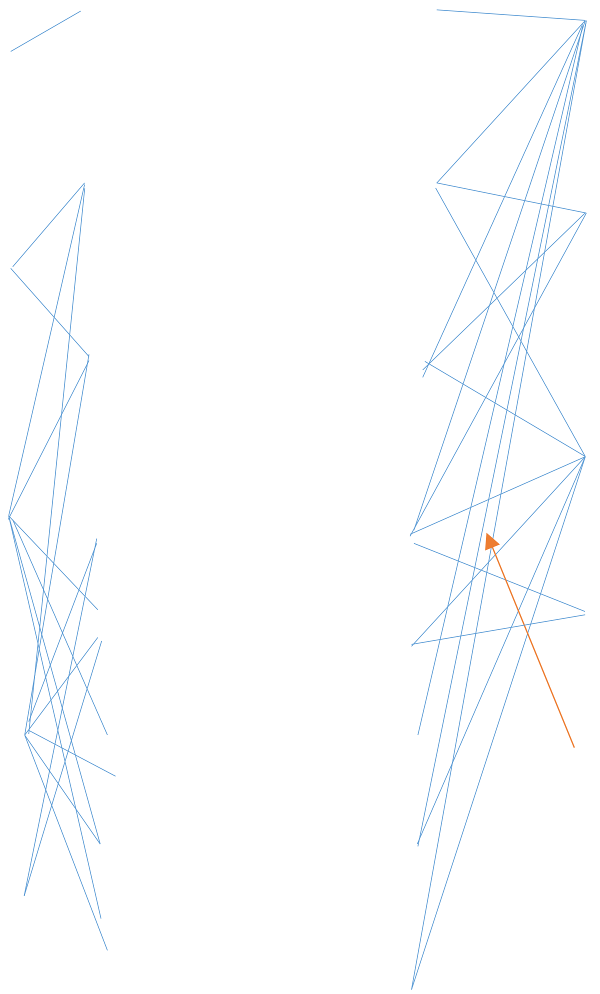


Fig. 1.2 The integrated approach for sustainable product development through product life cycle.