
Sustainable Product Innovation: The Importance of the Front-End Stage in the Innovation Process

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<http://dx.doi.org/10.5772/52461>

1. Introduction

With an overpopulated planet, hungry for electricity and resources, sustainability will be one of the biggest challenges in the future. Present production and consumption patterns are causing serious environmental and human problems and cannot be sustained in a world with rising human aspirations. The challenges and opportunities for sustainable innovation are immense, and the time horizon is shrinking. Going green isn't just about saving the planet; it's about finding a dynamic equilibrium between human and natural systems, between saving the environment, making profit and enhancing all stakeholders' quality of life. Companies, designers and engineers can play an important role in this transition process towards a sustainable and smarter society with an improved 'quality of life'.

The very early phase in the product innovation process, the so-called front-end of innovation (FEI), is the stage of the innovation process where product strategy formulation, opportunity identification, idea generation, idea selection and concept development take place and decisions about new product development are taken [1]. These first phases in the engineering design process have the largest impact on the end result of the project [1, 2] and the highest payback to one's investments [1]. Accordingly, the front-end of innovation is often described as being the root of success for any company hoping to compete on the basis of innovation [2].

Notwithstanding the logic behind integrating sustainability in the early stages of an innovation process, in practice it is flawed. Front-end innovation is a hot research topic, but there is still little research done on its relationship to design for sustainability.

This chapter addresses the existing knowledge in the field of sustainable product innovation and its relation to the front-end of new product development. The research in this chapter

aims to contribute to the understanding and implementing of sustainability in the early stages of an innovation process. A short overview of the used research method is presented in the first part. Secondly, the concept of the front-end of new product development is introduced by its different definitions. The section also describes the importance of the FEI, different types of innovation processes and the functions, activities and characteristics of the Front End. The third part looks to the concept of Sustainable Product Innovation (SPI) together with its drivers and barriers. Furthermore, it reflects on the current practice of the use of Sustainable Product Innovation tools. Next, the importance of integrating environmental considerations in the Front-End stage is presented. Different research results, insights and challenges are discussed in the penultimate part in order to identify successful patterns. At the end of this chapter, a summary is presented.

2. Research method

The represented research in this book chapter reviews the major works on the Front End of Innovation, Sustainable Design and the current state of the art in literature of front-end sustainability. It aims to identify gaps, challenges, issues and opportunities for further study and research. A literature review seems to be a valid approach, as it is a necessary step in structuring an in-depth research field and forms an integral part of any research conducted [3].

The main focus of this book chapter is the Product Innovation Process. Articles focusing on other aspects of an innovation process were not included, e.g. the review does not include new marketing methods, or dimensions on new organizational methods in business practices, workplace organization or external relations. To limit the number of publications, papers mainly addressing sustainable design on a macro ecology level were also excluded from the review. Similarly, research with a highly craftsmanship rather than an industrial product design perspective were also excluded. Although these variables might be important antecedents to how firms eventually perform their FE activities, they are not focused on here.

Furthermore, the term denoting 'product' has several meanings frequently used in literature. In this book chapter, the term product means either the physical form of an object, a service or otherwise a product-service system.

3. Front End of innovation

It is important to understand the nature and outcomes of the Front End of Innovation before we can go deeper in the relationship between Sustainable Product Innovation and the early stages of an innovation process. In this section we give a short overview on the different aspects of the front end.

3.1. The Front End of new product development

The Front End (FE) is considered as the first stage of new product development, which roughly concerns the period from the idea generation to its approval for development, or its termination [4]. Moenaert et al. [5] define the Front End as the process in which an organization formulates a product concept and decides whether or not to invest resources in that concept. Khurana and Rosenthal [6] note that the FE begins when an opportunity is first considered worthy of further ideation, exploration and assessment and ends when a firm decides to invest in the idea, commits significant resources to its development, and launch the project. The FE includes product strategy formulation and communication, opportunity identification and assessment, idea generation, product definition, project planning, and early executive reviews, which typically precede detailed design and development of a new product. One of the many other definitions of FE was formulated by Kim and Wilemon [7]; the Fuzzy Front End begins when an opportunity is first considered worthy of further ideation, exploration, and assessment and ends when a firm decides to invest in the idea, commit significant resources to its development, and launch the project' or shortly; the FE is the period between when a opportunity is first considered and when an idea is judged ready for development' [7].

Crawford and Di Benedetto [8] describe that the process in the FEI gives an answer to the primary questions: whether, what, why, who, when and how.

The decision is made whether or not a product innovation project passes to real development.

- What: the description of the project to be developed.
- Why: what is the strategy behind this new product development?
- Who: describes the human resources necessary to perform the development
- When: describes the timing of the project
- How: describes all the product requirements regarding the new development

We can detect some small variations in the above-mentioned explanations of the Front End. The definitions differ from author to author. Similar to Jacoby [9], we define the FE phase as 'all initial innovation activities, prior to development and ends where real new product development (NPD) starts'.

In contrast with new product development, there is no common terminology in academic literature and design practice as how to denote the early stages of an innovation process.

Different synonyms for the Front End can be found in literature; Fuzzy Front End [1], Front End of Innovation [10], pre-development [11], Phase zero, Stage zero, pre phase zero [12] or pre-project activities [13].

Cooper [11] introduced the term "pre-development" in 1988. Smith and Reinertsen first popularized the term "Fuzzy Front End" in 1991 [14]. Later on, in 1997, Verganti [12] descri-

bed these pre-development activities as “the early stages of development” or the “pre-project activities” while Khurana & Rosenthal [13] used the term “pre-phase zero” in 1997.

Koen et al. [10] were the first to use the term Front End of Innovation in 2002, with the purpose of replacing the “Fuzzy Front End”. The reasoning behind the wish to abandon the term Fuzzy Front End is that the word “fuzzy” implies that the Front End is mysterious, lacks accountability, and cannot be critically evaluated [15]. In this book chapter, we will refer to these early stages as the Front End of Innovation (FEI).

3.2. The importance of the Front End of innovation

The outcome of the FE process is of great importance on the innovation phases that come after the FEI. A variety of authors have recommended to focus/focusing on these early stages of NPD [16] [14] [9] [4] [13] [2] [15] [17]. This section gives an overview of different insights found in literature.

The complexity and cost of the complete innovation process depend to a large extent on the input: ideas for new products, user needs that have been detected, technological opportunities that have been scouted, choices that have been made between different options, and so on. Product success and firm success are to a large extent depending on decisions made in the FEI. The impact decisions can have on the final product result decreases along with the project evolution: whereas FEI decisions can impact the product as a whole, NPD decision have to take into account earlier decisions and can only have an impact on partial aspects of products [9].

Prior research by Khurana and Rosenthal [6] has pointed the importance of the early stages of the innovation process. Although an innovative company must be proficient in all phases of the new product development process, the most significant benefits can be achieved through improvements in the performance of the FE activities [6]. Also a study by Koen et al. [1] identified the front end as the key-contributing factor for new products. The FE presents one of the greatest opportunities for improving the overall innovation process [1]. Reid & Brentani focus on the roots of success; The FFE is the breeding ground for all new goods and services. Activities in the FFE are the root of success for any company hoping to compete on the basis of innovations [2]. Verworn [17] state that the best opportunities for improvement of the innovation process lie in the front-end activities. She suggests that a better understanding of the FEI, leads to a higher success rate in the overall new product development process. Koen and Bertels [15] highlight the importance of the path-dependency in an innovation process; the front end is very important because the product-development process is path dependent. This means that choices made in the front end lead to options as well as limitations regarding which products a company will ultimately be able to develop [15].

In Figure 1 the relationship is shown between influence, cost of change, and available information during the innovation process. At the beginning of the process, i.e. during the front-end, the degree of freedom and influence on the project outcome is high, while little information is available and the cost of changes is low. At later stages in the process one has

more information available, but then the cost of change will increase. Decisions made in the front-end influence all subsequent phases of the innovation process. Quality, costs, and timings are mostly set during the front-end [18]. The challenge in the FE is created by the low amount of information and certainty. Once the specification for the future product is set at the FE, only relatively minor changes of the products are possible – or they will be very expensive and time consuming.

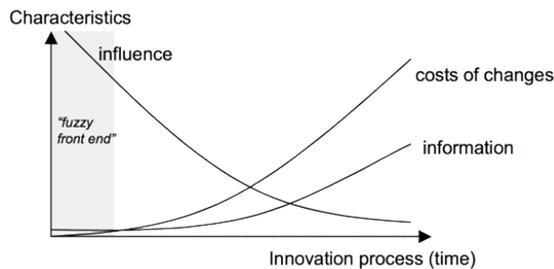


Figure 1. Evolution of influence, costs of changes, and information during the innovation process (von Hippel [19], modified by Herstatt & Verworn [18])

3.3. Front End functions

The reason of existence of the FE can be described through the functions of the FE. Jacoby [9] defines 6 crucial functions of the FE:

3.3.1. Product definition

The ultimate goal of the FE is to know what kind of product functions, product sub-functions and product characteristics a future product should have. It is not only about the idea of the new product or service, but also the added value it would represent and the major requirements [9]. As Cooper proposes [20], the desired goal of the FE is the creation of a well-defined product concept. A well defined product concept allows for a clearer understanding of development time, costs, required technical expertise, the right development team, market potential and positioning, risk, and organizational fit [4]. The product definition depends to large extend on the understanding of the customer needs, wants and preferences [21].

3.3.2. To define new business cases

The product definition and the business cases both describe the future business opportunity, but whereas the product definition focuses more on the product or the service itself, the business cases cover the possible benefits against the investments required. From that business point of view, a set of issues has to be addressed in the FEI in order to be able to com-

plete a business case, such as business and product strategy, target market, product positioning, competition, marketing and finance [9].

3.3.3. *Lower possible risks and reduce uncertainty*

Uncovering possible pitfalls and reducing uncertainty is a crucial function of the FE. When a product or service is considered ready to enter the stage of NPD, it is important to know that this development project can be carried out with controllable risks and technological and market uncertainties [9]. Uncertainties also refer to the freedom of operations relating to existing patents and regulatory requirements [8] [22].

3.3.4. *To decide on projects and products*

Bringing a new product or service into development, means to make choices, to determine priorities and to allocate resources. Decision-making also refers to prioritizing between different products or projects. Go/no-go and prioritizing decisions not only takes place at the end of the entire FEI process but also during the different sub-phases within the FEI based on specific evaluation criteria [9]. Many of the tools used in FEI have the purpose to force decisions. Carbonell-Foulquié et al. [23] categorize the different criteria in five dimensions: strategic fit, technical feasibility, customer acceptance, market opportunity and financial performance.

3.3.5. *To plan projects*

Project planning frames a project in a certain time, usually with defined stages, objectives, deliverables and designated human and financial resources, next to all the other defining and decision activities.

3.3.6. *To process and communicate information*

Gathering & processing information or informing the organization is a key element in the FEI [9]. Processing information is a necessary condition for many of the other process functions described [4]. Moenaert et al. [5] give evidence of the fact that communication flows between organizational functions contribute to innovation success. In general terms, every analysis or synthesis in the FEI, one way or another, is based on processed information. These information flows could be very informal and tacit.

3.4. **The Front End in an innovation process**

Over the last two decades, several researchers and companies have suggested different approaches to innovation in the context of new product development. Many models can be found in literature and practice [24]. This section offers some background in product innovation models, with special attention to the Front End of the Innovation Process and the activities that occur/involved within these early stages.

Innovation can occur in many different areas of an organization. The 'Oslo Manual' produced by the OECD [25] defines innovation as: *'The implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations'*. We will focus in this section on the product development process.

Two notable pieces of work that have emerged from the FEI research are the New Concept Development Model (NCD) developed by Koen et al. [1] and Cooper's Stage-Gate process. The original Stage-Gate framework uses a sequential process with specified steps and timing, while Koen et al. presents a non-sequential relationship model. Both approaches and their relation to the FE will be explained more in detail in this section.

3.4.1. The new concept development model

Innovation projects in industry generally move along three major activity domains as shown in Figure 2.

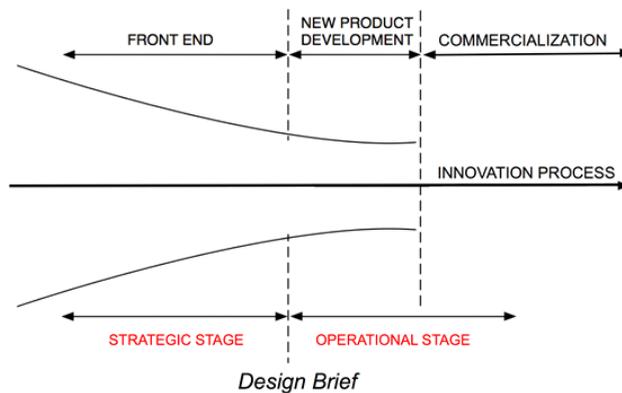


Figure 2. The innovation process. Adapted from Koen et al. [1]

The Front End of Innovation (FEI) or pre-development activities where future products are defined and decided on.

The New Product Development (NPD) where the products are actually developed.

The launching or commercialization activities where these newly developed products are brought to the market.

The NCD model shown in Figure 3 provides a good summary of the main FEI activities that occur prior to the Product Development Stage and consist of three parts: the relatively uncontrollable influencing factors, the engine that drives the activities of the FEI, and the five activity elements. These three key parts are explained more in detail below.

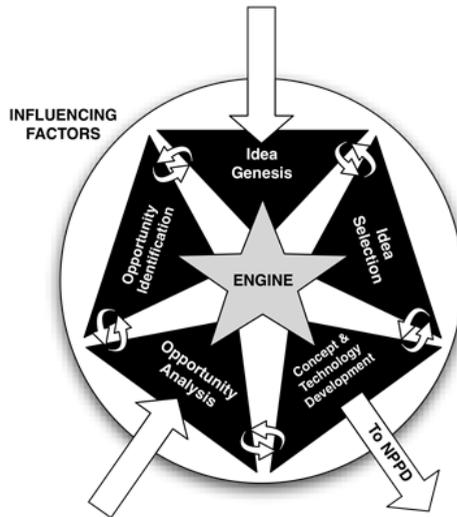


Figure 3. The New Concept Development (NCD) Model according to Koen et al. [1] (Image reproduced by the author)

The ‘**Engine**’ represents the leadership, culture and business strategy of the organization that drives the five key elements.

The inner spoke area of the NCD model defines the ‘**Five Activity Elements**’:

Opportunity identification

In this element, large or incremental business and technological chances and opportunities are identified, by design or default, in a more or less structured way. According to Koen et al. [10], the sources and methods employed by the company can range from formal, systematic tools such as future scenario mapping or problem-solving methods such as the fishbone diagram as well as less formal, ad hoc approaches such as water-cooler conversations or individual insights.

Opportunity analysis

The second activity involves gathering together the additional information required in order to translate the identified opportunities into specific business and technology opportunities for the company. This may involve focus groups, market studies and/or scientific experiments. The level of effort put into these activities is dependent upon the attractiveness of the opportunity, the size of the future development effort, the fit with the business strategy and culture, and the risk tolerance of the decision makers.

Idea genesis

The third element is the idea genesis, which is described as the birth, development and maturation of the opportunity into a concrete idea. This represents an evolutionary and itera-

tive process, including brainstorming sessions and idea banks, in which ideas are built upon, torn down, combined, reshaped, modified and upgraded. A new idea may emerge internally or come from outside inputs, e.g. a supplier offering a new material/technology or from a customer or user with a request.

Idea selection

Normally there are more opportunities and ideas than can be supported with the funding and time available within the company. The critical activity is to choose which ideas to pursue in order to achieve the most business and consumer value. The activity of prioritizing and selecting ideas may be based on an individual's choice or a comprehensive portfolio planning approach. Project selection, financial return and resource allocation in the FE is often just a wild guess, due to the limited information and understanding at this point.

Concept and technology development

Within this activity of the FE, the business case is developed, based on estimates of the other activities; market potential, customer needs, investment requirements, competition analysis and project uncertainty. This element is often seen as the final output of the FEI.

The relatively uncontrollable '**Influencing Factors**' consist of organizational capabilities, the outside world (distribution channels, law, government policy, customers, competitors, and political and economic climate) and the enabling sciences (internal and external) that may be involved. The 'influencing factors affect the decisions of the two inner parts.

The NCP model is a relationship model, not a linear process. The circular shape is meant to suggest that ideas are expected to flow and iterate between the five elements. Iteration and loop-backs are part of FE activities. The key elements of the FE are expected to proceed none-sequentially, as shown by the looping arrows between the elements. Interactions and intermingling between the influencing factors, the five key elements, and the engine are expected to occur continuously.

3.4.2. Stage-gate systems

Product innovation is a dynamic process; it begins with the discovery of new opportunities and product ideas and ends with the successful launch of a new product. Stage-Gate systems divide the steps between these point into a series of stages (=activities) and management decision gates. The original Stage-Gate model, introduced in the mid-1980s by Cooper, was based on research that focused on what successful project teams and businesses did when they developed winning products.

A Stage-Gate System provides a conceptual and operational road map to facilitate a project for moving a new-product project from idea to launch. It is a blueprint to improve effectiveness and efficiency [26]. The stages are where the work is done. Each gate serves as a Go/Kill/Hold/Recycle and prioritization decision point. Stage-Gate systems should provide a clear idea of where the project stands, where it is going, and what needs to be done next.

The typical Stage-Gate system is explained below and shown in Figure 4 [26].

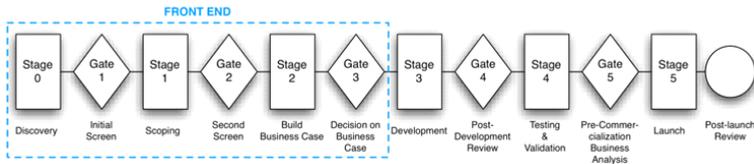


Figure 4. Overview of a Stage-Gate System. Adapted from [26]

Stage 0 – Idea / Discovery

Activities designed to discover opportunities and to generate new product ideas.

Stage 1- Scoping / Preliminary Assessment

A first quick and inexpensive assessment of the technical & marketplace merits of the project, so the project can be reevaluated more thoroughly at gate 2.

Stage 2 – Build Business Case

This is the final stage prior to product development. It is the stage that must verify the attractiveness of the project prior to heavy spending. And it is the stage where the project and product must be clearly defined. Here, market research, a detailed technical appraisal and a detailed financial analysis are undertaken.

Stage 3 – Development

Stage 3 involves the development of the product and of detailed test, marketing and operations plans. An updated financial analysis is prepared, and legal/patent/copyright issues are resolved.

Stage 4 – Testing & Validation

The purpose of this stage is to test the entire viability of the project: the product itself, the production/manufacturing process, customer acceptance, and the economics of the project.

Stage 5 – Launch

The final stage involves the full commercialization of the product; the implementation of both the marketing launch plan and the operations plan.

Post Launch Review / Post-Implementation Review

At some point, the product becomes a ‘regular’ product in the firm’s line. This is the point where the project and product’s performance is reviewed. A post-audit is carried out; the latest data on revenues, cost, expenditures, profits are analyzed together with a critical assessment of the project strengths and weaknesses, what we can learn from this project, and how we can do the next one better.

Preceding each stage is a decision point or gate. Gates are characterized by a list of pre-established criteria, ensuring that all projects are evaluated consistently and fairly. The role of

the gatekeepers is to take a Go/Kill/Hold/Recycle decision and to review and approve the action plan for the next gate. Deliverables for the next gate must be clearly specified [26].

The standard 5-Stage, 5-Gate Stage-Gate New Product Process shown in Figure x is fairly generic. It serves as a sample or skeleton from which to develop a custom-tailored model. Not all projects pass through every stage of the model. Stage-gate processes are not rigid process steps and should be adapted to the context they are used in. None of the activities is mandatory – each project is unique [26]. The project leader considers what activities seem reasonable for the next stage. According to Jacoby, specific activities could belong both to the FEI and the NPD [9]. Also parallel processing is an important feature of stage-gate systems. Activities are parallel rather than sequential. Parallel processing compresses the development cycle without sacrificing quality [26]. Note that today’s Stage-Gate processes are flexible, adaptive and scalable: they are iterative and features loops within these stages and potentially to previous stages [27].

Factors	Content
Factor 1 Strategic Fit and Importance	Alignment of project with our business’s strategy. Importance of project to the strategy. Impact on the business.
Factor 2 Product and Competitive Advantage	Product delivers unique customer or user benefits. Product offers customer/user excellent value for money (compelling value proposition). Differentiated product in eyes of customer/user. Positive customer/user feedback on product concept (concept test results).
Factor 3 Market Attractiveness	Market size. Market growth and future potential. Margins earned by players in this market. Competitiveness - how tough and intense competition is (negative).
Factor 4 Core Competencies Leverage	Project leverages our core competencies and strengths in: technology, production/operations, marketing, and distribution/sales force.
Factor 5 Technical Feasibility	Size of technical gap (straightforward to do). Technical complexity (few barriers, solution envisioned). Familiarity of technology to our business. Technical results to date (proof of concept).
Factor 6 Financial Reward versus Risk	Size of financial opportunity. Financial return (NPV, ECV, IRR). Productivity Index (PI). Certainty of financial estimates. Level of risk and ability to address risks.

Table 1. Typical scorecard for Gate 3 [27]

In the next paragraph we will give some insights in the different activities and sub-phases of the FEI in the Stage-Gate model. A project cannot pass into the next stage until the evaluation is done and the gate is opened.

The front end is typically thought of as consisting of the first three sequential stages of the Stage-Gate process with the remaining stages focusing on the development process: discovery, scoping and building a business case, as also shown in Figure 4. The decision to “move into a full-scale development project” cannot be taken until the Gate 3 criteria have been met. In the early stages, these criteria tend to be largely qualitative and deal with ‘must meet’ and ‘should meet’ criteria [26]. Scorecards are based on the premise that qualitative criteria are often better predictions of success than financial projections. In use, management develops a list of about 6-8 key criteria, known predictors of success, on a scorecard. A typical scorecard for Gate 3 is present in Table 1. Note that different scorecards and criteria are used for different types of projects.

3.4.3. Conclusions

Two notable pieces of work that have emerged from the FEI research were presented in this section; Cooper’s original sequential Stage-Gate process with specified steps and timing, and the non-sequential NCD relationship model from Koen et al. From a sustainable product innovation perspective, the problem with these frameworks is that they do not explicitly explain how sustainable design considerations can be integrated into the front end. None of them mentioned sustainability or provide sustainable design guidelines in the presented methodology.

3.4.4. Front End activities

There is no such a thing as a universal set of activities necessary to the FEI. The description of the different pre-development activities differs from author to author. The required innovation level, the context of the company, the available time, resources, strategy and markets...will usually determine the set of activities. A summary of the activities found throughout literature was made by Jacoby [9] and is presented in Table 2.

3.5. Front End characteristics

The FE phase is fundamentally different from the development stage of the innovation process. Characteristics of the FE compared to the traditional development phase is summarized in Table 3. Though all innovation processes does not follow a single pattern, the FE phase is intrinsically non-routine, dynamic and uncertain [7]. Essentially, the front end requires more expansive and divergent thinking [15]. The ambiguity level at the end of the FE can affect the risk related to the identified idea in the development stage [7].

Activity in the FEI	Author
Idea generation	Cooper (1994), Murphy & Kumar (1997), Khurana& Rosenthal (1998), Montoya-Weiss & O'Driscoll (2000), Koen et al. (2001), Krishnan & Ulrich (2001), Nobelius&Trygg (2002), Langerak et al. (2004), Sandmeier et al. (2004), Buijs&Valkenburg (2005), Braet&Verhaert (2007)
Product concept	
Idea genesis	
Business ideas	
Concept development	
Idea qualification	Montoya-Weiss & O'Driscoll (2000), Koen et al. (2001), Nobelius&Trygg (2002), Langerak et al. (2004), Sandmeier et al. (2004), Cooper (2008), Braet&Verhaert (2007)
Idea selection	
Idea screening	
Concept screening	
Opportunity identification & analysis	Koen et al. (2001), Cooper (2008)
Discovery	
Search areas	Buijs&Valkenburg (2005), Cooper (2008)
Scoping	
Product definition	Cooper (1988), Murphy & Kumar (1997), Khurana& Rosenthal (1998), Nobelius&Trygg (2002), Buijs&Valkenburg (2005), Braet&Verhaert (2007)
Design brief	
Concept definition	
Project evaluation	Cooper (1988), Murphy & Kumar (1997)
Product & strategic planning	Verganti (1997), Khurana& Rosenthal (1998), Langerak et al. (2004), Crawford (2006)
Product & portfolio strategy	
Concept generation	Verganti (1997), Koen et al. (2001), Crawford (2006)
Pre-technical evaluation	Cooper (1994)
(Preliminary) investigation	Cooper (1994), Verganti (1997)
Building business case (or value)	Cooper (1994), Hughes & Chaffin (1996), Sandmeier et al. (2004), Cooper (2008)
Business plan concept	
Business analysis	Nobelius&Trygg (2002), Langerak et al. (2004)
Capture market value	Hughes & Chaffin (1996), Khurana& Rosenthal (1998), Sandmeier et al. (2004)
Market analysis	
Market opportunities	
Technological analysis	Khurana& Rosenthal (1998), Sandmeier et al. (2004)
Technological opportunities	
Deliver winning solution	Hughes & Chaffin (1996)
Project & process planning	Hughes & Chaffin (1996), Khurana& Rosenthal (1998), Nobelius&Trygg(2002)
Feasibility	Khurana& Rosenthal (1998)

Table 2. Activities in the FEI according to different authors [9]

	Front End	Product Development
Nature of work / Method	Experimental Often chaotic 'Eureka' moments Often unstructured Creative	Disciplined Structured Systematic Goal-oriented with project plan
Degree of formalization	Low	High
Activity	Individuals and team conducting research to minimize risk and optimize potential	Multifunction product and/or process-development team
State of an idea	Probable Often fuzzy Easy to change Easy to reject	Determined Clear Specific Difficult to change More difficult to reject
Information	Often qualitative Informal Approximate	Quantitative Formal Precise
Degree of formalization	Low	High
Personnel involvement	Individual or small project team	Full development team
Commitment of the CEO	None or small	Usually high
Funding	Variable. In the beginning phases many projects may be 'boot legged', while others will need funding to proceed.	Budgeted
Revenue expectations	Often uncertain Great deal of speculation	Predictable with increasing certainty analysis and documentation as the product release date gets closer
Damage if abandoned	Usually small	Substantial
Commercialization date	Uncertain or unpredictable	High degree of certainty
Measure of progress	Strengthened concepts	Milestone achievement

Table 3. Difference between Front End of Innovation and the New-Product development process. Based on Koen et al. [10] and Kim & Willemon

Figure 5 below shows that the 'fuzziness level' of an idea gradually diminishes as the NPD process progresses [7]. When the fuzziness level or uncertainty level descends below the 'required' approval level (a) for a specific firm, the development phase usually begins. The start of development phase is the intersection point (b). The ambiguity level at the end of the FE can affect the risk related to the identified idea in the development phase. The approval decision at the end of the FE is usually the first formal go/no-go decision. It is a critical point, as it determines whether the firm will invest and if so, how much budget, time, people... it is willing to invest.

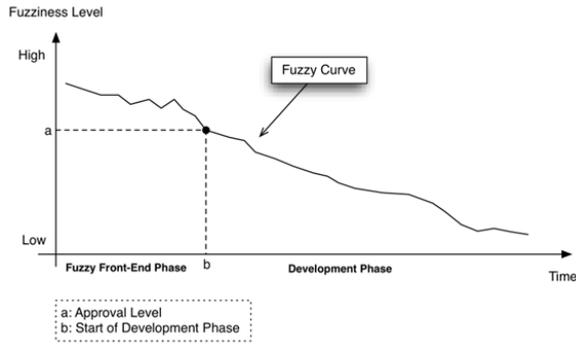


Figure 5. Patterns of the fuzziness level through the New Product Development [7] (Image reproduced by the author)

3.6. Conclusions

High-quality up-front analysis is essential to effective and efficient product development. Various authors have pointed out the importance of the Front End of Innovation. Over the last decade, the number of publications on the Front End has increased, providing more insights on the characteristics, process, activities, functions, and patterns in the Front End.

However, from a sustainable product innovation perspective, the Front End literature does not explicitly explain how sustainable design considerations can be integrated into these early stages. This problem is discussed further in Section 5.

4. Sustainable product design

4.1. What is sustainable product design?

4.1.1. Sustainable development

The World Commission on Environment and Development defined Sustainable Development in 1987 as 'A development that meets the needs of the present without compromising the ability of future generations to meet their needs' [28]. This definition has been taken over, reformulated and evolved over time by many. Other definitions on sustainability focus on the so-called 'triple bottom line': the three dimensions people, planet, and profit, also called social equity, economic efficiency and environmental performance. The International Institute for Sustainable Development in conjunction with the World Business Council for Sustainable Development has defined sustainable development from a business perspective view. "Sustainable development means adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future" [29]. The stakeholders include

shareholders, lenders, customers, employees, suppliers and communities who are affected by the organization's activities. This definition also highlights business's dependence on human and natural resources, in addition to physical and financial capital. The book "Sustainability by Design" by John Ehrenfeld is founded upon a new definition "Sustainability is the possibility that humans and other life will flourish on earth forever" [30].

4.1.2. Ecodesign

Ecodesign and Design for Environment (DfE) are terms for strategies that aim to integrate environmental considerations into product design and development. They involve life-cycle thinking, which means the integration of life-cycle considerations into product design. The overall goal is to minimize the consumption of natural resources and energy and the consequent impact on the environment while maximizing the benefits for customers [31].

The European Parliament formulated one of the many other definitions of Ecodesign in 2005 in Directive 2005/32/EG. 'Eco-design means the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle'. There are lots of synonyms for the term Ecodesign. Bhandar et al. [32] uses the following synonyms: Design for Environment (DfE), Eco-Design, Eco-innovation, Environmentally Conscious Design (ECD) and Sustainable Design. According to O'Hare [33] ECD is the umbrella term for eco-design, eco-innovation and DfE. Sustainable Design is any form of ECD that affects a social and an economic aspect as well as the ecological aspect.

4.1.3. Sustainable design

Sustainable product design (SPD) is more than Ecodesign, as it integrates social and ethical aspects of the product's life cycle alongside environmental and economic considerations, aiming for the so-called 'triple bottom line'. Sustainable product development and design is concerned with balancing economic, environmental and social aspects in the creation of products and services [31]. A framework that shows the relationship between the different disciplines is shown in Figure 6.

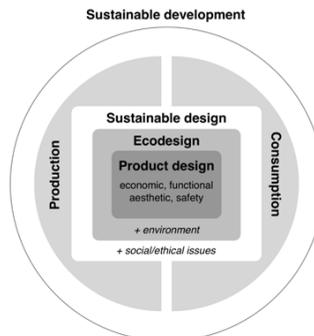


Figure 6. Relationship between ecodesign, sustainable design and sustainable development [31]

McLennan [34] defines Sustainable Design as 'a design philosophy that seeks to minimize or eliminate negative impact to the natural environment through skillful, sensitive design'.

Up till now, most attention has been given to environmental sustainability within the design process, both by academics as practitioners [35].

4.2. Drivers and barriers for sustainable design

Usually, there's no one-single driver or barrier for Sustainable Design. A combination of several factors, both internal and external determines whether a firm chooses the path of sustainable design or not. For this, the firm policy needs to find a balance between environmental, social and economic needs. This section summarizes the main findings in literature on the stimuli and barriers for enterprises to practice sustainable product design.

4.2.1. Drivers for sustainable design

Extensive research on drivers for sustainable design has been carried out by research organizations and industrial companies in the last two decades with significant insights achieved [36] [31] [37] [38]. Charter and Tischner mentioned already in 2001 a growing number of drivers for sustainable design worldwide. [31]

Van Hemel and Cramer [38] did a study on stimuli and barriers for ecodesign in SMEs and listed the most common and influential factors. The most influential internal stimuli were the opportunities for innovation, the expected increase of product quality and the potential market opportunities. The research revealed quite clearly that the most influential external stimuli for ecodesign are 'Customer demands', 'Governmental legislation' and 'Industrial sector initiatives'.

A recent study based on a survey conducted on 10.000 multidisciplinary professionals from Spanish innovation driven companies [37] shows that sustainability is a cardinal driver for innovation. Moreover, the study indicates that the main drivers for integrating sustainable criteria are environmental impact reduction, energy efficiency, marketing and brand value, and legislation adjustment. Internal drivers for practicing sustainable design can vary depending on the size of the company. The obtained results in the study show that for micro companies (1-10 employees), the driving element most considered is cost reduction, followed by marketing and brand value. On the other hand the driving elements less considered for micro companies are legislation adjustment and to avoid economic sanctions. In the case of SMEs (10-250 employees) the main driver is the client demand and being fashionable and the least important is to avoid economic sanctions. Finally for macro companies (over 250 employees) the least important driver is cost reduction. The most important ones are to avoid economic sanctions and legislation adjustment. Nowadays there are a lot of EU directives on a wide range of categories. These EU regulations determine common rules concerning responsibility and technical issues such as the end-of-life disposal treatment of equipment and financial issues for instance who has to pay for disposal treatment. By all the

directive requirements, companies are forced to constantly push their limits concerning sustainable development.

According to Mathieux et al. [39] there are also some parallel benefits regarded from business perspective if a firm decides to practice sustainable design. The product design team is stimulated to see the bigger picture, as they need to make decisions based on life-cycle thinking. This can give a greater understanding in the complex chain of stakeholders of the company and acquire a global view of the market opportunities, cost saving and the product portfolio.

4.2.2. Barriers for sustainable design

Not all companies chose to practice sustainable design. Some of them are struggling to integrate this way of thinking into their current design process, portfolio and business structure. The main barriers found in literature are listed below.

First of all, the board needs to be convinced of the goal they're setting. If there's a management's lack of commitment, as stated in [38], [33], [37] or if environmental improvements are perceived as not their responsibility, then it's practically impossible to implement sustainable design in an enterprise. The fact that a firm sees no clear environmental benefit is also often mentioned as a very important barrier [38]. Another common reason is the lack of acquisition of tangible benefits. This refers to the absence of direct benefits in the short term, such as the growth of production or sales, fiscal incentives or client satisfaction [37].

Also the practitioners need to be convinced of the new method that they're going to implement. The design team needs to be sure they can benefit from the ecological conscious design (ECD) tools. It is possible that a new tool isn't useful from the first second, tools often requires patience and has to be customized to the specific need of the design team [33]. On top of all this, the design team has to have the attitude, appropriate knowledge and skills to design and develop sustainable products [40].

Another frequent obstacle is the fact that an ecological optimized product can be in conflict with its functional product requirement. It can be a challenge for the designers and design teams to integrate the sustainable requirements without compromising on the technical possibilities and the functional needs.

For many companies, cost is a very important element when taking environmental oriented decisions [37]. Not only the costs for the optimization of the product need to be taken into account. Also the general costs to create an environment in a firm where it is possible to practice sustainable design. Maybe there is the need for a new team, including experts of the environmental or ecological sector, or a new structure, a new vision or an adjusted view on the business model. All this may cause a significant augmentation of the overheads. And that is what scares some companies to make the switch to a more environmental policy. Moreover, if the general cost of an enterprise rise, there is the pos-

sibility they can't compete with the direct competitors. This may lead to a commercial disadvantage.

One of the most important external barriers is the lack of involvement of consumers [37]. If they are not willing to pay for it, or simply aren't interested in an environmental friendly product, the whole project is doomed to fail. In general, market demand steers the companies whether to choose for sustainable design. If in a certain product sector the demand for environmental products rises, the entire sector will develop toward these kinds of products. The other way around is also possible; companies will hesitate to implement sustainable design if the market shows only little interest in these kinds of products. The influence of costumers can be very decisive for Sustainable Design.

From the study from van Hemel and Cramer [38] can furthermore be derived that three barriers must be characterized as 'no-go' barriers; their existence obstructs the ecodesign improvement options in question from being implemented. These were the following barriers: 'No clear environmental benefit', 'Not perceived as responsibility' and 'No alternative solution is available'.

4.2.3. Summary

The main drivers and barriers found in literature to practice sustainable design are summarized in Table 4. A distinction in the table is made between the forces within and outside the firm that gives the motivation whether or not to incorporate sustainability criteria in products.

Internal drivers and barriers are the internal factors that originate inside the company itself. External stimuli and barriers are the external factors that influence the decisions made towards sustainable design from outside the company.

In conclusion, practicing sustainable design is balancing between all the mentioned drivers and barriers. Every company needs to consider and determine its own specific requirements and goals.

Enhancing sustainable design does not only depend on finding alternative solutions for technical problems. Even more important are economical and social factors like the acceptance of environmentally improved products in the market, and the way the market will perceive these products. Sustainable design is most successful when supported by several strong internal and external stimuli and not blocked by any no-go barriers. It only stands a chance, if it is supported by stimuli other than the expected environmental benefit alone. Contrary to prevailing literature on environmental management in SMEs, Van Hemel and Cramer [38] concluded in their study that internal stimuli are a stronger driving force for ecodesign than external stimuli.

Many drivers and barriers for Sustainable Design have their roots in the Front End of Innovation. This topic will be discussed in the next section.

	Drivers	Barriers
Internal	Management’s sense of responsibility	No clear or lack of environmental benefits
	Business opportunities	Lack of acquisition of tangible benefits
	Innovational opportunities	Conflict with functional product requirements
	Risk Management	Not perceived as responsibility
	Long-term survival	No alternative solution available
	Competitive advantage	Lack of management’s commitment
	Improvement of product and product quality	Extra costs
	Improvement of brand image	Shortage of short-term benefits
	Cost reduction	Lack of understanding of sustainable design tools
	Environmental impact reduction	Lack of acquisition of tangible benefits
	Energy efficiency	
	The need for innovative power	
External	Governmental Regulations / Legislation	Lack of interest from consumers / Lack of market demand
	Increase awareness of the public / Public pressure	Consumers not willing to pay (extra) for it
	Customer needs and demands	Commercial disadvantage
	Growing pressure from different stakeholders	
	Market competition / Being ‘fashionable’	
	New market opportunities	
	Cooperation with supply chain partners	
	Development of external assessments (labels, standards...)	
	Availability of subsidies	
	Growing amount of knowledge	
	Industrial sector initiatives	

Table 4. Drivers & Barriers for Sustainable Design

5. Conclusions and insights on the importance of integrating sustainability in the Front End

High-quality up-front analysis is essential to effective and efficient product development. Various authors have pointed out the importance of the Front End of Innovation. Over the last decade, the number of publications on the Front End has increased, providing more insights on the characteristics, process, activities, functions, and patterns in the Front End. However, from a sustainable product innovation perspective, the Front End literature does not explicitly explain how sustainable design considerations can be integrated into these early stages.

Notwithstanding the logic behind integrating sustainability in the early stages of an innovation process, in practice it is flawed. Front-end innovation is a hot research topic, but there is still little research done on its relationship to design for sustainability. There are a number of tools available to guide designers, engineers and managers in the design process when the specifications of the product or service are already set. However, methods supporting target identification for sustainable innovations are rare [41].

In light of the increasing attention to sustainability, sustainable product innovation and pre-development activities in new product development, various authors have recently pointed out the importance of integrating sustainability in the front end [41], [42], [43], [33], [44], [31], [45].

This section aims to give an overview of the main reasons why integrating sustainability in the front end is so important.

5.1. Tackling sustainability problems at higher system levels

The international research literature on Sustainable Product Development (SPD) identifies the need to move beyond incremental change (e.g. redesign of existing products) to more fundamental, systematic changes. These are described as 'function innovation' or 'system innovation' [46].

Brezet's model of 'eco-design innovation' [46] defines four types of environmental innovation, characterized by product improvement, product redesign, function innovation and system level innovation, according to the environmental impact reduction or eco-efficiency that can be achieved, shown in Figure 7.

The vertical axis expresses the eco-efficiency or environmental impact improvement. For example, factor 2 equates to half the overall environmental impact of a product, or a factor 2 performance improvement in material and energy efficiency. The horizontal axis corresponds with the time that a company or industry needs to progress through on the way to achieving environmental sustainability.

The first two stages of 'product improvement' and 'redesign product' focus on lower systems levels and deliver small to moderate improvements in environmental sustainability.

The latter stages focus on function and system innovation and deliver considerably greater system improvements in environmental performance.

Modest eco-efficiency gains can be achieved with relatively little effort in the new product development stage of an innovation process. However, to tackle problems at higher system levels, the problem needs to be already integrated in the Front End. At a later stage in the innovation process, the design space is limited and the resources allocated, as also pointed out in the previous chapters. After this crucial phase only incremental environmental improvements or product redesign are possible.

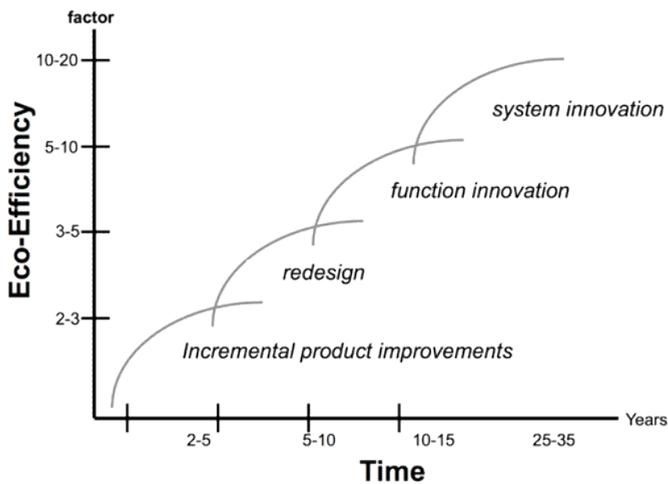


Figure 7. The four generic levels of eco-design, after Brezet [36]

5.2. Greening the design brief

A design brief is a written description of a project that requires some form of design. It is an agreement, or contract between the parties involved in the project. Often times, it is also a point of transfer between different professionals, where the project is handed over from marketing to design, or from a product manager to an in-house design team or external design agency. It is also a roadmap and project-tracking tool, defining the various steps that will be followed [47].

The role of a design brief is to provide the foundation to the entire design process and can be seen as the report or summary of the investigations steps and the decisions taken in the Front End, as shown in Figure 8 [48].

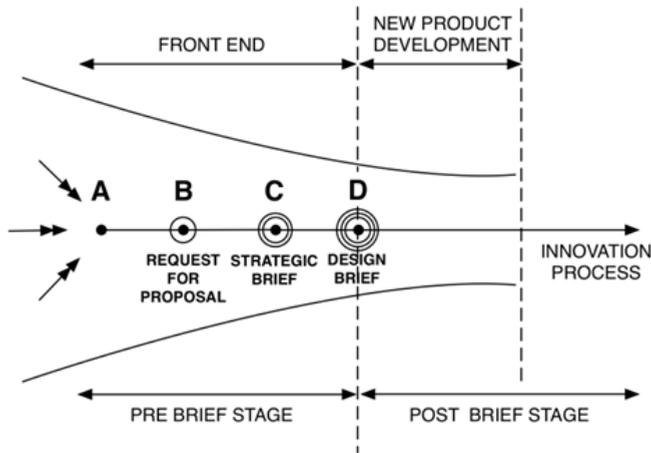


Figure 8. The various stages of a design brief in the front end of the innovation process [48]

Sustainable design projects would be far more effective if commencing from an environmentally responsible design brief. The secret to sustainable products lays upstream in the innovation process, in a good brief providing guidance to the design, engineering, and marketing and management team.

5.3. Commitment and allocation of resources

Decisions made in the front-end have a significant influence on all subsequent phases of the innovation process. For example, quality, costs, and timings are mostly set during the front-end phase [18]. The final approval at the end of the FE is usually a formal go/no-go decision. It is a critical point, as it determines whether the firm will invest and if so, how much it is willing to invest. This is also the moment where the other resources, e.g. time and people are allocated.

It is also a critical point regarding fruitful opportunities towards sustainable design, as the success of the product's final sustainability, is highly dependent on the previous committed resources. If no sufficient resources, e.g. time, budget and people with the right skills and knowledge are committed, the overall sustainability success is doomed to fail. Dewulf et al. [48] note that defining quantitative environmental targets in the early stage of an innovation project often appears to be very difficult for innovation projects with a high innovation level. As costs and timings are mostly set during the front-end, this is a hard part to deal with.

5.4. Early tackling of barriers

Table 3 in Section 4.2.3 summarizes the internal and external drivers and barriers for sustainable design. A lot of those barriers have their roots in the Front-End. Performing the

right actions in the FE can tackle various barriers. Performing an early financial and environmental analysis can, for example, make the benefits clear. One of other the barriers is lack of understanding of sustainability and sustainable design tools. To tackle this in an early stage, the intelligence level on those domains can to be increased by proper education and by providing relevant and reliable information.

5.5. Front-loading

In the FE stage, the degrees of freedom and influences on the project outcome are high, while little information is available and the cost of changes is low, as shown in Figure x. At later stages in the process one has more information available, but then the cost of change will increase. It is under these conditions that the front-end team needs to make decisions. That's why dealing with sustainability in the front-end of a product innovation process is often called 'wicked'; multidimensional with a complex interdependency. One promising method to deal with this 'wicked aspects' is 'front-loading'. Front-loading is defined as "a strategy that seeks to improve development performance by shifting the identification and solving of problems to earlier phases of a product development process" [49]. By spending more energy in the front phase on environmental analysis and strategic design one gets more information while the influence is high and the cost of change is low.

5.6. Doing the right thing vs. doing things right

Successful sustainable design requires both strategic (front-end) and operational (new product development) activities [50]. This perspective highlights the importance of including sustainability aspects already into the front-end activities of the innovation process in order for them to be considered at a strategic level [41]. The operational level is all about eco-efficiency or doing the things right, while the strategic level focuses on eco-efficiency or doing the right thing. Unfortunately, O'Hare [33] has noted that there is a lack of tools to support the early activities of eco-design in general. The majority of sustainability tools take the existing solution as a starting point, rather than considering the problem at a higher system level. They are generally intended for use after the strategic and conceptual design phase and cannot support the full range of challenges that are likely to be encountered during the front-end stage.

The study in this paper is part of a larger research at Delft University of Technology that is focusing on front-end sustainable product innovation. New research studies are planned to answer the question on how to best integrate sustainability in the front end. The insights provide by this book chapter will serve as the basis for future research.

Acknowledgements

The author would like to acknowledge the Howest Industrial Design Center in Belgium for their financial support for this research, and the Design for Sustainability research group at

Delft University of Technology, in particular dr. R. Wever and Prof. dr. J.C. Brezet, for their support and critical feedback.

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