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ENVIRONMENTAL NEW PRODUCT DEVELOPMENT THROUGH THE THREE DIMENSIONAL CONCURRENT ENGINEERING APPROACH

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1. Introduction

With its roots in concurrent engineering, which presumes that products and processes should be designed simultaneously, three dimensional concurrent engineering (3DCE) offers the next breakthrough in improving product development success. Defined as the simultaneous development of products, processes and supply chains; since its inception, 3DCE has been credited with many potential benefits, including reduced costs, reduced time to market, improved supplier integration and improved quality [Fine 1998], [Balasubramanian 2001]. The increasing importance of environmental new product development (ENPD) heightens the significance of the 3DCE concept as it appears to be a platform that allows for the assimilation of environmental considerations into the new product development (NPD) process [Ellram et al. 2008a]. Some organisations are enhancing their competitiveness by improving their environmental performance through the mitigation of the environmental impact of their production and service activities [Bacallan 2000]. However, the additional requirements are often viewed as mandates or burdens that slow development while ramping up cost, detracting from the main business of the company. As a result, environmental aspects are often considered an afterthought, resulting in delays and added costs as changes are made after the late addition of environmental requirements into the development process [Handfield et al. 2001], [Ellram et al. 2008a].

Adopting a cross-disciplinary perspective, this paper contends that 3DCE based approaches can be effectively used to integrate environmental considerations into the NPD process. The synergy provided by 3DCE will aid in the successful integration of environmental considerations and allow organisations to meet apparently conflicting goals of sustaining the environment while satisfying corporate profitability objectives and providing excellent new product performance. Supported by concurrent engineering, 3DCE is a simple yet powerful model of NPD in which the traditional focus on an appropriate match between product and process is augmented by an additional consideration of supply chain configuration. Through early supply chain design, specific information relating to suppliers and the components and materials they provide, making up the product's supply chain, is available during product development.

Using 3DCE as a platform, the purpose of this paper is to explore ways in which incorporating environmental considerations into the NPD process can have a positive or neutral impact on the new product development process, cost, and timeliness, while simultaneously meeting or improving upon environmental goals. The ideas presented forward in this paper are based on an in depth study of literature and theories relating to and supporting 3DCE where conceptual support for the strong relationship between 3DCE and ENPD is provided.

1.1 The Nature of Competitive Advantage

Whether rooted in market position, business models, processes or competences of organisations, it has always been a core tenet of the strategy field that maintainable competitive advantage is attainable. The concept of maintainable competitive advantage suggests that it is possible for a firm to not only attain but maintain a strategic advantage over rival firms in its competitive industry through the acquisition or development of an attribute or a combination of attributes that allows it to outperform its competitors [Porter 1985]; however, Fine [1998] proposed that all competitive advantage is temporary. History offers numerous examples of the transient nature of competitive advantage; from personal computers displacing word processing companies such as Wang [The Seattle Times 1992] to Amazon.com displacing numerous small and independent bookstores all over the world [WIRED 2013]. It is imperative that companies focus on exploiting their current capabilities and competitive advantage while also consciously and purposefully building new capabilities for the inevitable moment when the old ones no longer provide an advantage. As a result, the strategic planning process should consist of trying to think through the company's series of temporary advantage. In this climate, the only maintainable competitive advantage is the firm's ability to transition from one temporary advantage to the next.

1.2 The Missing Link: Three Dimensional Concurrent Engineering

Following the success of Japanese companies in the 1980s, based on their attainment of competitive advantage through manufacturing, western managers came to the realisation that in order to achieve improved manufacturing performance, they had to stop focusing solely or primarily on the factory but rather shift to concurrently designing the product and the manufacturing process – that is, designing the product for manufacturability [Nevins and Whitney 1989], [Fleischer and Liker 1997]. 3DCE is an extension of this concept, augmenting the concurrent design and development of product and manufacturing process with that of supply chains. 3DCE can be viewed as the integration of core competences of a manufacturing firm to achieve competitive advantage; its three aspects must be treated as a single, fully integrated capability and managed concurrently rather than as separate functions. It is almost such that the strategic nature of supply chain design advocates for its integration with product and process development [Fine 2000].

Under increasingly globally competitive conditions, as firms sought to attain sustainable growth and profitability through the rapid introduction of new products, the product development process, an inherently collaborative activity between internal groups (such as engineering, marketing, manufacturing, sales and service) increased in complexity due to the addition of external partners (such as subcontractors, customers, technology suppliers and co-development partners) [Wagner and Hoegl 2006], [Rufat-Latre et al. 2010]. This decrease in vertical integration, combined with increasing globalisation and outsourcing, resulted in the growth of supply chain management (SCM) which places great emphasis on the management of relationships within the supply chain; viewing the supply chain as more than just a logistic network comprising of interrelated companies built around delivering a specific product or service to the customer [Saeed et al. 2005]. While product innovations can be matched by competitors, due to its more tacit nature superior SCM can possibly offer a maintainable advantage [Fine 1998], [Christensen 2001]. It can be seen as a dynamic capability that enables the continuous strategy innovation that is necessary in the retention of competitive advantage in disruptive environments, as long as the executing firm does not get exhausted by continuous transformation and innovation or get complacent by success.

With concurrent engineering becoming commonplace enough to no longer provide a source of competitive advantage, 3DCE offers organisations the next level of breakthrough in improving performance. Since its inception, 3DCE has been credited with many potential benefits, including reduced costs, reduced time to market, improved supplier integration and improved quality [Fine 1998], [Balasubramanian 2001], which are generally NPD goals.

1.3 Environmental Sustainability: The Next Source of Advantage

For both prosperity and maintaining economic growth, firms are increasingly aware of the importance of being ahead of the next so-called 'waves' of innovation. Being able to accurately predict and prepare for the next wave of innovation gives firms the opportunity to become competitive through the attainment of the first mover advantage [Lieberman and Montgomery 1988]. A combination of a significant array of relatively new and emerging technologies and a recognised genuine need in the market that is leading to a market expansion is required in order for a wave of innovation to occur. Today, there is a critical mass of enabling technologies that make integrated approaches to sustainable development economically viable; added to increased regulation through, for instance, the ratification of the Kyoto Protocol, and the EU directives on waste and hazardous substances, this suggest that the next wave of innovation will be in environmentally sustainable development [Hawken et al. 1999], [Hargroves and Smith 2005]. With the next industrial revolution predicted to be driven by the emerging need for simultaneous productivity improvement while significantly reducing impacts on the environment, firms that work to address sustainable development can position themselves to be at the forefront of the next wave of innovation. Combined with the already increasing social and regulatory demands that organisations are facing to behave in an environmentally conscious manner on a global scale, environmental impact is fast becoming a factor considered on par with cost, functionality and value during the product development process.

3DCE holds great promise for the early integration of environmental considerations into the product development process; combined with the competitiveness potential that environmental performance offers, it can be argued that this is where the true value of 3DCE lies. The following sections will present literature, frameworks and visualisations of 3DCE and environmental three dimensional concurrent engineering (E-3DCE), along with models of the dynamics and factors at play during the integration of environmental considerations into the new product development process and required support mechanisms. Collectively, they provide support for the premise of 3DCE's value in ENPD.

2. The 3DCE Framework

Fundamentally, the concept of 3DCE is the consolidation of product design, process design and supply chain design. To attain a solid understanding of the 3DCE concept, the definitions of its founding concepts are outlined in Table 1. Various links exist between and among these three base concepts, some of these are shown in Figure 1. Figure 1 tries to capture visually the many ideas of 3DCE and shows in more detail the interface points and key issues.

Table 1. 3DCE Core Concepts

Concept	Definition	Contributing Authors
Product Design	Focuses the products specifications and can include activities of architectural choices and detailed design choices.	[Brown and Eisenhardt 1995], [Koufteros et al. 2005]
Process Design	Deals with methods that will be used to manufacture the product and can include the development of unit processes and manufacturing system development.	[Nevins and Whitney 1989], [Fleischer and Liker 1997]
Supply Chain Design	Can be divided into supply chain architecture decisions and logistics systems decisions. It considers in-sourcing and outsourcing, logistical channels and the types of relationships an organisation has with members of its supply chain.	[Handfield et al. 1999], [Parker and Anderson 2002], [Liker and Choi 2004]

3. Environmental 3DCE: Applying 3DCE to ENPD

With ENPD practices such as eco-design and environmentally responsible manufacturing (ERM) requiring the co-operation of the entire supply chain [Puraji et al. 2003], the importance of the early consideration of supply chain aspects increases incredibly. Through early supply chain design, specific information pertaining to the product's supply chain and characteristics of components and materials from the supply base is available during the design phase. It is this availability of information that can allow for various environmental assessments to be carried out, which are as accurate as possible as they will be based on supply chain specific information. Additionally, effects of making alterations to the product's supply chain can be seen in real time as the product is being designed. The availability of this information allows for certain environmental considerations and assessments to be made during the product's development and not after product design has been completed. An example of how information sharing can aid ENPD is as follows: a member of the supply chain provides information regarding a component, including weight of component, geographical location of the production plant and transport used to ship it. When the designer selects this component during the design process, they can get access to information regarding the transport scenario associated with the part. This information be used as part of calculations such as the environmental impact (S-LCA) and cost (S-LCC), giving the designer real time environmental feedback regarding the product being designed based on the use of different components from different suppliers.

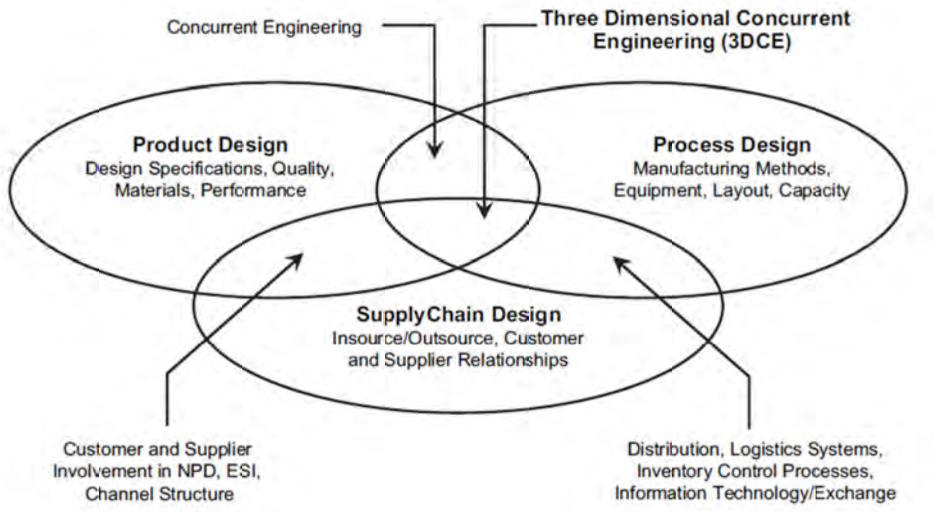

Figure 1. Visual Representation of 3DCE [Ellram et al. 2007]

As is currently common practice, environmental considerations can be integrated into the product development process without the use of the 3DCE approach; however, this will likely result in the neglect of supply chain design. Failure to explicitly integrate supply chain design as part of ENPD will likely result in increased costs and reduced performance [Ellram et al. 2008b].

Just as 3DCE can be broken down into its three foundation concepts, E-3DCE, which is 3DCE with the added element of environmental considerations, can also be broken down into three founding concepts as shown in Figure 2.

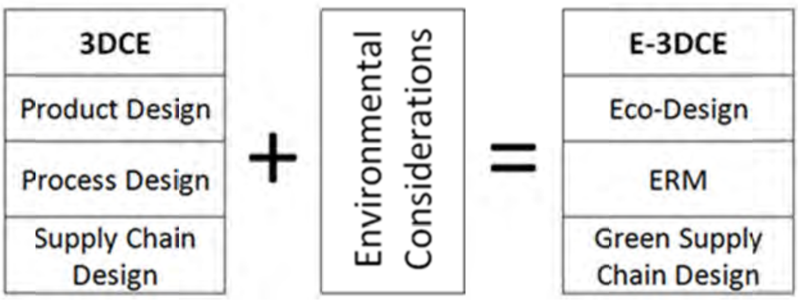

Figure 2. Transition from 3DCE to E3DCE

4. Theory Building for Environmental 3DCE

The nature and state of 3DCE research and industry implementation is such that, to increase its adoptability it is necessary to not only add to the existing 3DCE theoretical framework but to develop support to aid in the real life implementation of the practice.

E-3DCE can be seen as being made up of eco-design, ERM and green supply chain design (GSCD), Figure 3 illustrates this through a version of the 3DCE model that has been adapted to show E-3DCE. A summary linking ENPD literature to product, process, design and 3DCE is provided in Table 2.

4.1 The 3DCE-ENPD Link

Through the comparison of literature related to 3DCE concepts in the mainstream operations literature and in environmental literature, Ellram et al. [2008b] noticed that despite the two streams developing with many parallels, there have been limited overlaps. Literature supporting 3DCE concepts focuses on traditional NPD performance improvements such as cost reduction, cycle time reduction, and inventory reduction while literature focused on the base components within E-3DCE focuses on reduction of environmental impacts and improvement of environmental performance.

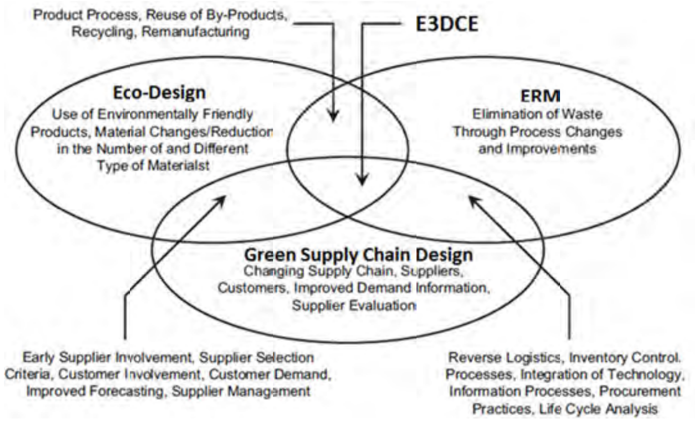

Figure 3. Visualisation of E-3DCE (Modified from [Ellram et al. 2008b])

Table 2. Complementary 3DCE and ENPD literature

Environmental Lit. Stream	Relationship to 3DCE	Some Contributing Authors
Product Design	ENPD takes a lifecycle view and focuses on making a product that uses environmentally friendly materials, fewer materials and mixes fewer materials together.	[Porter and van der Linde 1995], [De Ron 1998], [O'Brien 1999], [Sabatini 2000], [Nielsen and Wenzel 2002], [Waage 2007],
Process Design	Involves the reduction of the source of waste through production process and operational process changes including improved inventory management, procurement, and transportation. A sustainable process focus may result in improved process consistency and quality, reduced downtime, lower costs and lower waste.	[Porter and van der Linde 1995], [Walton et al. 1998], [Gungor and Gupta 1999], [Sabatini 2000], [Dault 2002], [Pil and Rothenberg 2003].
Supply Chain Design	Focus on the impact of the firm's activities outside of the firm's boundaries including supplier involvement, evaluation, and audit, customer demands and concerns, stakeholder perspectives, early supplier integration (ESI), and improved demand information. Consider the impact of incoming components as well as outgoing products.	[Walton et al. 1998], [Carter and Narasimhan 2000], [Chen 2001], [Handfield et al. 2002], [Sarkis 2003], [Rao and Holt 2005], [Hervani et al. 2005]
Integration of product, process and supply chain	Sustainable products and processes are designed simultaneously with supply chain member participation while giving consideration to the entire product lifecycle. Conceptual benefits of integrating 3DCE and sustainability include reduced operating costs, competitive advantage, differentiation, improved image, and reduced compliance costs.	[Hart 1995], [Starik and Rands 1995], [Shrivastava 1995], [Sarkis 2003], [Maxwell and van der Vorst 2003], [Manzini and Vezzoli 2003]

Where environmental impacts and traditional manufacturing goals such as quality have been studied together and applied in practice, it has been demonstrated that an environmental focus contributes to improved quality [Pil and Rothenberg 2003].

The extensive overlap in approaches used to facilitate NPD and environmental considerations within the supply chain suggests that there is great potential for synergy from simultaneously considering traditional performance issues and environmental performance issues and in embracing 3DCE concepts. Presently, most organisations still view, treat and manage environmental goals and traditional product development goals separately [Handfield et al. 2001], resulting in redundancy and waste in the system. Additionally, there exists a perception outside the environmental health and safety arena that pursuing environmental goals is strictly compliance-based; this results in increased product costs and slowing product development [GEMI 2004]. In the current parallel but non-integrated approach for traditional versus ENPD, this is probably true; however, by adopting an E-3DCE approach, organizations can enjoy all of the benefits of traditional NPD and ENPD.

4.2 From NPD to ENPD through the 3DCE Approach: A Framework for E-3DCE

Figure 4, which is presented as a framework for E-3DCE is a graphical representation of the of the real life situation surrounding environmental new product development through the 3DCE approach. The development of the frame work was informed by an in-depth literature study and two original case studies that were developed through site visits and interviews with managers and workers across a number of departments within two European SME's. The diagram shows that the nature of NPD is such that its main purpose is to serve core capability, customer value proposition and corporate value proposition; and these three, in turn, also serve NPD. This means that when a firm conducts NPD it is either because it wants to improve or exercise its core capability, or it wants to meet its customers' needs or the needs of the firm itself. However, at the same time, those three aspects can be drivers for product development. Through the adoption of a 3DCE based approach to product development, the process can be seen as being comprised simultaneously of product design, process design and supply chain design. If a firm possesses ESI as a core capability, the shift from traditional NPD to 3DCE is instigated through practices such as supplier collaboration in new product development (SCNPD), production outsourcing and SCM. In turn, competency at these three practices can lead to ESI as a core capability. The core capabilities of a firm greatly influence its strategy, especially with regards to innovation strategy; it is this strategy that influences the NPD process. For example, if early supplier involvement is a core capability, then the firm is likely to adopt an open innovation approach to product development. This works the other way round in that a firm that applies an open innovation strategy to the NPD process is likely to develop ESI as a core capability.

In terms of environmental considerations, these are likely to enter the new product development process due to either customer or corporate value proposition. Through the simultaneous practice of eco-design, ERM and GSCD, a firm can then move from performing 3DCE to performing E-3DCE. As with ESI, the ability to successfully integrate environmental considerations into the product development process can become a core capability that leads to competitiveness.

To supplement the framework, the model in Figure 5 adds more understanding by showing the interactions of various factors that are at play in the scenario illustrated in Figure 4. The model is based on splitting the product development into its motivations, which are corporate value proposition, customer value proposition and core capabilities [Leonard-Barton 1995]. The arrows represent the connections between the factors, with '+' and '-' representing positive and negative connections respectively. The lifecycle of an industry, its clockspeed, has an impact on the competitiveness of the firms within that industry. The faster the clockspeed, or shorter the lifecycle, the less maintainable competitive advantage is [Fine 1998]. However, a firm's ability to be competitive is positively impacted by its ability to satisfy its customers' needs, the environmental performance of its products, the architecture of its supply chain and its core capabilities. The adoption of a 3DCE based approach is positively impacted by ESI, this means that the implementing firm will increase supplier involvement in a various aspects of their product development process [Petersen et. al. 2005]; at the same time, having ESI within the firm makes the adoption of a 3DCE based approach easier. If not correctly managed, ESI can have a positive impact on value chain migration; this means that the initiating firm can unwittingly give up the value adding aspects of the product being developed to members of the supply chain. This pitfall results in firms approaching ESI with caution, however, the likelihood of value chain migration can be mitigated through superior supply chain design that is manifested in the architecture of the supply chain. Well executed supply chain architectures have a positive impact on competitiveness as value creation is still within the firm and on the environmental performance of products produced as the firm will have more control on the components from the supply chain that are being incorporated into its products.

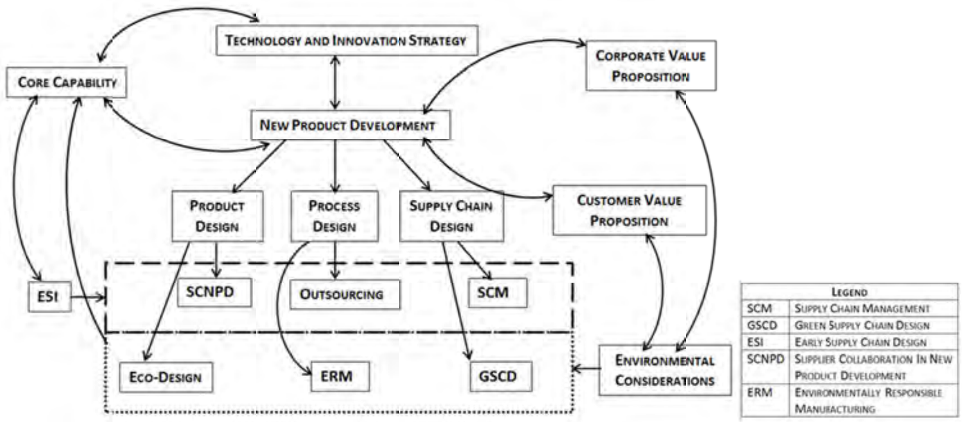

Figure 4. E-3DCE Dynamics Framework

Ultimately, the key factor is competitiveness; through the use of the 3DCE approach, firms can aim to attain a competitive advantage. In the current and future social climate, this advantage is likely to be influenced by the firm's ability to produce highly environmentally competitive products.

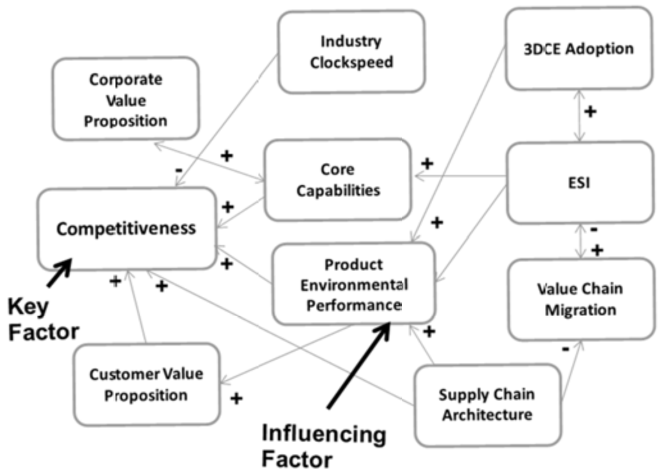

Figure 5. Interactions between factors at play in E-3DCE dynamics framework

5. E3DCE Support Mechanisms

The only way to reap the rewards associated with 3DCE and to encourage its adoption is to ensure its successful implementation. To do this, it is essential to have the necessary support mechanisms in place. To develop suitable support, it is essential to have an in depth understanding of the various issues at play.

Typically, information sharing within the supply chain is associated with maximising responsiveness and efficiency while minimising cost, with the relationships formed handled by the procurement and/or logistics department; while, information sharing within the product development chain is allied with the acquisition of resources and capabilities to improve product offerings, with the collaborative relationships formed more likely to have a research and development focus. On the one hand, there is Kanter's notion of collaboration advantage, defined as " *a significant leg up in a global economy due to a firm's well developed ability to create and sustain fruitful collaborations*" [Kanter 1994], which is associated with the product development chain; while on the other, there is the resource-based theory view that one source of differential performance between firms is the way in which they organise exchange activity [Conner and Prahalad 1996], which is related to the supply chain. Therefore, it would seem logical to then deduce that amalgamation of the two forms of information sharing would result in advantages gained through the unified use of the formed relationships, enriching the depth and quality of information shared via both design and supply chains. With particular focus on design chains and collaborative design, utilising supply chain information sharing relationships and methods within the product development process would offer a means of augmenting the match between product and process, which most companies accomplish through concurrent engineering, with an additional consideration of supply chain configuration. As the environmental performance of a product is the consolidation of its environmental impact through all the stages of its lifecycle, from the extraction of raw materials to its end of life, it is dependent on the totality of the supply chain in both upstream and downstream directions throughout its lifecycle. During the product development process, it is necessary to have as much information as possible pertaining to the environmental performance of the various supply chain partners and the products and services they provide.

Since internet communication technologies gained popularity as a means of simplifying business to business communications and were seen to have an impact on logistics process performance, purchase process efficiency and supplier relationships [Baglieri et al. 2007], supplier portals have been found to promote information sharing and coordination of operational flows, support supplier management and create a sense of community among buyers and suppliers; all the while increasing the stability of relationships and suppliers' loyalty to their customers [Roberts 1999]. It is this collaborative potential within supplier web portals that would make their use in the ENPD process invaluable. The web portal can be used as a tool during the ENPD process to ensure that when product and process are being designed, relevant and accurate information regarding the supply chain is available resulting in E-3DCE. However before one can accurately share information with the supply chain and utilise it for the benefit of the NPD process, it is essential to have precise knowledge pertaining to the supply base and its architecture. Through the use of supply chain mapping, firms can have an accurate picture of the supply chain of their products, in both up and downstream directions. Not only does this aid in the attainment of product information from the supply chain but it also allows for greater supplier chain visibility and helps firms understand any risks inherent in their supply chains. Firms will be able to acquire information pertaining to not just first tier suppliers but potentially second and third tier suppliers too. This understanding of risk and visibility will also allow firms during the make-or-buy decision. When determining the supply chain architecture of a product and whether to make or buy certain components, it is important to understand the impact choices made have on value chain migration and any associated risks.

The use of supply chain mapping and the web portal to make decisions during the ENPD can be seen as bridging the gap between SCM and ENPD, which is what E-3DCE aims to achieve.

6. Conclusions and Future Research

One of the aims of this paper was to use literature and previous, related research to provide greater conceptual support for the strong relationship between 3DCE and ENPD. Use of literature from supply chain management, new product development and strategy to show the efficacy of each of the integration points between product, process and supply chain from an environmental perspective should help strengthen the theoretical support for E-3DCE and lead to more meaningful managerial implications and richer future research.

This paper presents the results from an in depth study of 3DCE theory, explores its impact on the integration of environmental considerations into the new product development process and maps its benefits onto ENPD. The reviewed literature shows how ENPD would be improved through the addition of green supply chain design to environmentally responsible manufacturing and eco-design; which can be referred to as E-3DCE. The research then proceeds to show supply chain information sharing as a crucial new element that is required in the implementation of E-3DCE based approaches.

Future research will focus on developing and investigating further the effectiveness of the information sharing web portals and supply chain mapping as support mechanisms for E-3DCE.

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