NordDesign 2012
August 22 – 24, 2012
Aalborg, Denmark

Towards describing co-design by the integration of Engineering Design and Technology and Innovation Management literature

Pedro Parraguez Ruiz
DTU Management Engineering
ppru@dtu.dk

Anja M. Maier
DTU Management Engineering
amai@dtu.dk

Abstract
The purpose of this paper is to provide an overview of the available literature concerning the understanding and improvement of co-design processes. The most pertinent aspects of such processes are presented through an interdisciplinary analysis incorporating contributions from literature in the fields of *Engineering Design (ED)* and *Technology and Innovation Management (TIM)*. Interactions between design and third parties in a range of co-design situations are examined via a targeted literature review, and a map is developed containing a network of keywords. As a result of this review, key aspects from the literature are summarised and connected through an initial framework characterising, the *what*, *when*, *who*, *how* and *why* of co-design. The research motivation arises from the Danish Industry *Complex Cleantech Solutions* initiative and its need for a conceptual background that integrates the multiple perspectives addressing co-design.

Keywords: Co-design, Collaboration, Product Development, Literature Review, Cleantech, Design Process, Collaborative Design, Networked Innovation

1. Introduction

Motivation: Co-design and the Danish cleantech industry

The Danish cleantech industry directly involves a wide variety of organisations, including: new technology start-ups, technology based SMEs, big multinationals, public sector initiatives, universities, and research centres. Between the capital region and Zealand, this cluster includes 522 companies containing a large part of the complete supply chain for many of the developed products and employs approximately 30,000 people [1]. This industry also has a profound impact on the population, both in terms of economic development and as users of energy and other new resource efficient solutions [1,2]. The firms participating in this industry develop products and services within the scope of renewable energy, environmental solutions, climate adaption and other also called sustainable, green or resource efficient technologies. Interestingly, despite its comparatively recent formation, the industry has already organically generated public and private associative structures, such as the *Copenhagen Cleantech Cluster*, *State of Green*, *Copenhagen Capacity*, *VE-net* and *The Wind Energy Association.* This has resulted in a large number of collaborative research and development projects. Considering solely the Danish Energy Technology Development and Demonstration Programme database (EUDP), there are more than 357 associative energy technology projects since 2010, totalling an amount of 712 million USD [3]. This propensity for both project generation and association [2,4] positions the Danish cleantech industry as an attractive case example from which to examine co-design activities. Further, due to the multifaceted nature of the activities, such a study lends itself to the integration of different academic perspectives

To foster industrial collaboration the *Danish Industry Foundation* formed the *Complex Cleantech Solutions (CCS)* initiative in October 2011. This initiative acknowledges that urgent sustainability issues cannot be solved through individual technologies, but rather require combinations of them and inter-organisational collaboration. Thus, CCS is proactively seeking to facilitate jointly developed solutions through innovative forms of industrial interactions. Embracing the open innovation paradigm, CCS has a number of aspects that are relevant for this study. Firstly, it puts an emphasis on market pull - against the traditional technology push, creating the need to integrate users and industrial customers at the conceptual and system design levels [5]. Secondly, the development of customised and integrated solutions should happen between a number of companies stressing inter-organisational and inter-disciplinary design relationships [6]. Thirdly, the involved organisations create a shared platform to collaboratively address aspects of the marketing, development and production phases. This defines a situation where the cluster can move from merely transactional exchanges to long-term relational interactions enabling inter-organisational co-design projects [7]. Finally, CCS states [8,9] that currently an integrated method or framework to gather different company areas and industrial partners to collaboratively solve challenging cleantech problems does not exist and needs to be developed.

Scope of the review

The word co-design (or codesign) has been used in a variety of research and practice contexts, making it challenging to define the precise boundaries and meaning of the term. The “co” has been interpreted by different authors as concurrent [10,11], collaborative [12,13], cooperative [14,15], collective [10] or community [16,17]. Also, the term is used in computer sciences almost exclusively to describe the concurrent design of hardware and software components of an electronic system, highlighting the technical aspects and challenges of the process [18]. In Engineering Design (*ED)* the term has been adopted usually as a synonym of concurrent design/engineering [10,11] or as collaborative design [12,13]. In those cases the shared characteristic is an emphasis in socio-technical aspects, processes and tools enabling users, professionals or teams to participate in the design of a product, service or system. In turn, in Technology and Innovation Management (*TIM)* literature, the use of co-design tends to be associated with the engagement of users in the NPD process (also described as co-creation) [19, 20] or with the description of inter-organisational design relationships, usually with customers or suppliers [21, 22]. This diversity of usages for the term “co-design” creates challenges but also, interestingly, research opportunities; for instance, it allows identifying commonalities and differences in the different co-design situations. It also has the benefit of being used simultaneously in multiple research communities, allowing for the consolidation of common knowledge and best practices without coining yet another term: the rationale as to why this word was selected.

The paper presents a broad literature review of co-design aspects related to coordination, cooperation or collaboration in New Product Development (NPD). Considering the nature of the CCS initiative, this review focuses on complex design environments, where interdisciplinary and cross-boundary collaborations with multiple areas and stakeholders are necessary for the successful development of new products and systems. The objective is to provide an overview and connect the distinctive contributions to co-design stemming from the fields of *Engineering Design* (*ED*) and *Technology and Innovation Management* (*TIM*). Although other fields, for example, *Organisation and Management Studies*, *Information Science*, and *Operations and Production Management* also contribute to the understanding of co-design processes, this review will centre its efforts on the contributions of *ED* and *TIM* as well as the fuzzy boundary between both fields. This is in order to highlight complementarities between the engineering and management approaches and acknowledge their diverse perspectives.

Although literature reviews for specific aspects of co-design are available [23-28], this review seeks to go beyond one particular perspective, examining the spectrum of scenarios in which the different approaches can be applied. To achieve this, key themes in the literature are identified, described and analysed through targeted readings. A network analysis technique of paper's keywords is used and subsequently a set of aspects based on common themes described in the literature is proposed as a result.

The remainder of the paper is structured as follows: section two explains the research methodology. Section three presents and discusses the results and introduces the framework. Finally, section four concludes and suggests paths for further research.

2. Research Methodology

To accomplish the objectives of creating a comprehensive mapping of the literature and deriving its common aspects, the methodology has to allow for a systematic discovery and validation of the most relevant concepts. In order to achieve this, the selected methodology combines a quantitative keyword network analysis with a qualitative examination of the literature within the context of the cleantech sector as described in figure 1.

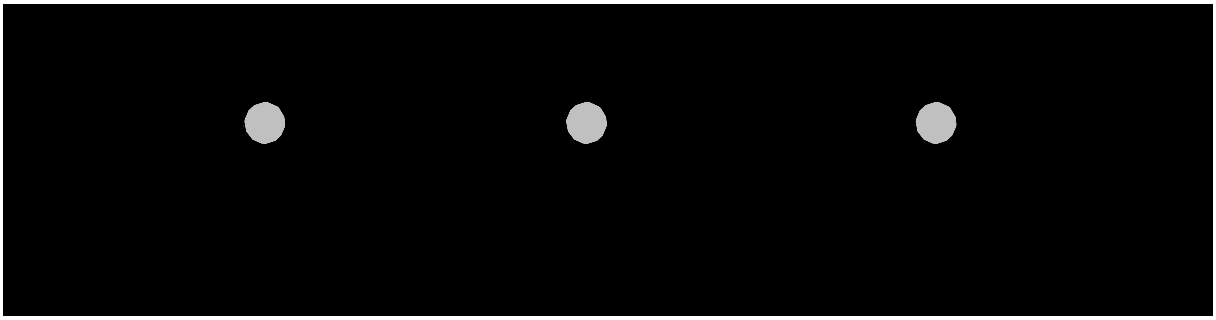

Figure 1: Diagram of the research steps used for the literature review

To build an initial list of relevant keywords in order to commence the research process, various sources with potential to contribute to an integral understanding of the co-design process were reviewed. The first step was the acquisition of information about the NPD process and the collaborative activities of the Danish cleantech industry. This was done through exploratory interviews, industrial visits, the revision of industry reports [1,4,8], and examination of databases [3,29]. With the industrial context and the broad nature of the co-design activities outlined, a targeted review of books [30-33] and papers was undertaken. The sources selected for this first step covered mainly *Engineering Design* and *Technology and Innovation Management*. Subsequently, a literature review enabled the building of a list of ten recurrent keywords related to aspects of co-design, which was later used to guide the review of journal articles. The ten keywords identified are: Collaborative Design, Collaborative Product Development, Communication in Design, Computer Supported Collaborative Work, Concurrent Engineering, Design for X (and its variants), Engineering Knowledge Management, Integrated Product Development, and Open Innovation

To scan and select relevant journal articles, a *Scopus* query for title, author keywords and abstract was performed, including each of the concepts previously identified and some variations. The query was limited to the *Scopus* defined areas of engineering, business and multidisciplinary studies and only to journal articles in English. That led to 4.182 papers, which were later filtered by journal title, limiting the search to only 35 relevant journals from the fields of *ED* and *TIM*. This returned 1.429 papers; which after the tabulation of their respective author keywords, titles, journal names and abstracts constituted the base of the subsequent network analysis.

To create the connections between the author keywords and enable the network analysis, a link was defined every time the keyword representing the particular concept reappeared in another article of the sample. The same logic was applied for keywords and their respective journals (intermediated through the articles of that journal). This was complemented utilising *co-occurrence significance* [34] analysis for the keywords, meaning that keywords that tend to appear more often in the same articles or journals are grouped into clusters, facilitating the identification of commonalities between the concepts. The keyword network analysis was performed using *Touchgraph* [35] as a tool to build the network map, produce the metrics and define the clusters, with the objective of identify natural groups of concepts that could suggest different perspectives or research themes related to co-design. Once this was done, key articles for each of the representative topics were analysed in depth to identify and validate the concepts previously gathered and build a framework to organise the literature.

Finally, utilising the inputs from the previous steps as well as pre-existent literature reviews of the topics involved, general aspects common to most of the literature were determined.

3. Results and Discussion

This section will describe the overall characteristics, contributions and limitations found in the surveyed literature. The keywords found will be grouped based on their respective research communities and key aspects that characterise their role in co-design situations.

Keyword map and literature analysis

After the contextual industry grounding, the targeted review of books and papers and the identification of 1492 relevant papers, the next step to understand the diverse literature perspectives was to use the keyword network map (elicitation process described in the methodology section). This map permitted the visualisation of relationships between the 2909 unique keywords, their respective articles and the 35 filtered journals. The visualisation of the network of keywords highlights connections between the topics, key areas of concern and differentiates lateral discussions from what constitutes the core and more widely used topics. Figure 2 shows the map restricted to keywords appearing in five or more journal articles. For readability reasons, only keywords either directly related to co-design activities or at least providing a context to interpret the surrounding keywords are displayed.

On the map, white nodes are academic journals and each journal is connected through an edge (line) with a set of keywords represented by the coloured nodes. Each colour is a cluster identified by a *betweenness centrality* algorithm [36]. In this filtered version there are two clusters: in red, keywords mainly associated with journals in the engineering field, and in blue with management science. Keywords located closer to the other cluster tend to be used in both fields; conversely, the further apart from the other cluster, the more exclusive this keyword is to the particular field. A referential border has been drawn to highlight shared keywords between the two clusters. Keywords at the centre of the graph show recurrent topics and are connected to more journals. Additionally, the size of the halo surrounding each keyword is also a visual indicator of the number of journals in which that particular keyword appears. This indicates the intensity of the research activity beyond one specific community.

Some interesting aspects that can be spotted in the map are the number of keywords involved, the clear differentiation of research angles between engineering and *TIM* (visually but also in terms of the cluster algorithm) and the keyword dispersion and variety, even inside the respective research communities. Using this network analysis and the literature review, we will take a closer look at the different perspectives and contributions to co-design that the two main fields involved have to offer.

Eighteen keywords (and some variations) were finally identified through the literature review and the analysis of the keyword map as the most relevant concepts to pursue further analysis (Table 1). They represent different research angles, contributing implicitly or explicitly to the understanding of co-design activities in the product development process. The main research communities are determined based on the journals where those keywords tend to appear. A short summary of the area of concern for each term was elaborated based on reading targeted examples of their use. Table 1 also shows how the keyword was originally identified (elicitation source), the number of publications containing the keyword in the title, abstract or author provided keyword (as an indicator or the research activity), the co-design boundaries mostly involved (functional and organisational levels) and the interfaces where the co-design activity generally occurs.

Against this background, co-design will be understood here as the set of interactions, usually mediated through communication instances, between design and one or more areas spanning organisational or functional borders, in order to develop or improve a product, process, service or system [12,15]. Although this concept is similar to collaborative design, its boundaries are wider, encompassing interactions that might be restricted to coordination or cooperation and not only collaboration, thereby allowing to cover all the perspectives included in this study. The distinction between these three levels of "interaction intensity" is important, despite the frequent interchangeable use of those words in the literature [12,23]. Coordination refers to a simple sequence of interdependencies to accomplish tasks efficiently, and does not require active reciprocal participation or direct interaction but only agreements or guidelines that can be imposed as rules [23,37]. Cooperation in turn does imply some sort of reciprocal interaction [23,38] that has to be agreed between the parties, and not just imposed, usually involving sharing information or resources [12]. Collaboration, although requiring coordination and cooperation [23], will be understood as an interaction of a higher order, and an "evolving process whereby two or more social entities *actively* and *reciprocally* engage in joint activities aimed at achieving at least one *shared goal*", following Bedwell's 2012 proposition [23].

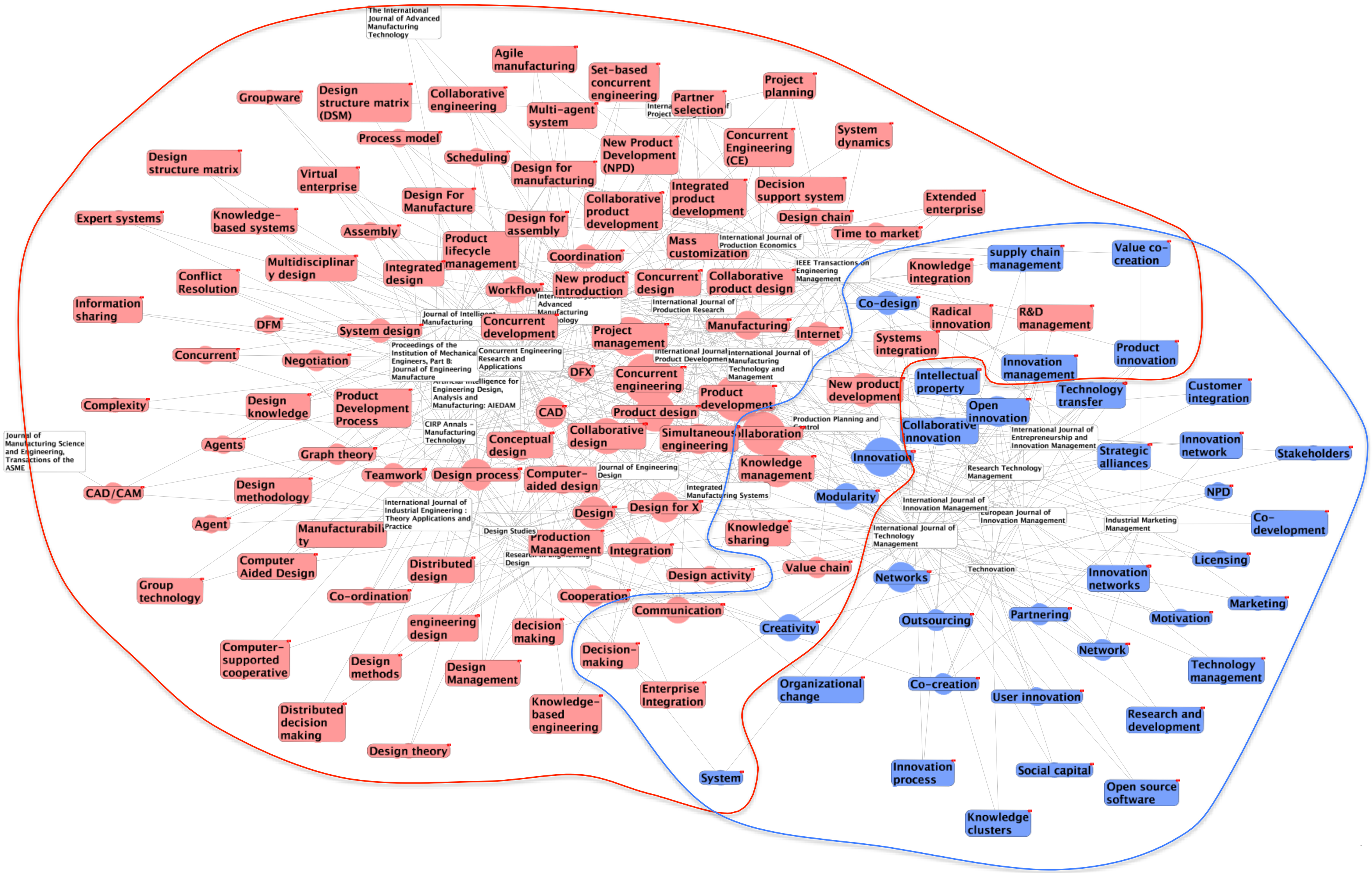

Figure 2: Keyword network map (filtered). In red (left) keywords associated mainly with *Engineering Design* (*ED*), in blue (right) with *Technology and Innovation Management* (*TIM*) and in white the journals. Lines connect keywords with respective journal(s).

Table 1: Literature summary

!"#$%	&#'()*%	+$","-.-")/ 1)2*,#	3)4526$",.-"7)/8	9."/*#8#.*,:,);;2/"-"#8<6.8#%)/ =)2*/.$8>	9."/ ,)/,#*/ "/ -:"8 ,)/-#?-	!2/,-")/.$ ./%)*@./"8.-")/.$ $#A#$8B	9."/ "/-#*4.,#8 (:#*# %#8"@/ "8 "/A)$A#%	C"-#*.-2*# #?.;D$#8
+/@"/##*"/@	!"#$%&&'#(*#+,#"&,#+	-"".	/012	34#%54$(%&,#+6*#+,#"&,#+7'8,+#	94&4::':,84(,"# "5 (48.8 ,# ;&"<%$(<'=':";>'#(	,#('&?('4>	<'8,+#?"(@'&	ABCD2BD2EF
	!"::4G"&4(,=' 7'8,+#	-"".	H0B0	!">;%('& I$,'#$'D *#+,#"&,#+ 7'8,+# 6 34('&,4:8J!"#8(&%$(,"# K'8'4&$@	-&"4< 8$";' G%('>;@48,8 "# $"::4G"&4(,"# ,#8,<' 4#< G'(L''# <'8,+# ('4>8	,#('&?('4>	<'8,+#?<'8,+#J <'8,+#?"(@'&	ABHDHBDHMDNCF
	*#+,#"&,#+ O#"L:'<+' 34#4+'>'#(	-"".	2EM	!">;%('& I$,'#$'D *#+,#"&,#+ 7'8,+# 6 ('$@#":"+P >4#4+'>'#(	3'(@"<8 4#< ("":8 (" >4#4+' 4#< 54$,:,(4(' .#"L:'<+' &':4('< L"&. ,# '#+,#"&,#+	,#<,=,<%4:D ('4> 4#< ,#('&?('4>	<'8,+#?<'8,+#J <'8,+#?"(@'&	ANBDNHF
	!"::4G"&4(,=' 9&"<%$(7'=':";>'#(	-"".	2N1	*#+,#"&,#+ 7'8,+# QRI3*SD 34#%54$(%&,#+ 6 !"#$%&&'#(*#+,#"&,#+	T#('&?<';4&(4>'#(4: 4#< ,#('&?"&+4#,84(,"#4: $"::4G"&4(,"#8 ,# U97	T#('&?('4> 4#< ,#('&? "&+4#,84(,"#	7'8,+#?V(@'&	AHND2BDN2F
	7'8,+#5"&W	-"".	2NC	*#+,#"&,#+ 7'8,+# QRI3*S 6 34#%54$(%&,#+	7'8,+# +%,<':,#'8 (" ,#('&4$(L,(@ "(@'& 4&'48 "& 4<<&'88 ,88%'8 "%(8,<' (&4<,(,"#4: <'8,+#$"#8,<'&4(,"#8	,#('&?('4>	<'8,+#? >4#%54$(%&,#+ J <'8,+#?"(@'&	A2BDNNF
	T#('+&4('<9&"<%$(7'=':";>'#(	-"".	2HE	*#+,#"&,#+ 7'8,+#D !"#$%&&'#(*#+,#"&,#+	T#('+&4(,"#"5.'P4&'48Q>4&.'(D;&"<%$(4#<;&"<%$(,"#S("'#&,$@(@'U97;&"$'88	,#('&?('4>	<'8,+#?"(@'&	A2CD2EF
	!">;%('& 8%;;"&('< $"::4G"&4(,=' L"&.	-"".	H2N	!">;%('& I$,'#$'	X8'"5 8"5(L4&' (" 54$,:,(4(' $"::4G"&4(,=' <'8,+# L"&.	('4> 4#<,#('&? ('4>	<'8,+#?<'8,+#J <'8,+#? >4#%54$(%&,#+	A2BDN1DN0F
	!"?<'8,+#	34;	BNB	*#+,#"&,#+7'8,+#D34#%54$(%&,#+	-&"4<8$";'YX#:,.'$"::4G"&4(,='<'8,+#,(,#:$%<'848;'$(8"5$"&<,#4(,"#4#< $"";'&4(,"#Y T($4# G' %#<'&8(""< 48 Z<'8,+# L,(@ "(@'&8Z	('4> 4#<,#('&? ('4>	<'8,+#?<'8,+#J <'8,+#?"(@'&	ABCDB2DB1DNMF
	7'8,+# !@4,#	34;	1H	V;'&4(,"#8 4#< 9&"<%$(,"# 34#4+'>'#(	K':4(,"#8 4((@' <';4&(>'#(:'=': G'(L''# <'8,+# 4#< "(@'& 4&'48Y *[(&4;":4(,"# "5 $"#$';(85&">8%;;:P $@4,#	,#('&? "&+4#,84(,"# 4#< ,#('&?('4>	<'8,+#?"(@'& J <'8,+#?<'8,+#	AN/DNEF
	!">>%#,$4(,"# ,# 7'8,+#	-"".	B/	*#+,#"&,#+ 7'8,+#D 7'8,+# I(%<,'8D !"#8(&%$(,"#	I(%<P,#+ 4#< 8%;;"&(,#+ (@' ;&"$'88 "5 $">>%#,$4(,"# ,# <'8,+#	('4> 4#<,#('&? ('4>	<'8,+#?<'8,+#J <'8,+#?"(@'&	AH0D1CF
EF9 ./% +/@"/##*"/@	\:"G4: 9&"<%$(7'=':";>'#(	34;	E2	9&"<%$(T##"=4(,"# 34#4+'>'#(D 34#%54$(%&,#+6*#+,#"&,#+7'8,+#	!'#(&'<"#$"::4G"&4(,"#84$&"88$"%#(&,'8D',(@'&G'(L''#(@'84>'"&<,55'&'#($">;4#,'8Y T(>4,#:P $"='&8 &':4(,"#8@,;8 4((@' :'=': "5 <'8,+# 4#< >4#%54$(%&,#+ ,# 4<<,(,"# (" 8%;;:P $@4,#	,#('&?('4> 4#< ,#('&? "&+4#,84(,"#	<'8,+#?<'8,+#J <'8,+#? >4#%54$(%&,#+	A1BD1HF
	!"?$&'4(,"#	34;	//	T#<%8(&,4: 34&.'(,#+ 6 !"#$%&&'#(*#('&;&,8,#+	9&"<%$(<'=':";>'#(,#=":=,#+ %8'&8	,#('&?('4>	<'8,+#?%8'&	A12F
	X8'&?<&,='# T##"=4(,"#	34;	0H	T##"=4(,"# 34#4+'>'#(D *#+,#"&,#+ 7'8,+#D !">;%('& I$,'#$'	R$(,=' ,#=":=>'#("5 (@' %8'& ,# (@' <'8,+# ;&"$'88	,#('&?('4>	<'8,+#?%8'&	A1NF
EF9	]'$@#":"+P]&4#85'&	34;	BM0N	T##"=4(,"# 34#4+'>'#(	]P;,$4::P 4 ;&"$'88 "5 ('$@#":"+P ;%8@Y]@' "G^'$(,=' ,8 (" $">>'&$,4:,8' (@' &'8%:(8 "5 K67 '55"&(8Y	,#('&? "&+4#,84(,"#	<'8,+#?&'8'4&$@	A11F
	!&"88_%#$(,"#4:]'4>8J T#('&<,8$,;:,#4&P ('4>8	34;	H/1	9&"<%$(T##"=4(,"#34#4+'>'#(6 *#+,#"&,#+34#4+'>'#(	K'8'4&$@,#(",#('&4$(,"#8J&':4(,"#8@,;8 ,#('4>8 $">;"8'<GP ,#<,=,<%4:8 5&"> <,55'&'#(5%#$(,"#8	,#('&?('4> 4#< ('4>	<'8,+#?"(@'&	A2MD2/D10D1MF
	V;'# T##"=4(,"#	-"".	M1	T##"=4(,"# 34#4+'>'#(	T#('&?"&+4#,84(,"#4:,##"=4(,"#(@&"%+@(@'";'#,#+"5(@'"&+4#,84(,"#4:G"%#<4&,'8Y *>;@48,8 ,#('$@#":"+P ;%::G%(('$@#":"+P ;%8@ ,84:8"<,8$%88'<Y	,#('&? "&+4#,84(,"#	<'8,+#?"(@'&	AMDH1D22D11F
	T##"=4(,"# U'(L"&.8 J !"::4G"&4(,=' T##"=4(,"#	34;	H1	T##"=4(,"#34#4+'>'#(D I"$,4: U'(L"&.8 6T#('&<,8$,;:,#4&PI"$,4:I(%<,'8	R#4:P8,84((@'#'(L"&.:'=':"5$"::4G"&4(,"#8:'4<,#+(",##"=4(,"#8	('4>D ,#('&?('4> 4#< ,#('&? "&+4#,84(,"#8	<'8,+#?"(@'&	A1/D1EF
	9&"<%$(7'=':";>'#(U'(L"&. J U'(L"&.'< 9&"<%$(7'=':";>'#(	34;	B0	34#%54$(%&,#+6*#+,#"&,#+7'8,+#	K':4(,"#8@,;8 4#< ;&"$'88'8 "$%&&,#+ G'(L''# "&+4#,84(,"#8 '#+4+'< ,# !97	,#('&?('4> 4#< ,#('&? "&+4#,84(,"#	<'8,+#?<'8,+#J <'8,+#?"(@'&	ABND0CF

`,#('&?('4> a ,#('&?<';4&(4>'#(4:

Engineering Design

Engineering Design provides a detailed understanding of a diverse set of co-design instances, emphasising the process, activities and people-related aspects [61]. It ranges from a view focused on coordination and cooperation (*Concurrent Engineering, Design for X, Integrated Product Development*) [39] to more collaborative aspects involving a higher level of involvement with third parties in the design process (*Collaborative Design, Collaborative Product Development*) [5,24,40]. It also includes contributions that cut across a wide range of co-design situations, with research areas such as *Communication in Design* [26,50] and *Engineering Knowledge Management* [41]. *Engineering Design* research so far has tended to focus on an intra-organisational view of the NPD and co-design, and only occasionally explores the role of such aspects as inter-organisational innovation networks, incentives and other issues more commonly associated with *Organisation and Management Studies* as well as *Technology and Innovation Management* (*TIM*).

Aspects that can be recognised as distinctive features and contributions from *ED* are:

- The clear understanding of the *stages in the development process*, adding the time dimension as a relevant variable to consider. This is reflected in the number of design process models describing different phases [30,31,62,63]. It is possible to argue that depending on the specific stage of a project, different approaches to co-design are required in issues such as communication [50], tools [45], disciplines involved and knowledge required to participate in the interaction [6, 64].

- Depending on the characteristics of *what is being developed* there can be differences in terms of the complexity [64], knowledge requirements [6] and the management of the process. For example, to co-design a part, a product, an integrated solution or an entire system the challenges can be significantly different [65]. This is relevant because it makes the scope of the co-design project explicit and reveals the literature that better responds to that level of complexity and subsequent level of detail required.

Two additional engineering research areas were identified through the literature review and the keyword map as strongly connected with *Engineering Design* in terms of co-design activities; *Information Sciences* and *Operations and Production Management.*

In terms of *Information Sciences*, the literature involving co-design has been significantly influenced by the developments of communication technologies, creating a bridge with *Computer Sciences* through the *Computer Supported Cooperative/Collaborative Work* (CSCW) research [50]. For example, more than a quarter of the recent journal articles in topics such as collaborative product development and collaborative design come from interactions with this discipline [66]. Despite considering the greater amount of articles published in the field of *Computer Sciences* and filtering through stricter queries, it is clear that facilitating through information technologies synchronous and asynchronous collaboration, cooperation and/or coordination are relevant research spaces. Two reasons seem to drive these developments; the widespread use of Computer Aided Design (CAD) and the cheap communicational infrastructure that the Internet provides [45,50]. Their combination has created numerous CSCW tools, also called groupware, with applications in areas like concurrent engineering and teamwork. This has meant thorough attention to the tools and their possibilities, but it can also distract attention from the socio-technical dynamics of the collaboration process itself and the important communicational aspects involved [50].

Given the increase in outsourcing and offshoring activities [65], *Operations and Production Management*, has taken its traditional strengths in supply chain and project management into engineering design issues, exploring beyond a transactional view some relational aspects between different partners in NPD. Examples of this are the development of areas such as Design Chain [48,49], Global Product Development [51,52] and Design for X [31, 44]. All these concepts emerged at the intersection between operations, production and engineering design; recognising that the traditional "over the wall" approach between different partners of an NPD process is not enough when the aim is to generate radical innovations [22,67]. *Operations and Production Management* is also an interesting complement to *Engineering Design*, because it brings a network perspective to the relationships between suppliers and industrial customers [21] and recognises their complex interdependencies.

Technology and Innovation Management

Research on inter-organisational collaborative innovation networks can be used as a source of influence for decision-making. When such research is considered within the context of industrial networks, business models and other economic incentives, cross-boundary collaborations are encouraged. Furthermore, such collaboration goes on to impact upon the economical feasibility for co-design initiatives [32,33]. Areas like *Open Innovation* and *Technology Transfer* are representative of *TIM* in terms of inter-organisational NPD processes. Their focus is usually on transactional exchanges of technology and intellectual property assets [55], meaning that there are not many examples in the literature of cases or models integrating the collaborative design aspects found in *ED* with the inter-organisational innovation angle of *TIM*. Against this background, *Organisation and Management Studies* provide useful perspectives on cross-boundary communication of domain knowledge to bridge this gap. As an example, Carlile [68,69] uses and appropriates the notion of "boundary objects" as a means to facilitate innovation across boundaries in product development.

Some aspects that *TIM* brings to co-design are:

- A discussion about the *nature of the interface*, where co-design dynamics can be explained in terms of the different objectives or mind-sets of the involved departments, areas or partners. These objectives or mind-sets can be classified as explorative or exploitative and their combinations define the nature of the interface [70,71]. Exploitative strategies focus on current processes and try to improve them gradually while explorative strategies in contrast seek to change and disrupt the status quo [70]. In this context, interactions between pairs such as design-manufacturing are characterised by an interface of the kind explorative-exploitative [70] leading to more tensions and difficulties in terms of the co-design activity because of the lack of sync in the mind-sets. In turn pairs like design-users, design-research and design-marketing can be described as explorative- explorative leading to interfaces with less friction at the conceptual level due to the openness of both sides in terms of exploring conceptual solutions.

- Clear distinctions for the classifications of different *interaction intensities*, describing more precisely the distinctions between collaboration, cooperation and coordination [23]. Not all the projects require or have the organisational skills to go beyond coordination or cooperation [12], therefore it is relevant to make this aspect explicit at the moment of selecting the strategies. In addition, management literature, and in particular *Industrial Marketing*, also makes the distinction between relational and transactional exchanges or interactions [72-74] as another form of characterising the interaction intensity. Transactional interactions are short, require low involvement and have a low dependency on the context, thus they can be described as an interaction related to coordination. In contrast, relational interactions are not only repeated over time but require higher involvement given that they are context specific (they are highly dependant on the characteristics of the co-design situation), therefore this interaction fits to what was described before as cooperation or collaboration. Although these issues are also considered implicitly in *Engineering Design* the use is less consistent and the nomenclature is used sometimes interchangeably in the discussions.

The intersection between Engineering Design and Technology and Innovation Management

As portrayed in the keyword map and the literature summary, there are areas such as New Product Development, Knowledge Management, Creativity, Collaborative Innovation and general innovation studies that act as bridges or common currency between the disciplines of *Engineering Design* and *Technology and Innovation Management*. Some aspects that emerge as significant contributions to the understanding of co-design at this intersection are:

- The discussion of *organisational, physical and knowledge closeness*. This discussion helps group factors related with the composition and general nature of the team and are focused mainly on the interaction across boundaries and people-related aspects. Considering that the design activity is heavily influenced by knowledge distribution and diversity of teams [6], interfaces involved [71], organisational boundaries [75] and physical proximity [76,77], these aspects appear as an important set of variables to consider. Some levels that can be identified are the functional design team (most of the project design activity occurs inside the design team itself, and an over-the-wall approach is predominant in the interactions with other functions), inter-functional teams (co-design situations inside of the company between functional areas), inter-organisational functional teams (co-design between design teams spanning different organisations) and inter-organisational cross-functional teams (co-design with areas different to design in external organisations). This spectrum of possibilities is enriched by considerations of physical and cultural distances between the teams. The categories above are an adaptation of Sullivan (2003) [77] and Kleinsmann's (2007) [40] characterisation of the possible levels of collaboration, where there is an explicit recognition of the differences between collaborations crossing functional disciplines [56] as well as organisational boundaries [60].

- What could be characterised as the *novelty objective of an NPD project* is a common distinction made in both *Engineering Design* and *Technology and Innovation Management* literature but using different terminology. For example Pahl and Beitz [78] describe designs as original, adaptive or variant while in *TIM* terminology the results of the NPD process could be defined as a radical innovation or an incremental innovation [79]. Although the meaning is not the same; in *ED* it is about the design objectives defined upfront while in *TIM* it is about the results, there is a common understanding that depending on the desired results of the NPD process different strategies will be required. In co-design terms this is relevant because based on the objective of the co-design activity (in terms of the novelty of the solutions pursued) different approaches are more or less appropriate. For example concurrent engineering centres on the parallelisation of tasks and coordination of activities of different areas in the engineering process [39], but its systematic approach is probably more suitable for incremental improvements. In contrast, collaborative design seems more suitable for original results given its greater emphasis on the exploration of different solutions through the engagement of actors with a wider knowledge base [21,40].

An integrated perspective of the literature with design at the centre

Considering the previous points, it is possible to frame co-design relationships in the development of new products or systems as a set of interactions between pairs of actors. Pairing of actors mainly occurs between the areas of engineering design and third parties, where designers takes a central role as integrators and translators of requirements from a diverse group of stakeholders [6,62]. The proposed pairs configure interfaces such as design-manufacturing [70,80], design-marketing [81], design-design [82] (interactions between designers in different teams) and design-research [83]. These interfaces can occur at different levels and intensities and assume a range of combinations of explorative-exploitative behaviours [86]. The differences can lead to tensions, for example the inter-functional, explorative-exploitative design-manufacturing interface creates difficulties in the collaboration process due to different functional dependencies [42] and different mental models [70]. This is aggravated even further in the case of inter-organisational relationships where cultural and communicational factors increase the distances [51]. This also occurs within the engineering design process itself, where arguably there is an explorative-exploitative interface between, for example, teams working in embodiment design and simulation [82], creating a situation similar to the one exhibited by the design-manufacturing interface.

Towards the development of a cross-disciplinary framework for co-design

Through the analysis of the most distinctive aspects identified above for *ED* and *TIM* literature, and considering frameworks and taxonomies from preceding reviews in collaborative product development [40], collaborative design [12,21,27,40] and the management of knowledge across boundaries [56,68,69], a set of aspects characterising co- design scenarios is proposed. These aspects should help distinguish the most characteristic contributions from each field, facilitating the identification of adequate approaches for a range of co-design situations. Figure 3 introduces and organises the proposed aspects. Its purpose is to act as a first step towards the development of a comprehensive framework able to describe and support co-design situations.

From *Engineering Design* the proposed framework includes:

- *When* in the NPD process the co-design occurs through the distinction between key design stages such as concept development, system level design and detailed design [30,62]

- The nature of *what* is being developed through the distinction between co-designing components/parts, a whole product or a system/integrated solution [86]

From *Technology and Innovation Management* the framework includes two aspects describing “how” the co-design process is carried out:

- The nature of the design-x interface (explorative-exploitative or explorative-explorative) [70,71]
- The interaction intensity in terms of the spectrum between coordination and collaboration previously explained [12,23]. This interaction intensity can also be mapped distinguishing between transactional or relational interactions [72-74]

At the intersection between *Engineering Design* and *Technology and Innovation Management* the framework includes:

- A characterisation of organisational, physical and knowledge closeness through the different modes in which interactions can be arranged [40,77]. This can be interpreted as the “*who*” in terms of co-designing.
- The objective of the NPD project, or in other terms “*why”* is the co-design project being pursued. The answer in this case can be framed as the need to develop either an original, adaptive or variant design [78] or alternatively the want for incremental or radical innovation [79].

Figure 3: Aspects characterising co-design

4. Conclusions and further research

The contributions of this paper are twofold: Firstly to provide a cross-disciplinary perspective, integrating *ED* and *TIM*, from where to explore literature sources with potential to explain or improve a range of co-design activities. Secondly, the identification of key aspects behind the different research perspectives that help in the development of a framework including the *When*, *Who*, *What*, *How* and *Why* of co-design. The aim of the proposed framework was to make a set of diverse literature viewpoints on co-design explicit. This facilitates the work of practitioners and researchers attempting to consolidate knowledge - a challenging task evidenced by the number of keywords identified and the conceptual overlap between them.

Design can be understood as a pivot of co-design interactions. Its objective is not only to design taking into account the needs or constrains of a third party (design *for* X), but actively inviting, guiding and engaging third parties, effectively sharing the "design canvas" with them. The need for this proactive and leading role of design is stressed in environments requiring disruptive innovation such as the *Cleantech Complex Solutions initiative*, where a large part of the activities and money is spent at the development stage, making "design – X" interfaces a common denominator of collaborative interactions.

Although informational technologies are enabling unprecedented possibilities in terms of distributed design and concurrent engineering, it is critical to remember that design is a social, creative and interactive process. Furthermore, it is a process that is enriched by collaboration, and thus relies heavily on people designing. The creative input required in this process is beyond the scope of what any tool can provide. Additionally, an integrated view that considers the multifaceted co-design process in context is required. This entails identifying, understanding and supporting the dynamics (when) of the design process, its participants (who), the characteristics of the new product or service designed (what), the mode that the co-design process adopts (how) and the reason behind the co-design project (why). The diversity of angles justifies the proposed integration of *Engineering Design and Technology* and *Innovation Management* perspectives for the advancement of co-design practices in industry and society.

In terms of this research, further work in the cleantech industry will allow for refinement of the analysis and for documenting co-design activities in industry practice in greater detail. The aim is to develop a robust characterisation of co-design situations that can be used in industry and also help with the conceptual organisation of research in this field.

4. References

1. Copenhagen Cleantech Cluster, 2010. *Monitor Copenhagen Cleantech Cluster 2010*, Available at: http://www.cphcleantech.com/.
2. Gray, M. & Caprotti, F., 2011. Cleantech clusters and the promotion of the low carbon transition: criteria for success and evidence from Copenhagen, Masdar and online platforms. *Carbon Management*, 2(5), pp.529-538.
3. Danish Energy R&D projects (DENP) - EUDP Database. Available at: http://iis-03.risoe.dk/netahtml/risoe/ens/efp_uk.htm [Accessed May 9, 2012].
4. Copenhagen Cleantech Cluster, 2011. *Monitor Copenhagen Cleantech Cluster 2011*, Available at: http://www.cphcleantech.com/.
5. Neale, M.R. & Corkindale, D.R., 1998. Co-developing products: Involving customers earlier and more deeply. *Long Range Planning*, 31(3), pp.418-425.
6. Dell'Era, C. & Verganti, R., 2010. Collaborative Strategies in Design-intensive Industries: Knowledge Diversity and Innovation. *Long Range Planning*, 43(1), pp.123-141.
7. Mortara, L. et al., 2009. *How to implement open innovation: Lessons from studying large multinational companies*, Cambridge, UK: University of Cambridge Institute for Manufacturing.
8. Copenhagen Cleantech Cluster, 2012. *Copenhagen Clean Tech Journal 2012*, Available at: http://www.cphcleantech.com/.
9. Anon, Complex Cleantech Solutions, Danish Industry Fond. Available at: http://www.industriensfond.dk/da/Projekter-og-Viden/Viden-og-kompetencer/?projectId=105 [Accessed May 22, 2012].
10. Détienne, F., Martin, G. & Lavigne, E., 2005. Viewpoints in co-design: a field study in concurrent engineering. *Design Studies*, 26(3), pp.215-241.
11. Garg, A. & Chawdhry, P.K., 1998. Concurrent Specification in the Co-design of Reactive Engineering Systems. *Journal of Engineering Design*, 9(1), pp.37-41.
12. Kleinsmann, M., 2006. *Understanding Collaborative Design*. PhD Thesis, Technische Universiteit Delft.
13. Kleinsmann, M. & Valkenburg, R., 2008. Barriers and enablers for creating shared understanding in co-design projects. *Design Studies*, 29(4), pp.369-386.
14. Coles, A. & Harris, L., 2003. Testing goodwill: conflict and cooperation in new product development networks. *International Journal of Technology*, 25, pp.51-64.
15. Design Council - UK, Design Guides: Co-design. Available at: http://www.designcouncil.org.uk/resources-and-events/designers/design-glossary/co-design/ [Accessed May 17, 2012].
16. Duarte, O. & Lulham, R., 2011. Co-designing out crime. *CoDesign*, 7(3-4), pp.155-168.
17. Thorpe, A. & Gamman, L., 2011. Design with society: why socially responsive design is good enough. *CoDesign*, 7(3), pp.217-230.
18. Woolf, W.H., 1994. Hardware-software co-design of embedded systems. *Proceedings of the IEEE*, 82(7), pp.967-989.
19. Buur, J. & Matthews, B.E.N., 2008. Participatory Innovation. *International Journal of Innovation Management*, 12(3), pp.255-273.
20. Bogers, M., Afuah, a. & Bastian, B., 2010. Users as Innovators: A Review, Critique, and Future Research Directions. *Journal of Management*, 36(4), pp.857-875.
21. Kamrani, A.K., 2008. Collaborative Design Approach in Product Design and Development. In A.K. Kamrani & E. S. A. Nasr, eds. *Collaborative Engineering: Theory and Practice*.
22. Spina, G., Verganti, R. & Zotteri, G., 2002. A model of co-design relationships: definitions and contingencies. *International Journal of Technology Management*, 23(4), pp.304-321.
23. Bedwell, W.L. et al., 2012. Collaboration at work: An integrative multilevel conceptualization. *Human Resource Management Review*, 22(2), pp.128-145.
24. Büyüközkana, G. & Arsenyanb, J., 2011. Collaborative product development: a literature overview. *Production Planning & Control*, (March 2012), pp.37-41.

25. Duarte, V. & Sarkar, S., 2011. Separating the wheat from the chaff – a taxonomy of open innovation. *European Journal of Innovation Management*, 14(4), pp.435-459.
26. Maier, A. et al., 2011. Improving Communication in Design: Recommendations from the Literature. In *18th International Conference on Engineering Design, Impacting Society through Engineering Design (ICED 11).* Copenhagen.
27. Ostergaard, K.J. & Summers, J.D., 2009. Development of a systematic classification and taxonomy of collaborative design activities. *Journal of Engineering Design*, 20(1), pp.57-81.
28. Klein, M. et al., 2003. The Dynamics of Collaborative Design: Insights from Complex Systems and Negotiation Research. *Concurrent Engineering*, 11(3), pp.201-209.
29. Anon, State of Green - Denmark. Available at: http://www.stateofgreen.com/en [Accessed May 22, 2012].
30. Andreasen, M.M., 1987. *Integrated Product Development*, Springer-Verlag.
31. Clarkson, J. & Eckert, C., 2005. *Design process improvement: A review of current practice* J. Clarkson & C. Eckert, eds., London: Springer London.
32. Hippel, E.V., 2005. *Democratizing Innovation*, MIT Press.
33. Chesbrough, H., 2003. *Open innovation: The new imperative for creating and profiting from technology*.
34. Chaudhari, D., Damani, O.P. & Laxman, S., 2010. Lexical Co-occurrence, Statistical Significance, and Word Association. *Computational Linguistics*, pp.1058-1068.
35. Touchgraph Navigator 2. Available at: http://www.touchgraph.com/navigator.
36. Pinney, J. & Westhead, D.R., 2006. Betweenness-based decomposition methods for social and biological networks. *Interdisciplinary Statistics and Bioinformatics*, pp.87-90.
37. Marks, M.A., Mathieu, J.E. & Zaccaro, S.J., 2001. A Temporally Based Framework and Taxonomy of Team Processes. *Academy of Management Review*, 26(3), pp.356-376.
38. Pinto, M.B., Pinto, J.K. & Prescott, J.E., 1993. Antecedents and Consequences of Project Team Cross-Functional Cooperation. *Management Science*, 39(10), pp.1281-1297.
39. Thamhain, H.J., 2005. Concurrent Engineering and Integrated Product Development. In *Management of Technology!: Managing Effectively in Technology-Intensive Organizations*. Wiley, p. 400.
40. Kleinsmann, M., Valkenburg, R. & Buijs, J., 2007. Why do(n't) actors in collaborative design understand each other? An empirical study towards a better understanding of collaborative design. *CoDesign*, 3(1), pp.59-73.
41. Wallace, K., Ahmed, S., Bracewell, R., 2004. Chapter 16: Engineering Knowledge Management. In J. Clarkson & C. Eckert, eds. *Design Process Improvement: A review of current practice*. Cambridge: Springer, p. 560.
42. Ramesh, B. & Tiwana, A., 1999. Supporting Collaborative Process Knowledge Management in New Product Development Teams. *Decision Support Systems*, 27(1-2), pp.213-235.
43. Bruce, M. & Leverick, F., 1995. Complexities of collaborative product development. *Technovation*, 15(9), pp.535-552.
44. Kuo, T. & Huang, S., 2001. Design for manufacture and design for "X": concepts, applications, and perspectives. *Computers & Industrial Engineering*, 41, pp.241-260.
45. Mi, X. & Shen, W., 2005. Computer Supported Collaborative Product Development: A Review. In *The 9th International Conference on Computer Supported Cooperative Work in Design*. pp. 181-187.
46. Horn, D., Finholt, T. & Birnholtz, J., 2004. Six degrees of Jonathan Grudin: a social network analysis of the evolution and impact of CSCW research. *Proceedings of the CSCW 2004*, pp.582-591.
47. Spina, G., Verganti, R. & Zotteri, G., 2002. Factors influencing co-design adoption: drivers and internal consistency. *International Journal of Operations & Production Management*, 22(12), pp.1354-1366.
48. Twigg, D., 1998. Managing product development within a design chain. *International Journal of Operations & Production Management*, 18(5), pp.508-524.
49. Austin, S., Thorpe, A. & Root, D., 2007. Integrated Collaborative Design. *Journal of Engineering, Design and Technology*, 5(1), pp.7-22.
50. Eckert, C., Maier, A. & McMahon, C., 2004. Chapter 9: Communication in Design. In J. Clarkson & C. Eckert, eds. *Design Process Improvement: A review of current practice*. Cambridge: Springer, p. 560.

51. Hansen, Z.N.L. & Kristensen, S.A., 2011. Global product development: the impact on the product development process and how companies deal with it. *International Journal of Product Development*, 15(4), p.205-226.
52. Eppinger, S.D. & Chitkara, A.R., 2009. The Practice of Global Product Development. *Business Insight/MIT Sloan*, (50437).
53. Zwass, V., 2010. Co-Creation: Toward a Taxonomy and an Integrated Research Perspective. *International Journal of Electronic Commerce*, 15(1), pp.11-48.
54. Buur, J. & Matthews, B.E.N., 2008. Approaches to User-Driven Innovation. *International Journal of Innovation Management*, 12(3), pp.255-273.
55. Parraguez, P., 2010. *Technology & Knowledge Transfer Under the Open Innovation Paradigm*. University of Bath. Available at: www.openinnovate.eu
56. Mohammed, S. & Dumville, B.C., 2001. Team mental models in a team knowledge framework: expanding theory and measurement across disciplinary boundaries. *Journal of Organizational Behavior*, 22(2), pp.89-106.
57. Marks, M.A., Mathieu, J.E. & Zaccaro, S.J., 2001. A Temporally Based Framework and Taxonomy of Team Processes. *Academy of Management Review*, 26(3), pp.356-376.
58. Batterink, M.H. et al., 2010. *Orchestrating innovation networks: The case of innovation brokers in the agri-food sector*
59. Gloor, P.A., 2006. *Swarm Creativity: Competitive Advantage through Collaborative Innovation Networks*, Oxford University Press, USA.
60. Knudsen, M., 2007. The Relative Importance of Inter!rm Relationships and Knowledge Transfer for New Product Development Success. *Journal of Product Innovation Management*, (May 2002), pp.117-138.
61. Horváth, I., 2004. A treatise on order in engineering design research. *Research in Engineering Design*, 15(3), pp.155-181.
62. Ulrich, K.T. & Eppinger, S.D., 2008. *Product Design and Development*, McGraw-Hill Higher Education.
63. Cooper, R.G., 1990. Stage-Gate Systems: A New Tool for Managing New Products. *Business Horizons*, (May-June), pp.44-54.
64. Kleinsmann, M., Buijs, J. & Valkenburg, R., 2010. Understanding the complexity of knowledge integration in collaborative new product development teams: A case study. *Journal of Engineering and Technology Management*, 27(1-2), pp.20-32.
65. Edward G. Anderson Jr., Davis-Blake, A. & et al, 2007. The effects of outsourcing, offshoring, and distributed product development organization on coordinating the NPD process. In C. Loch & S. Kavadias, eds. *Handbook of New Product Development Management*. Butterworth-Heinemann, pp. 259-290.
66. Scopus. Available at: http://www.scopus.com/home.url [Accessed May 22, 2012].
67. Reich, Y. et al., 1996. Varieties and issues of participation and design. *Design Studies*, 17(2), pp.165-180.
68. Carlile, P., 2002. A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. *Organization science*, 13(4), pp.442-455.
69. Carlile, P., 2004. Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries. *Organization science*, 15(5), pp.555–568.
70. Smulders, F., 2006. Get synchronized: bridging the gap between design and volume production. PhD Thesis. Delft University: The Netherlands.
71. Calantone, R. & Rubera, G., 2012. When Should RD&E and Marketing Collaborate? The Moderating Role of Exploration-Exploitation and Environmental Uncertainty. *Journal of Product Innovation Management*, 29(1), pp.144-157.
72. Dwyer, F.R., Schurr, P.H. & Oh, S., 1987. Developing Buyer-Seller Relationships. Journal of Marketing, 51(2), p.11.
73. Wiel, A. & Vlaar, P., 2011. When firms do not benefit from collaborative experience: differences in the intensity and nature of interorganizational relationships. In The Nature of the New Firm: Beyond the Boundaries of Organisations and Institutions. pp. 138-153.
74. Whipple, J.M., Lynch, D.F. & Nyaga, G.N., 2010. A buyers's perspective on collaborative versus transactional relationships. Industrial Marketing Management, 39(3), pp.507-518.

75. Im, G. & Rai, a., 2008. Knowledge Sharing Ambidexterity in Long-Term Interorganizational Relationships. *Management Science*, 54(7), pp.1281-1296.

76. Moultrie, J. et al., 2007. Innovation Spaces: Towards a Framework for Understanding the Role of the Physical Environment in Innovation. *Creativity and Innovation Management*, 16(1), pp.53-65.

77. O'Sullivan, A., 2003. Dispersed collaboration in a multi-firm, multi-team product-development project. *Journal of Engineering and Technology Management*, 20(1-2), pp.93-116.

78. Pahl, G., Beitz, W. & Wallace, K., 1996. *Engineering Design: A Systematic Approach*, Springer.

79. Ettlie, J. & Bridges, W., 1984. Organization strategy and structural differences for radical versus incremental innovation. *Management science*, 30(6), pp.682-695.

80. Vandevelde, A. & Dierdonck, R.V., 2003. Managing the design-manufacturing interface. *International Journal of Operations & Production Management*, 23(11), pp.1326-1348.

81. Gupta, A.K., Raj, S. & Wilemon, D., 1985. The R&D-marketing interface in high-technology firms. *Journal of Product Innovation Management*, 2(1), pp.12–24.

82. Maier, A. et al., 2009. Reflecting communication: a key factor for successful collaboration between embodiment design and simulation. *Journal of Engineering Design*, 20(3), pp.265-287.

83. Verganti, R., 2011. Radical Design and Technology Epiphanies: A New Focus for Research on Design Management. *Journal of Product Innovation Management*, 28(3), pp.384-388.

84. Kratzer, J. & Gemünden, H., 2011. The Organizational Design of Large R&D Collaborations and Its Effect on Time and Budget Efficiency: The Contrast Between Blueprints and Reality. *IEEE Transactions on Engineering Management*, 58(2), pp.295-306.

85. Greve, H.R., 2007. Exploration and exploitation in product innovation. *Industrial and Corporate Change*, 16(5), pp.945-975.

86. Yassine, A.A. & Wissmann, L.A., 2007. The Implications of Product Architecture on the Firm. *Systems Engineering*, 10(2), pp.118-137.