Technological Confluence

Technische Universiteit Delft

"The effect of innovation via the combining of technologies on the process of development and diffusion"

TU Delft

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October 2015

TU Delft

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The effect of innovation via the combining of technologies on the process of development and diffusion

MASTER OF SCIENCE THESIS

FOR THE DEGREE OF MASTER OF SCIENCE IN MANAGEMENT OF TECHNOLOGY

DELFT UNIVERSITY OF TECHNOLOGY
FACULTY OF
TECHNOLOGY, POLICY AND MANAGEMENT

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12 OCTOBER 2015

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1. Introduction

The fast pace of current technological change in most industries asks for a different approach to innovation, because it is hard for any given company or policymaker to possess all of the resources needed to research, develop, and apply different technologies on its own. No longer is it about the amount spent on research and development (R&D), but about how R&D is defined. One such definition is the "traditional" breakthrough approach where an older generation of technology is replaced by investing in the technology's components (Kodama, 1992, p. 70). Another definition lies in the creating of new combinations of technologies. It is proven a fruitful approach to innovation that results in many new products, as described by Kodama (1992, p. 70). The duration that development of a combination of technologies takes has not been investigated yet. The duration, however, is surely the most interesting part worth investigating because of the fast pace of technological change, and the chance for companies to reach a competitive advantage by speeding up innovation. As of yet, the combining of technologies is still a field covered in mystique that needs to be further unraveled, for which this study will be the foundation.

What is known already is that often, previously unrelated technologies originate from different application domains (Levinthal, 1998), and sometimes even an entirely different field of science (e.g. optics and electronics) (Kodama, 1992, p. 71). A technology resulting from a combination of technologies can then either be launched in the same domain as one of the previously unrelated technologies, or in a completely new domain.

Let us look at smart TV technology, born by combining digital television technology with personal computer (PC) technology. The combination enlarged the amount of functions a television can fulfill, such as streaming media over a network, and browsing the internet. All of its functions are managed by an operating system, and made available to the user via a user interface. Simply put, the functions that a PC entails are embedded in the television. Smart TV technology opened up a new application domain; not because the customer need changed, but because the smart TV customer considers different aspects to be important compared to the digital television customer (Prabhala & Ganapathy, 2011). Connectivity and the software in a smart TV, for example, have become important aspects. Interesting as well is that other technologies also embedding PC technology, such as the smartphone and tablet, can communicate with the smart TV. PC technology here acts as a sort of platform that other technologies can build on, and enables the integration of these various devices (Lei, 2000, p. 707).

Our research begins with four perspectives on the combining of technologies, being technological convergence (Rosenberg, 1963), technology fusion (Kodama, 1992), technology integration (Stock & Tatikonda, 2004), and cross-sectoral innovation (Breschi, 2000). Currently, however, it is unclear what each perspective entails, which makes the boundary of each perspective a gray area, and increases the possibility of overlap between these perspectives. The four perspectives have been introduced and further developed over a course of over 50 years. And while the essence of the combining of technologies may not have changed much, the means to and influences likely have and, over time, each field possibly adapted to this changing environment in their own way. Fact here is that the perspectives have never been systematically evaluated and compared, and we do not know for sure whether there is overlap, or what perspective fits a certain situation best. Possibly, we have become accustomed to using a certain perspective in a certain context, but whether this is actually the best perspective to opt for is a different question. Even more fundamental is the question whether the current perspectives actually cover all variations of the combining of technologies. This study will be the bedrock for the combining of technologies; a base for researchers to build upon, and an infrastructure for both policymakers and managers to base their strategic decisions upon.

The study is fascinating for policymakers because national regulation is found to influence the speed of technological change, and possibilities for new and existing companies in the market. In the 1990s in the United States of America and Europe deregulation took place in financial services, telecommunications, cable television, internet-based electronic commerce, electric utilities, and health care which transformed the nature of competition, market size, and employment of technologies (Lei, 2000). Cable television companies, for example, were now allowed to upgrade their infrastructure to enable signal multiplexing for internet purposes. Policymakers should understand the combining of technologies so that legislation facilitates firms in this field rather than suppresses. For managers from firms it is interesting because the combining of technologies results in many new products, and is possibly less time-consuming in comparison to any former, traditional approaches to innovation. We will target ourselves at the latter group.

The goal of this study is to identify all perspectives on the combining of technologies, along with the differences between them, and to systematically determine all variations of the combining of technologies on the basis of their process of development and diffusion. The main research question can be found in the first row of Table 1, which is further divided into five sub-research questions also shown in this table.

Table 1 Formulation of the main research question and the sub-questions

MAIN-RQ: What is the effect of innovation via the combining of technologies on the process of development and diffusion?
>> SUB-RQ1: What perspectives to the combining of technologies can be identified?
>> SUB-RQ2: How are these perspectives different from each other?
>> SUB-RQ3: How can the overarching perspective "technological confluence" be defined?
>> SUB-RQ4: What types of technological confluence can be recognized?
>> SUB-RQ5: What process(es) of technological confluence can be identified?

First, the different perspectives on the combining of technologies will be identified, after which the structural differences between these perspectives are analyzed. Then, in order to verify whether the identified perspectives indeed cover all variations of the combining of technologies, an "umbrella" perspective will be developed to funnel all perspectives into an overarching perspective, which we will refer to as "technological confluence". This term is chosen because of its fluent nature in which, previously separate, flows together form a new whole; similar to two rivers that reinforce each other's current. And besides that, confluence has, as of yet, not been associated with any form of development. After having defined this umbrella term, the variations on the combining of technologies will again be categorized into, what we refer to as "types of technological confluence", by developing a model that distinguishes these types based on a currently unknown set of variables (relating to the process of development and diffusion). Because our research focuses on aiding companies engaging in the combining of technologies, the process of development and diffusion of each type of combination is very interesting. Each type of technological confluence is expected to vary in terms of this process, which is what our last research question is aimed at.

The conceptual process of this research is shown in Figure 1. The circles on the left side resemble the perspectives identified in research question one, then, the vertical line in the center of the figure is where our umbrella perspective will be defined. Having defined this perspective, we broaden again by systematically splitting into the types of technological confluence.

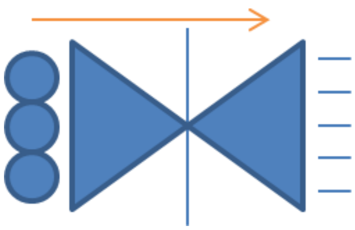

Figure 1 Process through which this research unfolds.

This study takes place on the macro level of innovation, being the pattern of development and diffusion of a technology. Each type of technological confluence is expected to differ in terms of its process of development and diffusion. As a basis to start from, the process of development and diffusion is split into different phases as also shown in Figure 2: the Innovation-, Market adaptation-, and Market stabilization phase (Ortt & Schoormans, 2004). In order to aid a company in their strategic decision making, knowledge of all phases is required. This research however limits itself to the innovation, and adaptation phases, because these phases entail the development and "settling" of a technology on the market. After these phases, a "dominant" shape of the technology is often present, with which the market stabilization phase begins.

The innovation phase begins with the first prototype of the technology (invention) and ends when the technology is first introduced in the market in the form of a product (Ortt & Schoormans, 2004, p. 296). The innovation process adopted by a company developing such a new technology is important because the process is expected to be different for each type of combination of technologies. This phase entails the way in which a company fills the gap between its own knowledge base and the required (domain specific) knowledge, resulting in its first product introduced to the market.

The market adaptation phase starts where the innovation phase ends, and continues until market stabilization takes off, which is characterized by large-scale diffusion (Ortt & Schoormans, 2004, p. 297). Large-scale diffusion is in turn characterized by for instance dedicated production lines, or when a technology's predecessor is replaced by a new technology. During the adaptation phase an erratic process of diffusion occurs where products are re-introduced and a dominant design has yet to rise.

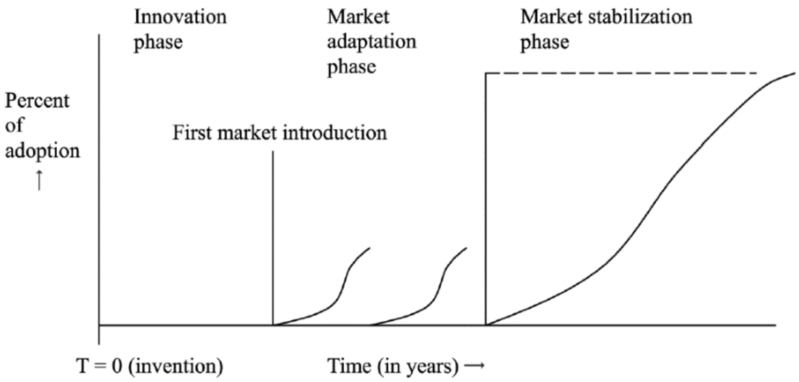

Figure 2 Three phases in the process of diffusion (Ortt & Schoormans, 2004)

1.1.1. Academic relevance

The differences among the various perspectives on the combining of technologies have, by our knowledge, never been evaluated, and it is unclear how each perspective differs from each other. The result is that terms are sometimes used in a context different from where it originates, thus pulling it out of context. This happened with the Skype case described by Rao, Angelov, & Nov (2006), who discuss Skype to be a technology fusion case because two previously unrelated technologies were combined to develop Skype technology. However, technology fusion originally discusses the combining of previously unrelated technologies *from different technological fields*, such as optics and electronics, or electronics and mechanics (Kodama, 1992, p. 71). The technologies used in Skype are from the same field (software). Furthermore, Skype did not follow the process of fusion because it was not developed as part of a strategic alliance (Kodama, 1992, p. 74), rather, its developers had worked together earlier on a different project called Kazaa (Wikipedia, 2015). This illustrates that a perspective is interpreted in a different way than originally intended, and confirms the need for a systematic literature review on each field, and their differences.

The bedrock that we wish to develop for this research is the overarching perspective of technological confluence. And besides that, we aim at developing a model that gives insight in the different types of combining technologies so that researchers can better focus their studies towards the development and diffusion of a technology, and on new product development. By referring to a (group of) type(s) in the model, the scope of future studies can be defined much clearer. In time, the adoption of this model possibly boosts research in the field of combining technologies because there is only one overarching perspective that entails all types of combining technologies. There would no longer be need for a researcher to put effort in the understanding of all different perspectives on the combining of technologies before selecting one and continuing research, our model will guide in doing so.

1.1.2. Practical relevance

The combining of technologies brings forth many new products which makes this approach to innovation essential for managers to understand. These products are created by looking at a company’s current technologies, and considering the technologies from other domains that could be a key addition. When combined, a new product results. Simply put, the company that owned digital television technology acquired PC technology to develop the smart TV. The knowledge that needs to be acquired is the difference between the domain specific knowledge and a company’s knowledge base, and there are different ways to fill this knowledge gap.

Besides this, we expect there to be different patterns of development and diffusion for different types of combinations of technologies, for which different strategies are applicable. Our vision is that a manager can position its technology in the confluence model, and insight will be given in the different processes through which the selected type of combination of technologies moves, together with a recommendation for a strategy to product development and diffusion. However, this remains an ideal situation that unfortunately is hard to reach within the boundaries of this study. First, much effort needs to be put in the structural development of the model, and second, due to the limited time available for this research, the managerial application of the model and the impact of the identified factors on each type of confluence in the innovation and adaptation phases is left for further research. This study focuses on developing the first building blocks for future researchers to continue with.

2. Application Domain

This study is aimed at developing the confluence model to guide innovation via the combining of technologies, to eventually aid a manager in foreseeing the consequences of choosing such an innovation strategy. The perspective through which this study unfolds is technology management as it contributes to the fields of technology strategy and technology forecasting. Its contribution to the field of technology strategy consists of the systematic development of a model that distinguishes the different types of combinations of technologies. This model will help in guiding a manager of a firm in finding a strategy that matches the combination of technologies that this firm wishes to develop. The model, however, does not stop at the strategy, and will also give insight in the pattern of development and diffusion through which a certain type of combination of technologies moves. This way, a manager can foresee what to expect when choosing a certain combination of technologies. Thereby our contribution to the field of technology forecasting. Key here is recognizing the pattern of development and diffusion characteristic to a certain type of combination of technologies.

3. Research methodology

The study is divided into two papers, each handling two or three of the sub-questions. Table 2 contains the research questions, the methodology applied to answer this question, and in the final column the paper that the question is discussed.

Table 2 Overview of the research questions and the approach to answering them

Research Question	Method adopted	Described in paper
1. What are the different perspectives	Systematic literature review Synonym search	Paper 1
2. What are the differences between the perspectives	Systematic literature review Meta-synthesis	Paper 1
3. Defining Technological Confluence	Theory development	Paper 1
4. Types of Technological Confluence	Theory development Embedded multi-case study design Intersubjective experiment	Paper 2
5. Process of Technological Confluence	Same as RQ4	Paper 2

3.1. SUB-RQ1, -2, -3: Systematic literature review, meta-synthesis, theory development

The first research question asks for a systematic literature review with the primary objective of identifying the different perspectives on the combining of technologies. Earlier, four perspectives have been identified already, however, this list may be incomplete. A synonym search using the already identified terms will help in acquiring a more complete set of terms that could be used to describe similar phenomena. Then, every term (including the synonyms) will undergo the same method of acquiring literature via the search engines Scopus and Web of Science. In case too much unrelated literature is found, a term is excluded from further research.

The final set of terms will be analyzed in isolation, and then compared, which in essence comes down to a meta-analysis. Each publication will be read and data will be collected according to a prior defined set of variables. To not limit the data collection to these variables, an additional variable, "Remarks", will be added for interesting data that cannot be placed under one of the other variables. The findings from this comparison will give insight in the structural differences of the various perspectives, which, in turn, help us develop the boundaries and the definition of the overarching perspective of technological confluence via meta-synthesis.

3.2. SUB-RQ4, -5: Embedded multi-case study design

With the relatively broad umbrella term of technological confluence defined, it is time to break it down into smaller pieces again in research question four. A case study research of 10 to 20 cases will give additional information on what variables play an integral role in the combining of technologies. A case study design will be adopted where first each case is reviewed on a set of variables in isolation, to then perform a cross-case analysis (Cunningham, 1997; Yin, 1994, p. 41). In the next section a type of case study design will be selected.

Earlier, several phases in the development and diffusion of a technology have been recognized (innovation- and market adaptation phase). Even though the phases seem distinct (innovation phase ends where the market adaptation begins), the technology is continuously enhanced by the growth of understanding over time; in other words, knowledge and the application of knowledge (the technology) co-evolve. Products thereby improve over time, functions change, and the scope of products available often becomes wider. Acquiring knowledge does not end when the innovation phase is over, it is expected to be a continuing process of which its approach is prone to change over time. The fact that two variables on distinct levels have been identified (knowledge and technology) led to the decision to opt for an embedded multi-case study design, a design that allows the analysis of two distinct, but related, units of analysis (Yin, 1994, p. 41).

The cases that will be used to base our analysis on will mainly follow from the literature found during research questions one to three. For the other part they will come from the authors' knowledge of cases that are a combination of technologies. In the selection of the cases, attention will be paid to heterogeneity in terms of their industry. Heterogeneity follows from the exploratory nature of this study, a diverse set of cases from a variety of industries helps in finding the extremes so that the full range of situations that exist is represented better (Seawright & Gerring, 2008). From each industry, an attempt is made to include cases from different degrees of complexity in terms of functions because we expect this to influence the process of development and diffusion. For instance, the smartphone is considered a complex technology, and Skype a more simple. Both the process of development and diffusion and its duration are suspect to differ depending on these different degrees of complexity. Also, by considering cases from different industries, the population is not only represented better but also makes contrasting the cases more robust as industry specific characteristics are more easily spotted (Collier & Mahoney, 1996; Yin, 1994). Cases from the same industry may very well be more interwoven than expected, companies may for example adopt a similar process to product development, potentially influencing analyzed variables. This is all the more reason to validate the model and the cases via an experiment that will be discussed in the next subsection. Furthermore, the cases selected need to have reached at least the market stabilization phase (Ortt & Schoormans, 2004, p. 297). A technology needs to have passed the innovation and adaptation phase for it to be valuable to this study, if it has not, there is too little relevant data available.

Today, many technologies tend towards including a technology from the field of Information and Communication Technology (ICT). ICT is often found to be combined with the type of technologies under investigation. Since the 1990s, ICT has been reaching out to other technological areas and is growing into many technologies that used to be analog. For example, conventional electronics are replaced by programmable microcontrollers in many technologies, ranging from toothbrushes and microwaves to the ABS system in cars and the controlling of robot-arm movements. Thus, even though an in terms of industry heterogeneous set of cases will likely contain many technologies embedding technologies from the ICT sector.

3.3. SUB-RQ4, -5: Experiment

In order to validate the model that distinguishes the types of confluence developed in research question four, an experiment will be held where the model will be validated via a practitioner's ability to position the gathered cases without ambiguity. There are two types of experiments considered here: Q-methodology[1] and an intersubjective experiment[2].

With Q-methodology, the perspectives and opinions from multiple experts on a specific topic can be quantified and analyzed (Brown, 1980). Respondents are asked to express their views on multiple isolated statements, after which these statements are ranked or sorted on importance. This methodology is for example applied to learn the perspectives from different parties on biomass and other renewable energy sources (Cuppen, 2012; Webler, Danielson, & Tuler, 2009).

In an intersubjective experiment, a subject is confronted with a problem that ought to be solved, while a researcher observes the subject, and, in our case, looks for hard to position (potentially ambiguous) cases, and cases that are positioned differently among subjects in order to validate a model. After the experiment an interview follows. This method is based in Phenomenology, a school of thought that emphasizes a focus on people's subjective experiences and interpretations of the world (Waters, 2015). The phenomenologist wants to understand how the world appears to others.

In order to make a deliberate choice on the type of experiment that is performed for the validation of the model, the two experiments are weighed in Table 3. The factor that the models are evaluated upon can be found in the left column.

Table 3 Weighing the two experiment types for RQ2.

Factor	**Intersubjective experiment**	**Q-methodology**
General goal of method	Helps in verifying whether the dimensions found (from literature / case studies) are applicable to all cases and are clear to practitioners. Additional interview during the experiment can bring forward new dimensions.	Helps in finding what people think are the most important aspects of the topic, and therefore can hint towards the dimensions to be used in the model. Interview after experiment gives room for people to suggest other statements that could lead to new dimensions / factors / types. Makes quantitative analysis possible.
Preparation time	Takes only a short period of time to prepare for.	Takes about a month in preparation (estimation from two colleagues who used this method).
Preparation work	Requires literature review, and a set of cases.	Requires literature review, best to do pre-experiment interviews to inquire most relevant statements from practitioners on the topic.

After having weighed the experiments, an intersubjective experiment was selected. Q-methodology is great for, especially ethically sensitive, situations with many stakeholders to find someone's opinion and perspective on a certain topic. As with the earlier mentioned case of biomass or renewable sources. Even though Q-methodology will work in validating our model, it takes much more time in preparation compared to the intersubjective experiment. For both, the literature review is already performed during the prior research questions, however, the preparation time is much longer with Q-methodology because about 40 statements need to be developed on the basis of pre-experiment interviews with practitioners. This is estimated by two colleagues, who used this method, to take about a

[1] Q-methodology reading: (I) Brown, S. R. (1980). Political subjectivity: Applications of Q methodology in political science. (II) Cuppen, E. (2012). Diversity and constructive conflict in stakeholder dialogue: Considerations for design and methods. (III) Exel, J. Van. (2005). Q methodology: A sneak preview.

[2] Intersubjective experiment reading: (I) Waters, J. (2015) Phenomenological Research Guidelines (website: www.capilanou.ca/). (II) Giorgi, A. (1997). The Theory, Practice, and Evaluation of the Phenomenological Method as a Qualitative Research Procedure.

month. With an intersubjective experiment the confluence model can similarly be validated but with much less preparation time, ideal considering the time constraints for this research.

During the intersubjective experiment, the model that distinguishes the types of confluence is presented to a practitioner, together with a set of cards where each card contains the name of a case. The practitioner is then asked to position each case within the model and explain their decision in order to check for intuitiveness and ambiguity. Each practitioner will be interviewed and asked the following questions: (i) “What case did you find the hardest to position in the model and for what reason?”, (ii) “Do you think there is a factor not in the model that should be there?”, (iii) “Are there cases that you know of missing from the set?”.

This semi-structured interview type is chosen to allow room for deeper, follow-up questions resulting from the three main questions. Or for instance when a relatively extreme deviation in a practitioner’s decision to position a case somewhere is noticed.

4. Outline of the work

Figure 3 is a representation of what the research entails, and how it is divided into the research questions. This document is the overall introduction, which is followed by two papers about the research questions. In the end, an overall conclusion will be drawn, and a discussion will be held followed by a quality judgement and personal reflection of the work.

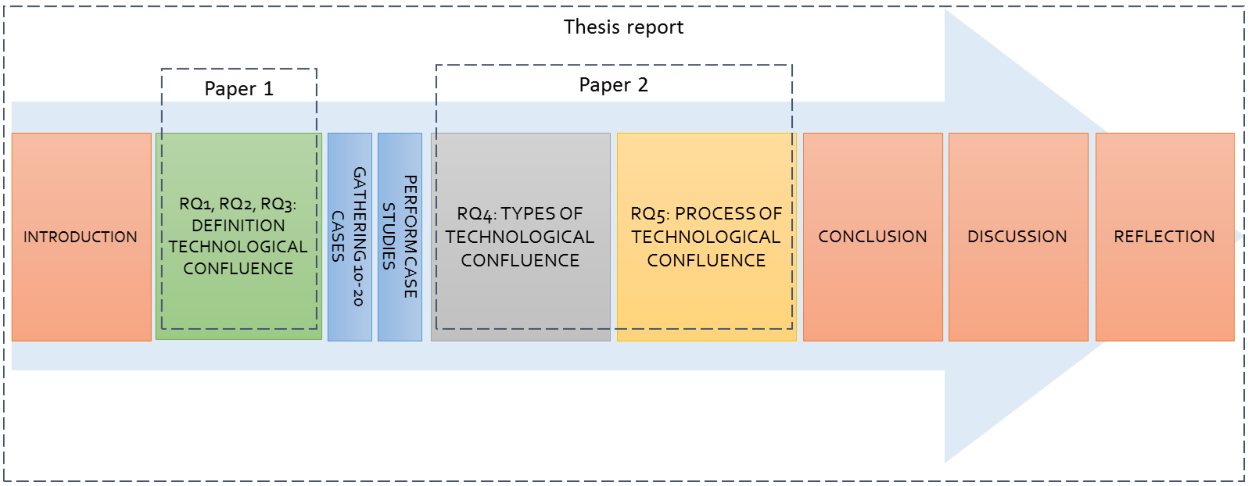

Figure 3 Thesis report and the inner divisioning of the research questions into papers

In the first paper, the first three research questions are answered. Starting with identifying all perspectives on the combining of technologies (RQ1) and then comparing these (RQ2). The paper is concluded with the definition of the overarching perspective of “technological confluence” (RQ3).

The second paper builds upon the definition of technological confluence, and will result in a model in which the different types of confluence can be distinguished (RQ4). In this same paper, the process of development and diffusion of each type of confluence is discussed in order to answer RQ5.

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Paper 1

"Technology Fusion, Technological Convergence, Technology Integration, and Cross-sectoral innovation: Solitary or Complementary?"

TU Delft

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Technology Fusion, Technological Convergence, Technology Integration, and Cross-sectoral innovation: Solitary or Complementary?

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Abstract

The combining of technologies as a means to innovation is an approach described from different perspectives. By acquiring literature systematically, four perspectives have been revealed: technology fusion, technological convergence, technology integration, and cross-sectoral innovation. Of each perspective in isolation we analyzed the context together with their definition of the combining of technologies, after which a meta-synthesis led to the conclusion that, over time, the boundaries of, once separate perspectives, have become blurry. Which according to our findings occurred because in literature, no systematic analysis on the combining of technologies has been performed as of yet. Because of this, we have developed a definition for an overarching perspective: technological confluence, in which the widest boundaries of the three perspectives are captured by placing the change in the essential technologies of a system central. This perspective will help future research in systematically identifying the various approaches to the combining of technologies for innovation, and verify whether the current perspectives are all-embracing.

Keywords: Technological confluence; Technology fusion; Technological convergence; Technology integration; Meta-synthesis; Systematic literature review

1. Introduction

Over the past 50 years, interest in the phenomenon of innovation via combining technologies has grown, and a multitude of perspectives were brought to existence. Among these perspectives are technological convergence, technology fusion, technology integration, and cross-sectoral innovation. Currently, however, it is unknown whether this list of perspectives is complete, and besides, it is unknown how these perspectives are different from each other. The perspectives have never been evaluated and compared to each other, and it is therefore also unknown whether all approaches to the combining of technologies have been identified. A systematic evaluation of the different perspectives is lacking in literature. It is likely that because the differences have, by our knowledge, never been identified, the context in which a term is used is possibly broadened, and definitions are perhaps more open to interpretation by researchers.

As follows from Figure 1, the amount of publications in each of these fields has grown in the 1990's. This can be because of an increased interest by researchers in these fields, or the digitalization in terms of literature being published online (the figure is after all based on data from an online database), or in terms of technologies that incorporate Information and Communication Technology (ICT). The field of ICT has since the 1990's reached out to other fields of technology and is currently embedded in many technologies. Software is playing an increasingly important role in technologies, if not for the user interaction, then in the smaller components such as programmable microprocessors to control for instance robotic hardware movements. The fact that ICT has been reaching out has

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possibly stimulated innovation by combining technologies; previously analog technologies are now (partly) controlled by software, such as wristwatches and washing machines.

In Figure 1 it is visible that research has had a peak in 2008 - 2009[1], after which a somewhat downward slope can be observed for "Convergence" and "Integration". "Fusion" and "Cross-sectoral" on the other hand appear to continue with a relatively steady amount of publications per year. These observations, including the downward slope, can be interpreted as researchers having found, and described, most of the context of each respective term, but continue to have interest in the fields. Because the contexts are likely to be described more complete, there is more reason for a systematic review to take place.

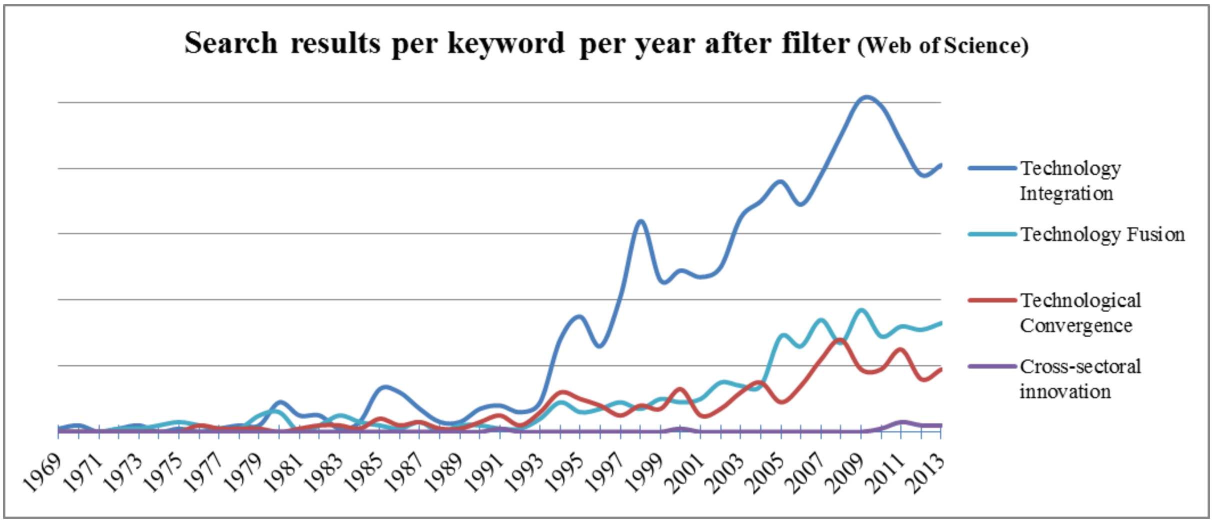

Figure 1 Search results per term per year in database Web of Science[1]

In this paper, the boundary of each term will be analyzed in isolation, after which the different perspectives are compared. Furthermore, because there are different perspectives, we wonder whether all variations have been identified, or if there is still a variation to the combining of technologies missing in literature. The goal of this paper is therefore to identify all currently used perspectives, to compare them, and develop an overarching perspective. The overarching perspective is required so that in a follow-up research, the different variations to the combining of technologies can again be systematically split in order to be able to structurally evaluate how complete the current list of perspectives is. We will refer to this overarching term as "technological confluence". Confluence has been chosen because a multitude of perspectives flow together, and are expected to reinforce each other, similar to rivers that come together. Besides that, the term is not linked to any other form of development nor innovation.

The process of evaluating the field of innovation via combining technologies is depicted in Figure 2. The circles on the left hand side are the currently used perspectives (e.g. convergence, fusion, etc.), then, the vertical line resembles the overarching term of technological confluence. After having defined this broad term, it will be split up again into variations of combining technologies. This paper is about the first half of Figure 2, and ends with defining the term technological confluence.

In the following chapter, the research methodology is explained in which a unit of analysis is chosen, and the method of acquiring literature is discussed and performed. Having gathered the literature, we will describe our meta-synthesis approach and the criteria by which literature is selected. Next, a chapter follows with an analysis of each term in isolation, from which the boundaries of each perspective will become more clear. In the discussion the

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[1] Data acquired in the final quarter of 2014 from Web of Science and filtered on Western countries (Europe, United States of America and Canada), and excluded Web of Science categories containing anything related to Nuclear science and radiology nuclear medicine medical imaging because of their overlapping vocabulary: e.g. nuclear *fusion*, and image *fusion*.

context of each term will be compared, and possible overlap and/or complementarity of the fields will be identified. Finally, the paper is concluded with the overarching perspective that we call "technological confluence".

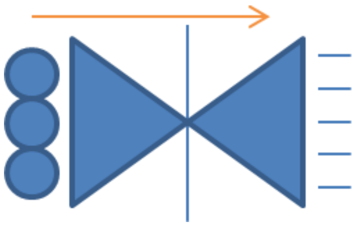

Figure 2 The process of evaluating the field of innovation via combining technologies.

2. Research methodology

In this chapter the unit of analysis is first described, after which we explain the process of identifying all relevant terms, and the acquiring of literature. Then, the acquired publications are read and assessed according to a set of criteria. One of these criteria is our unit of analysis, the other selection criteria will be elaborated upon in section 2.3. At the end of this chapter, a set of publications is retrieved for each identified perspective on which the literature review in chapter 3 is based.

2.1. Unit of analysis

In this study, we define our unit of analysis as a technology existing of three components: (i) technological principle, (ii) specific main functionality, (iii) set of essential technologies. The essential technologies are these "parts" or "components" of a technology that allow it to fulfill its function via its technological principle. When combining technologies, the set of essential technologies changes, often causing the technological principle, or its function to change as well. Because the combining of technologies has not been systematically analyzed, a systematic approach to defining the essential technologies is lacking. In the next subsection we will discuss our approach to identifying the essential technologies.

2.1.1. Essential technologies

We have attempted two approaches to defining essential technologies. The first is by looking at the technologies that, *when removed*, cause the system to lose its functionality. A DVD reader for example uses laser technology to read the content from a DVD, when removing this laser the reader loses its functionality. This approach works to a certain extent, but fails. For example when a technology relies on remote energy sources (batteries), such as mobile phones do. When removing the battery from a mobile phone the whole stops functioning, obviously. However, the battery is actually an *indirect part* of the system that the mobile phone uses to fulfill its function.

A second approach to defining the essential technologies is by looking at what technologies the technological principle requires to fulfill its main function. This, however, depends on the level of abstraction the principle is defined at. The technological principle is derived from the process that a technology embeds to carry out its main function. For a mobile phone, for example, the technological principle can be described as: a technology that establishes a wireless multiplex connection with the telephone network to allow voice-, and short text communication to be transmitted and received, the user can control the technology via a keypad, and the outcome of any form of input is shown on a display or turned into sound waves. From this technological principle we derive the following components: signal transceiver, input keypad, audio receiver, audio emitter, and a display. Using this method, the indirect components of the technology are left out, such as the battery, FM receiver, and photo camera. Often, indirect components are found to be features, and therefore not essential to fulfilling a technology's main function.

Because the combining of technologies is about "major" changes that a technology undergoes, an, as systematic as possible, distinction needs to be made between features and essential technologies. The second approach to defining essential technologies appears to do so best in our situation, and will be used during this research. To further elaborate this approach, another example will be discussed.

One of the currently most complex technologies to define is the smartphone due to the versatility of functions it fulfills. It can both be used as a "pocket computer" as well as a mobile phone, also it has such a variety of sensors inside that expand its functionality even more. A smartphone can be used to browse the internet, telecommunicate with other people via the telephone network, play videogames, view media, act as a navigation system in a car, capture photos or film, and much more. Some of the prior mentioned functions will often be categorized a feature, and not essential to the main functionality, such as most sensors. What is troublesome is that the main functionality of a smartphone is ambiguous, and heavily depends on the perspective through which the smartphone is looked at. Because we are interested in the combining of technologies, we have attempted to split the essential technologies of a smartphone into two aggregated groups: personal computer (PC) technology, and mobile phone technology. Figure 3 is a visualization of what we consider the essential technologies of a PC and mobile phone, which, in turn, are the essential technologies of the smartphone.

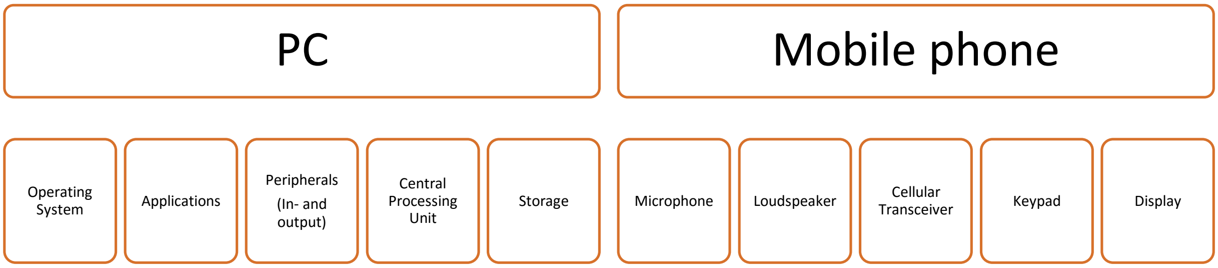

Figure 3 Decomposition of the essential technologies of a smartphone: a PC and a mobile phone.

The functions that today's smartphone can fulfill is not exactly the same as a PC, but nears that of a PC, while still being able to access the cellular network. A computer's basic function is to input data, store, process, and output data. A PC expands this with the functions an operating system (OS) fulfills such as: resource management, multitasking, and a user interface. In order to use these functions, the PC is dependent on a set of technologies being: the OS, central processing unit (CPU), storage, input and output peripherals, and software applications. For a large part, the hardware is controlled by software; called drivers. The OS "talks" to these drivers to employ the hardware for its user. Furthermore, the OS allows the user to adapt the system to a user's needs via software applications, thus allowing a user to manage the applications installed on the system, and therefore as well the amount of functions the PC can fulfill. When a user wants to play a game, he or she will have to install a game on the system after which it can fulfill this function. In a smartphone, the same technologies a PC has can be found, however, less elaborate versions. A smartphone offers for example less freedom in networking with other devices, and in file management. For this reason it *nears* a PC, but is not similar to one in terms of the functions it employs.

For complex products, key is recognizing groups of technologies that originate from a different technology, to then go one step deeper into each of these groups to recognize their essential technologies. In short, the rule for essential technologies is that all technologies that are required for a technology to exercise its basic functions according to its technological principle, are considered its essential technologies.

2.2. Acquiring literature

Before acquiring the literature with the already identified terms: convergence, fusion, integration, and cross-sector, we perform a synonym search with these terms to identify potentially overlooked terms that could just as well be relevant to our study. Synonyms are found using the websites: Thesaurus.com (Thesaurus, 2015) and Merriam-Webster (Merriam-Webster, 2015). The starting terms are shown in the left column of Table 1 where the right column represents the synonyms found that are most similar to the context of the combining of technologies.

Table 1 Results from the synonym search, the keywords found using the two thesaurus' are in the right column.

No.	Starting term	Synonyms selected
1	Fusion	Synthesis, Unification, Union, Integration,
2	Converg*	Combine, Confluence, Merge
3	Hybrid*	Combine, Union, Crossbreeding
4	Cross-sector*	No results
5	(No. 1, 3) → Union	Coupling, Merge, Interfuse, Linking

Row number five contains an additional starting term often found during the preceding searches: Union. This because it came forth multiple times (row numbers 1, 3) and it resulted in interesting additional synonyms. In total 15 keywords have been identified (see Table 1). These keywords are used in the following literature search engines: Web of Science and Scopus. In these search engines the search query is built as follows: "Technolog* AND [keyword]", except for "Cross-sector*" which is combined with "Innovation". Due to the vast amount of literature returned when searching in the title, abstract, and keywords, and even when excluding the abstract, we have chosen to limit the search to a keyword being found in the title. This still resulted in over 39,000 hits in the two search engines.

Table 2 Keywords in literature in relation to the context of combining technologies in database Web of Science, and in color the final keywords.

Keyword:	Fusion	Synthesis	Unification	Union	Merge	Integration	Converg*	Combine
Feedback:	Medium amount; Related	Medium amount; Unrelated results	Low amount; Unrelated results	Medium amount; Unrelated results	Medium amount; Few related results	High amount; Related	Medium amount; Very related	High amount; Few related results
Keyword:	**Confluence**	**Hybrid***	**Crossbreed**	**Cross-sector***	**Coupling**	**Interfuse**	**Linking**	
Feedback:	Low amount; Few related results	High amount; Few related results	Very low amount; Unrelated results	Medium amount; Related	Medium amount; Unrelated results	No results	Medium amount; Unrelated results	

The first database approached for the literature search is Web of Science. Results are filtered on research area so that topics such as nuclear power, chemicals and image fusion are excluded. These areas hamper the search to related results due to a similar use of words: nuclear fusion and image fusion results for example appear in great numbers with the query "technolog* AND fusion". A title is considered interesting when it contains a keyword in the query. From each of the interesting papers the abstract is read to get a glimpse of what the paper discusses, in search of matches with the topic of combining technologies.

In relation to the keywords found in Table 1, Table 2 presents feedback on the 15 keywords in terms of their relation to the combining of technologies. The feedback consists of two parts, and is split by a semicolon. The first part is an indication of the amount of results (very low: 1-49, low: 50-499, medium: 500-999, high: >=1000). The second part gives an indication of the relation of the results found, to the topic of research (e.g. few related results means there are results related to the topic, but in relation to the amount of papers found, the majority is unrelated).

One keyword was easily excluded as no results were found: interfuse. Others were found to have unrelated results: Synthesis, Unification, Union, Interfuse, Crossbreed and Linking. The next group of keywords: Merge, Combine, Confluence and Hybrid*, has many unrelated results due to the versatile meaning of the word, and therefore the context it is used in. In relation to the amount of results they are considered uninteresting. These keywords are not considered in further searches in Scopus.

The keen reader may have noticed "confluence" in the list of keywords, a term that returned unrelated results in Table 2, but is nonetheless chosen for the overarching term. This is done exactly because it is free of any context related to innovation or development, and, in addition, the word nicely represents the fluent nature of the combining of technologies.

Having performed this first search, a second search within Web of Science is performed using the remaining keywords – this time filtering on country/area of the publication where only European countries, United States and Canada are included.

In Scopus, the same search queries and methods are used as in Web of Science. In the end, a total of 51 papers are found. An overview of the results per step is given in Figure 4. In Figure 4, we started in the top with 15 keywords, which resulted in an initial amount of 39,782 hits in Web of Science and Scopus. By applying filters on, among others, research area and number of citations, and by excluding the unrelated titles and abstracts, the vast amount was eventually reduced to only 51 publications.

In the end, all papers are placed under one of the four headers, being: fusion, integration, convergence and cross-sectoral (colored items in Table 2). Even though we ended with the terms we identified at first, we can now at least state these are indeed all current perspectives on the combining of technologies. With these four perspectives the research continues to the selection criteria and data collection, which are further described in the following subsection.

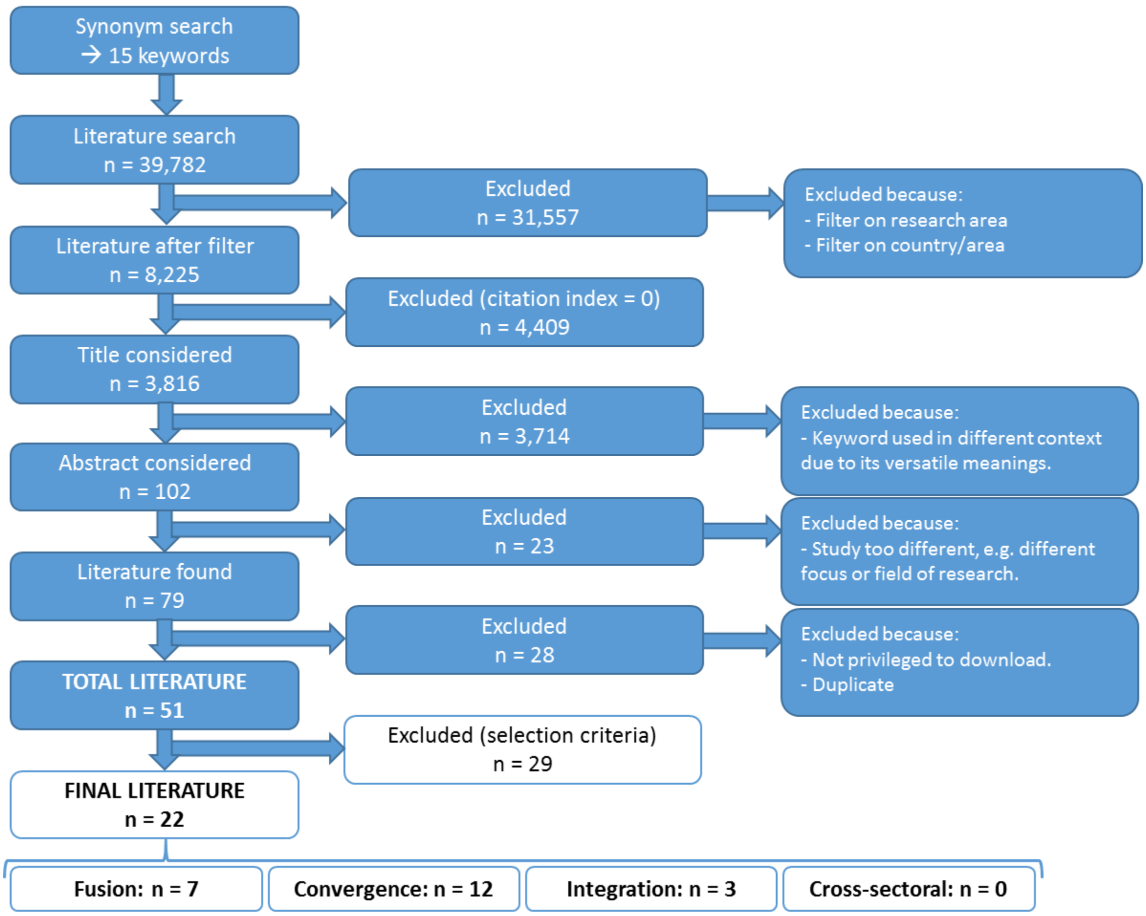

Figure 4 Overview of the results using the search methodology

2.3. Acquiring data and criteria for selection

Now that we have established a literature list of 51 publications, the process of reviewing the papers using selection criteria is presented in this subsection. During the initial read of the article, specific data will be collected. Table 3 contains an overview of the data that will be collected per publication. The first column categorizes the variables in the middle column. In relation to our research question, most relevant are the variables in the terminology category. In this category, the definition of the term that a publication uses is gathered. Besides that, "scope" refers to the level of aggregation on which the combining of technologies takes place (see Figure 5). For example, technologies may be combined resulting in a new, complementary technology as happened with combining mobile phone technology with satellite transceiver technology resulting in the satellite telephone. Furthermore, antecedents will be looked for, along with possibly similar phenomena discussed in a publication. The final category in the table, "Remarks", is a place for relevant data that does not find its place in any other group.

In the most right column the selection criteria can be found. A paper that does not comply to these criteria is excluded from the research. The result of applying these selection criteria is shown at the bottom of Figure 4. The selection criteria (right column of Table 3) led to a reduction of 51 publications to 22 (see Figure 4).

Most of these are excluded due to a mismatch with the unit of analysis or because they did not revolve around one of the four terms. For example, three papers discussed process approaches where one of the four terms was mentioned as being part of, but not further elaborated upon its role. Besides, no technology consisting of a combination of technologies was put central, instead, process approaches were. For such reasons publications are excluded from this study. Besides this, the focus of the entire field of cross-sectoral innovation appeared to lie in the collaboration of firms, whereas for this research, a technology based unit of analysis is chosen. For this reason, the field of cross-sectoral innovation is scrapped from further analysis, leaving us with three terms.

Furthermore, the study is limited to cases from the western world (i.e. USA, Canada, Europe). It is chosen to do so for both a better accessibility of data in terms of literature, the possible need for interviews, and better generalization of the study due to larger cultural differences with other parts of the world. This, however, as well led to a reduction of the literature found. And lastly, few studies fell outside of our time span.

An overview of the amount of papers found per term on which the literature review is performed is given in the bottom of Figure 4. In some cases, additional literature is acquired due to interesting concepts inside a paper, which are not elaborated upon enough in the paper itself. Therefore, the bibliography contains more references.

Table 3 Data collection per publication and selection criteria

Data collection groups	**Group variables**	**Range for selection**
Context	1) Timeframe (t)	1) 1950 < t <= 2014
	2) Geography	2) Western world (USA, Canada, Europe)
	3) Industry	3) N/A
	4) Product	4) Matches description of unit of analysis
	5) Type of technology	5) N/A
	6) Essential technologies	6) N/A
Terminology	1) Term	1) Paper revolves around one of three terms
	2) Definition used	2) N/A
	3) How it is measured	3) N/A
Methodology	1) Aim of study	1) N/A
	2) Type of paper	2) N/A
	3) Data collection method	3) N/A
Antecedent(s)	N/A	N/A
Scope	N/A	N/A
Similar phenomena	N/A	N/A
Remarks	N/A	N/A

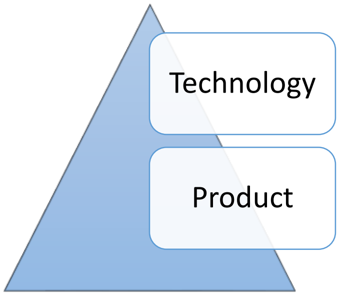

Figure 5 Levels of aggregation where combinations can take place

3. Literature review

This chapter serves as a descriptive analysis of the context of each of the three terms in isolation, starting with technology fusion, then technological convergence, and ending with technology integration. In chapter 4 the three terms are compared and contrasted.

3.1. Technology Fusion

Within the group of researchers using the term technology fusion, the interpretation of the word appeared quite univocal. Six out of seven papers refer to the publications of Kodama (1986; 1992), who is found to be the father of technology fusion. Kodama argues: *"the difference between success and failure does not depend on how much a company spends on research and development (R&D), but how it defines it"* (Kodama, 1992, p. 70). A company can either go for a "breakthrough" approach by investing in R&D to replace an older generation of technology, or invest in the "technology fusion" approach by combining existing technologies. A breakthrough approach is considered a linear strategy of technology substitution such as the DVD replacing the VHS tape and MP3 players replacing portable CD players. Technology fusion, on the contrary, is non-linear, complementary and cooperative. Technology fusion blends incremental technical improvements from previously separate fields of technology to create new products. An example from Kodama (1992, p. 75) is the NC (Numerical Control) machinery which is a complementary product resulting from a blend of electronic and mechanic technology. Later on, by the addition of computer technology, the CNC (Computer Numerical Control) machinery was born. Kodama (1992, p. 71) emphasizes the combining of technologies whether it be inter- or intra-industry, because it focuses on different technological fields instead of industries. It occurs, however, that his definition is narrowed down by some authors to inter-industry, such as in the publication of Lei (1997). Protogerou et al. is another such example that looks further into collaborative research networks in three ICT areas: mobile commerce, telecommunication, and multimedia applications to elaborate on the complexity of dynamically interrelated processes or elements of such networks, which means a focus on actors (Protogerou, Caloghirou, & Siokas, 2013). Ko et al. analyze the knowledge flow across industrial sectors by performing a patent analysis, but also look at the intra-industry aspect. Patents are linked to an industrial sector to group them and citations (patent cites other patents, and patent is being cited) are analyzed. By doing so a knowledge map is created and a diversity of variations of patent knowledge flows is recognized: external and internal absorption, and external and internal diffusion. External knowledge flow takes place between different sectors and internal within sectors (Ko, Yoon, & Seo, 2014), this however, implies a focus on industry instead of technological fields. Another patent analysis leaves out all industry or sector links, and considers the knowledge flow of the patent itself via its citations. A variety of types are recognized here as well: very heterogeneous-like fusion, slightly heterogeneous-like fusion, diverging fusion, absorbing-only fusion, and radiating-only fusion (No & Park, 2010). These depend on the inflow (patent cites patents) and outflow (patent being cited) a patent has. Heterogeneous indicates an (approximately) equal in- and outflow, diverging more outflow than inflow, and the other two are the extremes.

With Kodama, a clear distinction is made between a "breakthrough" and technology fusion approach. Rao, Angelov & Nov add that technology fusion entails the combining (and creation) of disruptive technologies.

According to them, an example of this is the case of Skype, where the two disruptive technologies VoIP (Voice over Internet Protocol) and P2P (Peer-to-Peer) are combined (Rao, Angelov, & Nov, 2006). In their consideration the Skype case matches Kodama's essentials for technology fusion: demand articulation, knowledge gathering competences, and a strategic alliance. As the fusing of technologies from different fields of technology is broader than linear innovation, a certain mind-set is required. Kodama (1992) therefore identified three essential principles to technology fusion, which is later expanded by a fourth.

First off, a company's R&D department should be in close contact with the customers, their values should be an R&D project's starting point, resulting in market-driven R&D. This market-driven approach starts with demand articulation. In short, demand articulation is the translating of market data into a conceptual product, after which this concept is decomposed into development projects.

Second, companies need knowledge gathering competences in order to trace usable technology developments inside and outside their own field of technology. This is also referred to as the scanning for currently invisible assets and enemies (Lei, 1997, p. 21). A proper scanning goes further than formal efforts, such as monitoring patent applications around the world. Informal methods that, according to Lei (1997, p. 21), work better include: talking with a potential competitor's customers, prompting conversations about technological developments with technical staff or managers from a related or distant sector, and spotting new market trends through brainstorming sessions that seek to produce a high level of "creative tension". These methods however often tend to be highly tacit (Lei, 1997, p. 22).

Lastly, strategic alliances with a variety of companies across different fields of technology are a necessity. Their relationship should be both reciprocal and substantial. Which is about mutual responsibilities, -respect, and -benefits, and about commitment by the management of a company to a R&D project from exploratory research to advanced product development respectively. Substantiality between the partners is important as the risk of joining an R&D venture is often high, thus management of a company must accept that it cannot evaluate each research investment on a short-term financial basis.

An addition to this list is the architecture of a system (Kodama, 2014). In Kodama (2014), it is discussed that a system should have an "open" architecture, before it can fuse with another system. Earlier the example of the NC to CNC machinery was mentioned, which was only possible when both the NC system and the Personal Computer (PC) system reached a modular architectural structure. This architecture resembles the way that a system is build and communicates with its core parts. The PC had reached an open architecture, meaning it is modularized and open for communication with other systems. For a long time this has not been the case for NC machinery, which allowed only internal communication leaving it a closed architecture. It took up to the point where evolution of the NC machinery modularized the system into three functions (display, control, drive), when it reached an open architecture, allowing the birth of CNC machinery (Kodama, 2014, p. 508).

In summary, the most interesting observation in the field of technology fusion is the wider perspective. Originally technology fusion discussed the combining of technologies from different technological fields. Currently, however, the term is also used in describing combinations of technologies that simply were not related to each other before, thereby widening the perspective of technology fusion.

3.2. Technological Convergence

The majority of literature agrees on technological convergence being about the process of combining two or more technologies from different industries. It is therefore also referred to as *interdisciplinary co-evolution*, we will elaborate on this in this subsection.

The first to notice the phenomenon of convergence is Rosenberg (1963). Rosenberg observed that previously unrelated industries became closely related on a technological basis due to having a similar issue with their metal-cutting machinery. Harianto and Pennings (1994) and Gambardella and Torrisi (1998) find themselves agreeing to this definition. Most articles, however, have their additions to this definition such as Schnaars, Thomas and Irmak (2008), who state that often an entirely new product or entirely new industry results from the process of convergence. Schnaars et al. define new products using the definition from Urban, Weinberg and Hauser (1996) as revolutionary products that shift market structures, require consumer learning and induce behavior changes such as the case with Electric Vehicles or Personal Computers. This is interpreted as the possibility of the process of convergence resulting in a radical or breakthrough innovation in a new application domain. Lei (2000, p. 709), on the other hand, states that when a firm develops a new generation of a product (substitution), the new technology often leans on breakthrough innovations from other industries. Such as the transistor radio substituting the vacuum tube radio. Both types of radio share the same attributes, functionality and even technological principle but the transistor radio is perceived as providing a higher level of performance/price. Different industries thus can stimulate each other's development. In this case, convergence *uses* a breakthrough technology, but does not *result* in one, as Schaars et al. (2008) describes.

Drivers for convergence are deregulation, innovation in complementary products, and integrative technological platforms (Lei, 2000, p. 702). During the 1990s, deregulation took place in the United States and Europe in, among others: telecommunication, cable television, electric utilities and financial services (Lei, 2000, p. 703). This meant that more room was given for newcomers to introduce their, often alternative, technology and be able to compete with an incumbent. Due to the rising competition, technological development was pushed because every company wanted to get and preserve a competitive advantage.

The second driver is innovation in complementary products (Lei, 2000, p. 705), which is about reaching economies of scale and cost efficiencies through product bundling strategies. In particular so for highly complementary products, such as these within a computer operating system (OS). In the current OS, software such as internet browsers, virus detection and word processing is embedded in the system, while previously it was only available separately. This drives convergence because improvements in the attributes of one product stimulates firms of complementary products to further improve, innovate, and integrate. This is similarly the case with the hardware and software industry. New hardware capabilities allow video game designers to create more complex games with a greater visual experience, and vice-versa, when the software developers desire a certain complexity that the hardware industry is not yet capable of.

The last imperative to convergence is the constant innovation of new integrative technological platforms that enable previously discrete functions or features to link up into a single system (Lei, 2000, p. 707). An example of such a platform technology is the semiconductor, that is incorporated in many products. Due to continuous innovation in the semiconductor, it now also embeds a graphics chip since the year 2000. For many products this means that no longer a separate graphics chip is required, influencing for instance the size of the product, and its power usage. Another example is bandwidth-expansion technology, which enabled more data to be send over the same line (e.g. one line for TV, plus telephone, and internet).

Lei (2000, p. 702) adds that convergence only occurs when technological advances or innovations commercialized in one industry begin to significantly influence other industries. Thus, stating that before two technologies can converge, both have to be commercialized in their respective industry. Furthermore, Lei clarifies that convergence *"serves as a catalyst for technological and competitive changes in neighboring industries"* (Lei, 2000, p. 702), after which the different industries begin to share technical and market-based characteristics. This is also referred to as the process of mergers and alliances to position themselves in the framework of ICT convergence as described in the article of Borés, Saurina & Torres (2003).

Spohrer and Engelbart (2004), Roco and Bainbridge (2002), Grunwald (2007) and Loveridge, Dewick and Randles (2008) discuss convergence in the field of nanotechnology to enhance human performance, these publications share the same thought which can be described as technological progress characterized by co-evolution resulting in new or improved nanotechnology and nano-artefacts by combining the knowledge from different disciplines.

Up to now, we found inter-industry convergence the typical way to go, however, intra-industry should not be forgotten. A first example of this can be found in the paper of Vrdoljak, Vrdoljak and Skugor (2000), who find themselves in the telecom industry where convergence takes place between the fixed telephony and mobile telephony. A second example can be found in the publication of Lei (2000, p. 705). In the software industry, today's operating system, such as Windows, embeds a variety of once separate applications, such as: word processing, virus detection, spreadsheets, internet browsers, cloud computing, and media players. Also, intra-industry convergence appears to stimulate inter-industry convergence. The advances within the software industry stimulate the hardware industry to innovate faster. Video game developers for instance wish to create ever more complex and visually strong games, which puts pressure on hardware innovation. And vice-versa where new hardware innovations incentivize the developers to enhance new games, or even develop a game optimized for a certain graphics card. This phenomenon is similar to the concept of co-specialization by Teece, because of an innovation's dependency on certain complementary assets, in the previous example being the dependency of the hardware on the software industry and vice-versa, which complement each other from each respective point of view (Teece, 1986).

Technological convergence requires firms to continuously scan their own and neighboring industries' environments, both for new opportunities that are possible due to new technological advances in an industry, and new competitors, that are entering a firm's domain due to convergence in their direction. When new opportunities arise firms need to act quick and either acquire the firm owning the technology, or engage in a strategic alliance; thus consider to integrate or contract (Teece, 1986).

An interesting paper is that of Gill and Lei (2009), who elaborate on the technology selection part whereas the other literature focuses on the business and knowledge side of convergence. Gill and Lei describe a way to select technologies that enrich a product by added functionality for products within the computers, communications, and consumer electronics industries. They found that an added functionality with a different goal compared to the base functionality enriches the base product, for example the adding of a camera and an MP3 player to a mobile phone. The camera and MP3 player enable a consumer to be entertained, where a mobile phone enables communication, which even though it is a secondary functionality (a feature), it can make a difference in the consumers' perceived price/performance ratio.

In conclusion, the context that convergence is used in has broadened. Currently, not only combinations of technologies from different industries are made, but also within industries. Furthermore, not only technology is pulled towards an industry where the combination of technologies is launched within the same context, but the process of convergence can also result in new (sometimes revolutionary) products and new industries.

3.3. Technology Integration

Different phenomena are used within the literature of technology integration: External Technology Integration (ETI) and Complementary Product Integration (CPI).

ETI is a codification for "*the process of acquiring technology from an external source, and incorporating it into a new product or operational process under development"* (Stock & Tatikonda, 2004, p. 642). Iansiti (1995) uses the term technology integration and defines it, similar to Stock and Tatikonda, as: *"Fusion of new and existing knowledge; new technical concepts must be carefully selected and adapted to match the complex requirements of an organizations' existing environment"* Iansiti (1995, p. 521). Both are related to knowledge accumulating within a firm to get acquainted with a new technology before a new product should be developed. Iansiti refers to this as the set of knowledge-building activities. Iansiti discusses a roadmap that guides design and development activities that are most important to find the right match between a firm's skills and competences, and a new technology which the firm wishes to integrate (Iansiti, 1995, p. 522). A firm thus requires the technology integration process to account for an effective fusion of knowledge.

The efforts required for technology integration are dependent on the type of technology a firm wishes to get acquainted with, and thus how much interaction is required with the external source (Stock & Tatikonda, 2004, p. 643). An upgrade of a warehouse inventory system might be successful with very little interaction with the supplier of the system, whereas the installation of an entire ERP (Enterprise Resource Planning) system probably requires a higher level of interaction with the software vendor. However, only if the firm integrating the new technology has little experience with this type of technology. Examples from the software industry are the integration of: ERP systems, Computer-Aided Earthmoving system, desktop office software, single sign-on environment software and internet portal software.

CPI entails the development of a new product that integrates well with relevant complementary products (Nambisan, 2002, p. 382). CPI lays emphasis on the importance of a firm's product to cooperate with complementary products so that the aggregate customer experience is enhanced. The example given by Nambisan (2002, p. 389) takes place in the software industry and is about software development tools. A variety of tools can be identified that are required for software product development: visual programming tools, interface design tools, multimedia authoring tools, networking tools, security tools, project management tools, code generation tools, and more. From the perspective of the software developer, these tools complement each other as they support various phases of software development. Significant emphasis is placed on cross-product integration by these developers, as it is critical for the efficiency and effectiveness of the development of their products. A new software development tool therefore is required to work together with the relevant other tools already in the field.

To summarize, the field of technology integration describes two strategies: (i) for the implementation of a product within an existing environment, such as an ERP system, and (ii) the developing of a product that fits within an existing environment, such as a software development tool.

4. Discussion

Up to now, the environment of each term has been described in isolation. The focus of the discussion lies in the contrasting and comparing of the terms in search for each of their demarcation, which, in the end, leads to the development of a definition of technological confluence. An overview of all literature used, their respective term and definition used, and the cases or examples described, can be found in Appendix A.

4.1. Scoping the terms

The scopes of the three terms are defined by the type of combinations made at the levels of aggregation. Which are defined from high level of aggregation to low respectively as: technology, product (see Figure 5). Figure 6 is a visual representation of the scope of each term.

Technology fusion is positioned at the utter end of *technology*; all the literature mentions the combining of technologies. Differences only lie in the type of technologies that are combined: breakthrough, new or existing.

The first notice of convergence was in 1963 by Rosenberg, who explained that "*convergence exists throughout the machinery and metal-using sectors of an industrial economy*" (Rosenberg, 1963, p. 423), which became apparent as, from the point of view of the nature and uses of the final product, unrelated industries became closely related on a technological basis in order to tackle a common technical issue with their metal-cutting machinery. As new technological progress was the result, the initial definition of convergence is in pure *technology*. Nowadays, convergence is used more versatile in the literature which creates diverse scopes in both *product* and *technology*. The one time, a more *product* like example is used such as the adoption of Videotex into the banking sector (Harianto & Pennings, 1994, p. 294). Where other papers discuss the coming together of NBIC technologies or NBCST (scope: *technology*) (Grunwald, 2007) (Loveridge, Dewick, & Randles, 2008) (Roco & Bainbridge, 2002) (Spohrer & Engelbart, 2004). 75% of the literature was found to discuss a technology.

Technology integration is defined, in short, as the combining of knowledge to develop new products or processes. The examples however betray a more "product implementation" look, such as the embedding of an ERP system in a company. In many examples, an existing product is embedded in an environment in which the knowledge on the product is low, hence external expertise is required (Stock & Tatikonda, 2004) (Iansiti, 1995). The term is also used in situations where a new product is developed to fit in an existing environment by making it compatible with other technologies (Nambisan, 2002). Because of this, integration is placed more towards a *product* scope than *technology* (67% of the literature placed the product central).

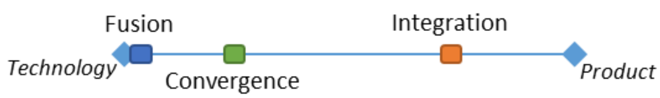

Figure 6 Each of the terms relative to the level of aggregation it belongs to.

4.2. Contrasting and comparing the terms

Similarities are found between the papers on technology fusion and convergence, with the biggest being their shared principle of interdisciplinary co-evolution. Both state that new products are the result of the co-evolution of two previously unrelated sectors (i.e. technological fields in fusion literature and industries in convergence) by which existing technologies are combined, sometimes with new or breakthrough technologies. For both, a previously unrelated technology (or a multitude) was combined with another technology from which a product followed in which this new technology is an essential technology. With Skype, Peer-to-Peer became essential to the functioning of voice calling over the internet, similarly, flash storage and the CCD chip did so for the digital camera, and the electric motor for the hybrid vehicle. However, in fusion literature this is the *addition* of a technology, where in convergence literature it is considered both the *adding and replacing* of a technology. Skype, a fusion case, shows the clear addition of a technology. Convergence also discusses substitution induced by breakthrough technologies from other industries, such as the transistor replacing the vacuum tube in several technologies from other industries.

The industry aspect from convergence has however sneaked in fusion literature. An example is that of Lei (1997), which only discusses inter-industry fusion. Other publications do not, and either also look into the intra-industry aspect, or solely consider technological fields. Interestingly, in the year 2000 Lei publicizes a very similar paper but instead focuses on the term technological convergence while sharing 30% of its total references in the new paper with its 1997 paper about technology fusion (Lei, 2000).

In Appendix B a cross-reference network map can be found showing the interrelatedness of the different fields of research. The map is created by manually going through the references of one paper and searching through the others one by one, and iterating this for each publication. When two papers refer to the same publication it counts as one cross-reference.

Looking in terms of papers sharing references, we find that every fusion paper shares at least one reference with convergence and integration papers. For convergence literature this is 75% with fusion (9 out of 12 papers) and 25% with integration. And lastly, each integration paper has at least one reference in common with fusion literature, and two out of three papers with convergence. Table 4 shows the amount of cross-references among the different fields of research. As can be seen in the table, there is a deviation in for instance fusion – convergence and convergence – fusion which, admittedly, is due to the author having overseen some linkages which became apparent after having gone through all publications. Yet, it gives a sufficient level of insight in the knowledge shared by all three fields for this study. From Table 4 it appears that the literature from the field of fusion shares 14% of its references with other fusion literature, a surprising 21% with convergence, and 12% with integration (remaining percentage of references are “unique”). This indicates that the fusion literature in our dataset is for one fifth made up of literature shared with the field of convergence. Similarly, from the perspective of convergence, the biggest share in the row in Table 4 is made up of references shared with the field of fusion (12% versus 7% and 4%). This again indicates that the fields of fusion and convergence are moving closer to each other, while originally being different phenomena.

Table 4 Cross-references overview categorized by field of research

Cross-references	Fusion	Convergence	Integration
Fusion	14%	21%	12%
Convergence	12%	7%	4%
Integration	11%	6%	10%

Even though the literature currently appears to share quite some ideas (references), there are still differences to be found. The basis of Rosenberg (1963) was that different industries, from the perspective of their final product, start to cooperate to solve a common issue with metal-cutting machinery. In many examples from Lei (2000) about convergence we find co-evolution, but not in the way that common issues are being solved. Different industries stimulate and push forth each other as they are dependent on each other, such as the hardware and software industry pushing each other’s development. Furthermore, Lei (2000, p. 699) implies it is convergence when an industry is significantly influenced by a commercialization in another industry. Implying that firms wait for changes in their environment, to then adapt. This in contrast to fusion literature, where companies develop competences to keep track of their environment, both visible (tight links) and invisible (weak or no links), which turns them into active players (Kodama, 1992).

Figure 7 contains a representation of the different approaches to innovation that are used by fusion, convergence, and integration. The two vertical lines under fusion represent different technological fields, for convergence these lines represent industries, and for integration these are products. The arrows represent the flow of technology which, when combined, result in a new product.

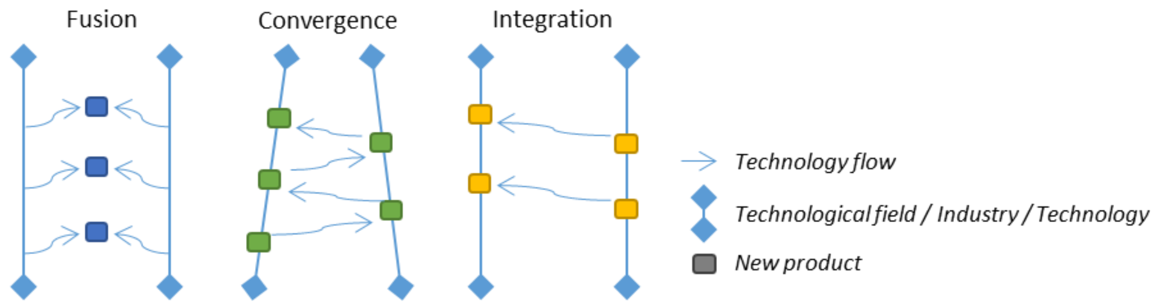

Figure 7 Innovation in the fields of fusion and convergence; differences in technology flow and the residing of the resulting product.

Technology fusion literature emphasizes fusion products are complementary to the products that reside in each of the technological fields. A product is the result of the cooperation of firms in a strategic alliance, where this alliance cooperates with a certain goal in mind; it is there for the purpose of developing a technology.

Regarding convergence, industries influence one another. Improvements in one industry influence the development in another, which is shown on the middle part of Figure 7. Co-evolution often comes with dependencies between industries, where an industry pushes forth, or stimulates, the innovation of another by which the both grow closer as with for example the electronics and mechanical industry, and hardware and software industry. This is indicated in the figure by the sloped vertical lines.

For integration, products are often found to be embedded in an existing environment (e.g. ERP system in a firm), or be developed to fit in an environment (e.g. software developer tool compatible to other tools). Even though one industry may become dependent on this technology, it does not mean the two co-evolve. With integration, the technology flow appears to be directional instead of bidirectional as with the other two.

In all perspectives knowledge is put forward as an important piece. For fusion and convergence this is however different than integration, first the former two are discussed. In high-tech environments, rapid technological change is likely to be present. In these contexts, with complex technologies, it is unlikely that one firm can keep pace with all technologies and stay competitive; hence it chooses a narrowed expertise. Take for instance the lenses, laser, precision motors and manufacturing from a lithography machine, at ASML there is one firm per component[2]. Due to the complexity of the machine itself it is impossible for one firm to technologically advance all components and keep up with its competitors. Alliances and acquisitions are common because of this; each partner continuously improves its expertise and uses it to contribute in the alliance. Who to start an alliance with is dependent on the direction a company wishes to pursue, this can follow from demand articulation. In the construction industry in Japan for example, a higher efficiency was desired. In order to accomplish this, a company implemented a GPS and communication system in construction machinery (e.g. bulldozers), in order to track the machines at the workplace to allow for an improved efficiency (due to theft prevention and better work alignment) (Kodama, 2014). How well a firm is able to scan its environment for alliances or invisible assets or enemies, depends on its knowledge gathering competence.

Technology integration is different from technology fusion and convergence in the sense that it is mainly about acquiring new knowledge to use a product or technology within a specific environment such as a firm (learning to use and maintain CAD software). This knowledge comes from an expert who aids the firm in developing the required skills, a directional relationship compared to bidirectional with convergence and fusion.

Technology integration also discusses the creating of a product that fits in some existing environment, where the existing environment exists of separate products that, in aggregate, work together to enhance the customer's experience. This is similar to the concept of intra-industry convergence. However, from the examples it followed that the actor differs. Where the initial actors ensuring proper collaboration of the separate parts is the developer of this separate part (bottom-up); with intra-industry convergence it is the other way around, the one responsible for the "environment" or "aggregate of complementing products" is responsible for the collaboration of the parts (top-

[2] Major suppliers: Agilent, Carl Zeiss, Cymer, and Philips. Data from ASML Corporate Fact Sheet: http://www.asml.com/

down). Examples are software development tools which need to complement other tools, and Microsoft who gathers and integrates the software from different developers into their Windows platform, respectively.

All in all, there are still some fundamental differences between fusion, convergence, and integration, but as shown in this paper, a thorough literature analysis of each field is required in order to discover them. Table 5 contains a brief overview of the differences among the three perspectives, as discussed in this chapter, and found in chapter 3, the literature review. The scopes of the fields are widening resulting in a growing overlap. From each perspective it is shown what type of combinations are originally discussed, versus what is currently discussed. Current convergence literature is found to currently have broadened its view by both allowing components to be added and replaced, and by adding intra-industry convergence. Technology fusion is broadened by letting loose the requirement of a technology being from a different technological field by discussing combinations of previously unrelated technologies. The field of technology integration is the youngest of the three, and does not appear to have changed over time. In addition, the perspective through which each perspective approaches is given. Convergence looks at industries, where fusion and integration at firms. This way, all perspectives are connected to each other in their own way.

The combining of technologies is used for both adding technologies to an existing base, as well as replacing technology in this existing base. It is also used in the sense that industries stimulate each other, and it is both intra- and inter-industry, also it is about combining technologies that revolutionize markets. Fields are growing towards each other causing boundaries to fade, indicating it is time to combine this knowledge and develop one model that captures these multiple perspectives in a systematic way.

Table 5 Differences among the three perspectives

	Technological convergence	**Technology Fusion**	**Technology Integration**
Main concept	Co-evolution of industries that stimulate and influence each other. Inter- and intra-industry.	Reciprocal strategic alliances to develop new complementary technologies by combining.	Embedding products in an existing environment.
Unit of analysis	Technology	Technology	Product, partly technology
Perspective	Industry	Firm	Firm
Combinations of (original)	Replacing a component in your technology with this from a different industry	Adding technology from different technological fields	Develop a technology for a certain environment. Implement a product within a certain environment.
Combinations of (current)	*Adding* or replacing a component in your technology with this from a different *or the same* industry	Adding *previously unrelated* technology	Has not changed.
Drivers	Deregulation, innovation in complementary products, integrative technological platforms	Open architecture technologies	From a company's perspective, external products
Strategies	Strategic alliances, co-specialization, focus on core competences	Reciprocal and substantial strategic alliances, knowledge gathering competences, market-driven R&D	External technology integration, complementary product integration
Resulting application domain	Mostly same	Mostly new	Same
Knowledge flow	Bidirectional	Bidirectional	Directional

4.3. Defining Technological confluence

In this subsection our definition of the overarching term is described. We start with the unit of analysis after which we define what we believe should be the focal point of technological confluence, and explain its characteristics.

First the unit of analysis. Knowledge is without question the highest level of aggregation, and also considered crucial in all perspectives, however, it is not the focal point of the different perspectives on the combining of technologies. The focal point is the developing of a new technology by combining technologies, in which knowledge acquiring plays an integral role. With a particular focus on changes occurring in the essential technologies of a system, which is at the core of confluence.

For the definition of a technology we stick to the unit of analysis chosen in this study, and described in chapter 2.1. In short, a technology is defined as a set of components that fulfills a specific function, and follows a certain technological principle. The components are a technology's essential technologies, and allow a technology to execute its technological principle. In defining these essential technologies we adopt our approach from section 2.1.1.

When technologies are combined, the composition of the essential technologies changes; technologies are either added (fusion and convergence), or replaced (convergence). These technologies are previously unrelated technologies from different domains, may that be intra-, or inter-industry, same or different field of science. The new composition often goes hand-in-hand with a different technological principle, because the core set of components changed (e.g. hybrid vehicle versus internal combustion engine vehicle[3]). But can sometimes be the same as with for example the vacuum tube radio versus the transistor radio[4]. The new combination is then launched in a new, or the same application domain as its former (parent) technology. In short, technological confluence is defined as:

Innovation by changing the set of essential technologies of a system, where previously unrelated technology replaces an essential technology in the system, or a technology is added to this system.

4.4. Limitations

This research is limited to the literature found via the described process of acquiring it, which is subject to the filters applied and interpretation of the author(s) of the publications. Literature can be excluded by unclear or misinterpreted titles of publications, or be excluded because of filtering on for instance the region. Literature may for instance be on the topic of a Western country, while being published in a non-Western country, causing the publication to be wrongfully excluded. Similarly so with other filters applied. A systematic literature review would, however, not have been possible with the initial ±39,700 pieces found due to time constraints, and filtering has been a necessity in bringing down this myriad of publications. In an attempt to mitigate this limitation, interesting publications that literature from our dataset of 22 papers referred to, were added to the literature review. This way, overlooked but, what other studies considered, relevant literature pieces are added as well.

Besides the filtering in the search engines, the final 51 publications are read, and the data gathered, after which the data was contrasted to our selection criteria. In some cases, however, the selection criteria are ignored. Some publications from outside Western countries are used for the perspective of Technology Fusion because it is first used by Kodama in Japan, but has spread to Western countries, from which all other publications came. Also, the definitions used in many of the publications were not made explicit, after which they are interpreted and formulated to use in this study, resulting in Appendix A.

5. Conclusion

Three perspectives on the combining of technologies have been identified of which the scope over time has widened: technological convergence, technology fusion, and technology integration. There is an increasing gray area between the perspectives which indicated the need to once again streamline the literature. A new, overarching, term called Technological confluence is put into play with the purpose of doing so. Technological confluence positions technology central, and concerns the defining of the knowledge gap, and, based on this, the approach to acquiring knowledge. Based on the findings from our systematic literature review, the combinations of technologies can be created by both the adding, and the replacing of essential technology(-ies).

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[3] The electric motor requires battery packs, and complements the combustion engine of which the ratio is regulated by the transmission.
[4] The working principle of the radio did not change; an amplifier is still part of the equation only the technology has changed.

In short, Technological confluence is defined as: innovation by changing the set of essential technologies of a system, where unrelated technology replaces an essential technology in the system, or a technology is added to this system.

Further research is needed in order to distinguish the different types of combinations of technologies. And, more interesting for companies is the question whether a different process to product development is required for a different type of confluence? We suspect there is due to the versatility of perspectives there currently is. And what strategy should a company opt for, depending on the type of confluence? Further research should also point out the influence of the distance of knowledge on the process of innovation. The process of innovation may not only depend on the technologies used, but also the distance of the required knowledge relative to a company's knowledge (Ensign, Lin, Chreim, & Persaud, 2014) (Ganesan, Malter, & Rindfleisch, 2005). Combining technologies from, for instance, different fields of applied science goes hand-in-hand with a large knowledge gap that needs to be filled. Furthermore, it is not clearly defined what the application domain actually entails in the context of the combining of technologies, and thus when we can for example state that a new domain has opened. Following the definition from Kotler (1988), an application domain can be defined with three variables as the (i) technology that fulfills a certain (ii) customer need and is developed for a specific (iii) customer group. Any change of variable on this three axis model (e.g. other technology, or different customer group) means a new application domain is opened. Which is odd in the context of combining technologies because in many cases, the technology or the customer group changes, while the context of the resulting product is in many ways similar to one of its essential technologies. In the context of the combining of technologies, we for example would argue the satellite telephone is in a similar application domain as the mobile telephone even though it is focused on a different customer group. We do so mainly in an attempt to link the distance of knowledge from the perspective of the company, from Ensign et al. (2014), to the equation. We hypothesize that a technology in a new application domain requires more understanding from the newly added essential technology, than when launching a technology in the same application domain.

Besides this, it is unclear whether there are different generations of technological confluence. Perhaps companies are more open to collaborate with other industries now than before, or have a smaller scope of expertise that cause a higher level of modularization in the 21st compared to the late 20th century. In the 20th century, many technologies started incorporating electronics due to the increasing rise of the transistor and microprocessors. Current day this is the case with ICT, which has given rise to many new technologies. Both infrastructural network technologies and products. Infrastructural as in the cable companies that upgraded their analog infrastructure to digital ones, and products such as the personal computer. In 2014, Kodama presented the move from technology fusion towards technology-service convergence; the enhancing of products by adding a service dimension (Kodama, 2014). Think of "Internet of Things" examples such as connecting your refrigerator to the grocery store and allow it to order certain products to keep in stock. Or the live traffic updates in Google Maps and by TomTom. The inter-connectivity of previously disconnected networks of devices is what we are currently heading for. An age in which we talk to our smartphone or smartwatch to find the information we are looking for, an age in which we order food, clothes, and other goods online instead of going to a store. Most fascinating is the future scenario in which "the internet" becomes the "base technology" that pulls other technologies towards itself, instead of the other way around which is currently the case. The internet then becomes the base technology for the simplest of goods, enabling all goods to be connected to each other. The internet becomes the thing on which we rely and in which we put trust, in which we have unlimited access to unimaginable quantities of data that continue to grow and even learn from our behavior. One thing is for sure, in the foreseeable age of the internet, innovation via the combining of technologies plays an essential role in the move to a world where devices are all interconnected.

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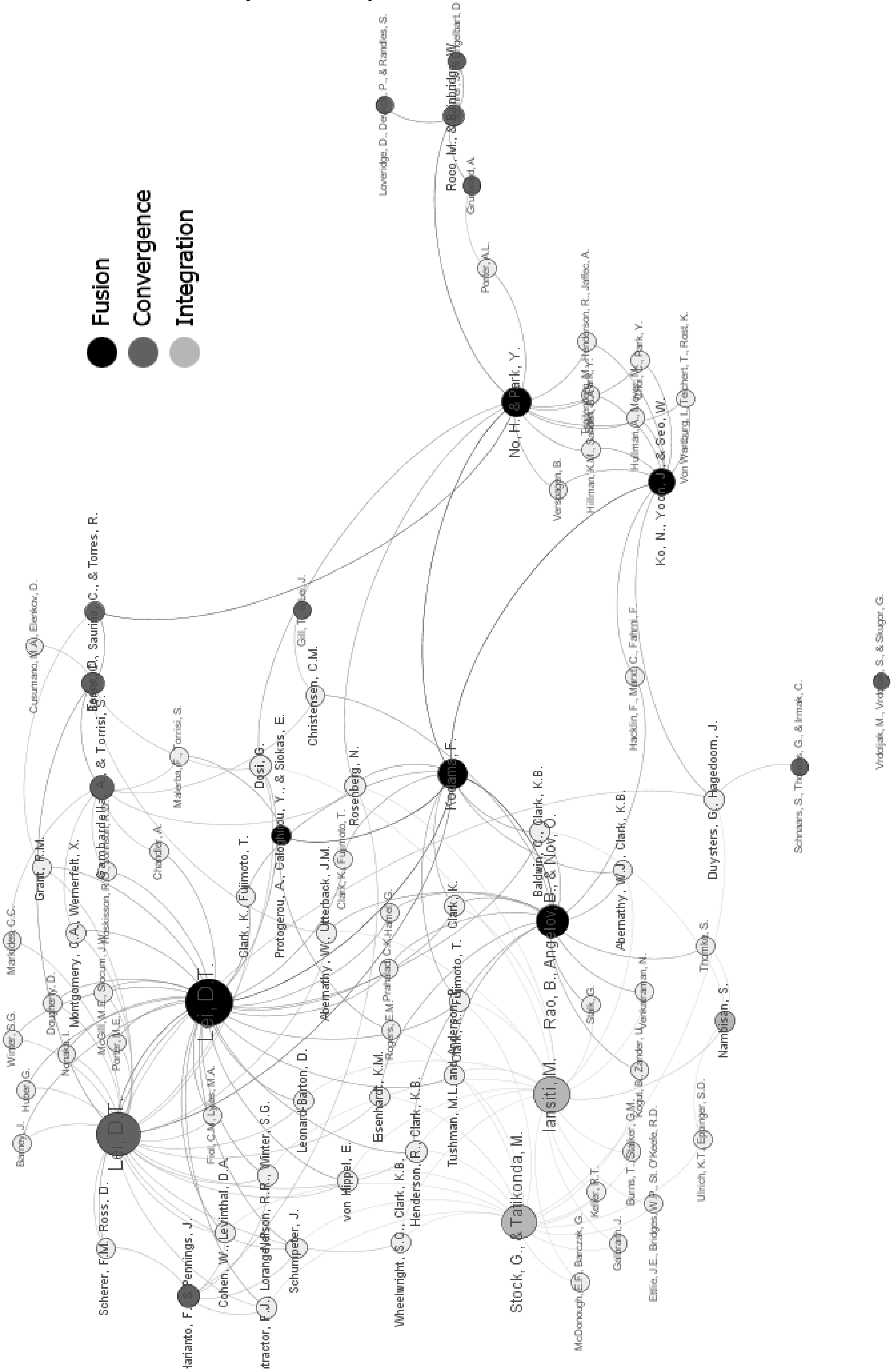
Appendix A: Overview of the literature used, their respective term, definition and cases used.

Reference	Term	Definition	Case(s) analyzed and/or examples used
(Kodama, 1992)	Technology fusion	A non-linear, complementary, and cooperative method that blends incremental technical improvements from previously separate fields of technology to create new products.	Companies in fiber-optics, mechatronics, and optoelectronics.
(Ko, Yoon, & Seo, 2014)	Technology fusion	Definition of Kodama, 1986. Due to patent knowledge flow analysis are the patents linked to industrial sectors.	new and renewable energy-based railway technology.
(Kodama, 2014)	Technology fusion and Technology-service convergence	Fusion among different kinds of technologies: joint research among different industries in order to enhance the product by adding or improving the service dimension. Also devoted to definition of Kodama, 1992.	Construction machinery (integrate GPS); PC with NC machinery.
(Protogerou, Caloghirou, & Siokas, 2013)	Technology fusion	Collaboration in a network enables knowledge sharing. Also devoted to definition of Kodama, 1992.	Collaborative research networks in three ICT areas: Mobile commerce-, telecommunication- and multimedia technology.
(Rao, Angelov, & Nov, 2006)	Technology fusion	Definition of Kodama, 1992.	Skype: combining VoIP and P2P.
(Lei, 1997)	Technology fusion	A blending of older, current or emerging technologies from different industries to create higher-order products and competencies. Also devoted to definition of Kodama, 1992.	Kodak with electronics firms to develop digital cameras; Toray Industries; AT&T; Komatsu.
(No & Park, 2010)	Technology fusion	Definition of Kodama, 1986. Due to patent knowledge flow analysis are the patents linked to industrial sectors.	Nano-biotechnology.
(Rosenberg, 1963)	Technological convergence	Interdisciplinary co-evolution. Previously unrelated industries cooperate on a technological basis due to having a similar issue.	Metal-cutting industry, machinery.
(Schnaars, Thomas, & Irmak, 2008)	Technological convergence	Occurs when two or more existing technologies combine to create an entirely new product, sometimes an entirely new industry.	Television; Video Telephone; Faxed Newspapers (Videotex technology); Computer Phones.
(Borés, Saurina, & Torres, 2003)	Technological convergence	A process by which telecommunications, broadcasting, information technologies and entertainment sectors may be converging towards a unified market.	Digital TV - Interactive TV; alternative data transmissions.
(Harianto & Pennings, 1994)	Technological convergence	Convergence of technologies from different industries.	Video Banking (Videotex technology).
(Spohrer & Engelbart, 2004)	Converging technologies	Type of progress characterized by rapid advances across multiple areas of technology, accelerated by cross-fertilization as the advances in one area speed progress in others (interdisciplinary coevolution).	Nano-Bio-Cogno-Socio-Techno (NBCST).
(Loveridge, Dewick, & Randles, 2008)	Converging technologies	Not specified. Interpretation: technological progress characterized by co-evolution resulting in new nanotechnology and nano-artefacts.	Nano-Bio-IT-Cognitive (NBIC).
(Vrdoljak, Vrdoljak, & Skugor, 2000)	Services convergence	Convergence of fixed and mobile telephony services (= protocols = technology).	Fixed and mobile phone network.

Appendix A (continued).

Reference	Term	Definition	Case(s) analyzed and/or examples used
(Grunwald, 2007)	Converging technologies	Same as (Spohrer & Engelbart, 2004).	Nano-Bio-IT-Cognitive (NBIC).
(Roco & Bainbridge, 2002)	Converging technologies	Refers to the synergistic combination of four major 'NBIC' (Nano-Bio-Info-Cogno) provinces of science and technology, each of which is currently co-evolving at a rapid rate.	Nano-Bio-IT-Cognitive (NBIC).
(Lei, 2000)	Technological convergence	Occurs when advances or innovations commercialized in one industry begin significantly to influence other industries.	Long-distance and local telephone markets; financial services; computer hardware and software; semiconductor, computer, communications and content industry; fiber optics.
(Gambardella & Torrisi, 1998)	Technological convergence	The process by which different industries come to share similar technological bases.	Computers, telecommunications, semiconductors and other electronic products.
(Gill & Lei, 2009)	Convergent products	The addition of new functionalities to a product's existing base.	MP3 player +GPS or +SAT; PDA +SAT.
(Stock & Tatikonda, 2004)	External technology integration	The process of acquiring technology from an external source, and incorporating it into a new product or operational process under development.	ERP software; desktop office software; paperless warehouse system; internet portal software; report writer software; single sign-on environment software; collaboration software; computer-aided-earthmoving system.
(Nambisan, 2002)	Complementary product integration	Combining of complementary products and services with new products.	Integrating new product into existing group of complementing software development tools.
(Iansiti, 1995)	Technology integration	To effectively use the fusion of new and existing knowledge, new technical concepts must be carefully selected and adapted to match the complex requirements of an organizations' existing environment.	No examples used.

Appendix B: Cross reference network map, build with Gephi 0.8.2.



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Types of Technological Confluence

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Abstract

Technological confluence is an overarching perspective of technological convergence, technology fusion, and technology integration. This paper focuses on systematically evaluating the types of combining technologies by building forth on the combined perspective of technological confluence. By approaching this with an embedded multi-case study design with 10 cases from seven industries, we have been able to distinguish the types of technological confluence based on the distance of knowledge, and the change of the technology itself. All relative to the base technology that, we assume, a company has, to which it desires to either add a new technology, or replace a technology with another. Each type of technological confluence shows a different process and duration of development and diffusion. Also, we have established a model in which a company can position its desired combination of technologies, after which insight is given on the process of development and diffusion via the developed typology. Most interesting for companies is our empirical evidence implying a shorter duration of the innovation phase when innovating via the combining of technologies, compared to other types of innovation.

Keywords: Technological confluence; combining technologies; interrelatedness of essential technologies; innovation management.

1. Introduction

A review of the literature on the combining of new or established technologies into new artefacts, such as the combining of Numerical Control (NC) technology and personal computer technology into Computer NC (CNC) machinery, revealed three perspectives (Jonckheere, 2015). These perspectives are technological convergence (Rosenberg, 1963), technology fusion (Kodama, 1992), and technology integration (Stock & Tatikonda, 2004). Jonckheere (2015, p. 15) established an overview of structural differences among the terms, and found that, over time, the boundaries of the, once separate, perspectives have become blurry. Indicating the need for a more clear approach to distinguishing the perspectives, a systematic approach to distinguishing the various types of combining technologies. In order to do so, an overarching term, called "Technological confluence", was brought to life, which is defined as: innovation by changing the set of essential technologies of a technology, where unrelated technology is added to the existing base, or replaces an essential technology of this base (Jonckheere, 2015, p. 15). Because there currently are different perspectives, we can already state there are multiple ways through which one can innovate by combining technologies. Current perspectives are found to have different drivers, and different strategies that each recommends (Jonckheere, 2015, p. 15). Jonckheere found that, for instance, technology fusion emphasizes the development of knowledge gathering competences by firms, and strategic alliances, whereas with technological convergence emphasis is laid on a firm's core competences. These perspectives, however, have not been systematically developed nor afterwards verified whether they together embrace all variations of combining technologies. So, what are these variations of the combining of technologies?

In this study, we will continue to build upon the currently laid foundation of technological confluence, and attempt to find the factors that make each type of combining technologies different from another, to develop a model in which

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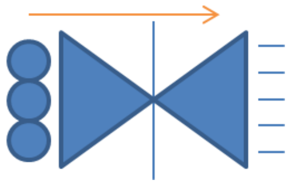

Figure 1 The process of evaluating the current list of perspectives.

these types can be distinguished systematically. The relation of this study to that of Jonckheere (2015) is depicted in Figure 1. The circles on the left hand side are the perspectives of convergence, fusion, and integration. Then, the vertical line resembles the overarching term of technological confluence, as defined in Jonckheere (2015, p. 15). And finally, this broad term will again be split up into the variations of combining technologies. This paper is about the right half of Figure 1, and results in a model that distinguishes the different types of combining technologies.

To begin with, one of the factors considered of importance is the application domain; the confluence either opens up a new domain, or starts from the same as one of the technologies in the confluence (Levinthal, 1998; Jonckheere, 2015, p. 15). Levinthal (1998) describes an application domain as the context in which a technology is applied. A technology has certain functional attributes of which some are valued more in a specific context by a certain group of customers. In the disk drive industry a shift in the importance of size, weight and power requirements was necessary to enter the domain of portable computers, while a threshold in the functionality of the disk drive is still being met (Christensen & Rosenbloom, 1995). Different needs in the domain required an emphasis on different attributes of the technology that were found largely irrelevant in the prior domain. The disk drive is however not a product of confluence, an example that is, is the digital camera which is developed to allow its users to capture photos (still or moving). A digital camera differs from an analog camera in that it digitally stores the photo instead of on a 35 millimeter film-roll. However, both the digital camera and the analog camera fulfill the same need, even have the same relevant attributes. In both cases the camera's size, weight, quality of photo, and storage size were important. Because the need remained the same, and the attributes of the technology that are of importance to the customer are too, the context in which the technology is applied is the same as the analog camera; in Figure 2 this means analog camera technology is technology A, technology B is the flash storage and the light sensor (for the example taken together), and technology C the combination of the two that is launched in the same domain as technology A. Technology A is also referred to as the "base technology".

Kotler (1988) defines the application domain as the function a product fulfills derived from a certain customer need, for a certain customer group, and a technology that can satisfy this need. Following Kotler's definition means that a new application domain is opened in the event that one of these factors changes, which is nearly always the case when combining technologies. Following Levinthal's line of reasoning, we argue that every customer group considers specific attributes to be important: these can be different or the same as its base technology (technology A). But, even though a product is developed for a new customer group (e.g. digital photographers in the early years), the attributes this group considers important can be the same compared to its base technology (e.g. digital camera: size, weight, quality of photo, storage size). It depends on the context of a technology. Thus, a customer group has specific attributes it finds important of a technology, but they are not by definition unique for each customer group, and therefore a new application domain is not always entered.

The smart TV is a case that opened in a new domain (see Figure 3) because the attributes that are important

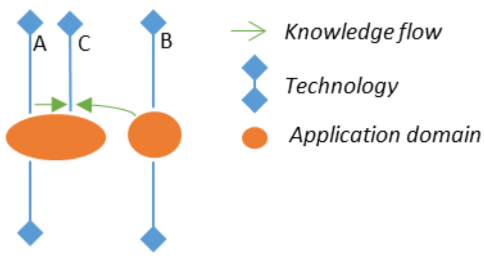

Figure 2 Pulling technology B to technology A to develop technology C within the same application domain (Levinthal, 1998).

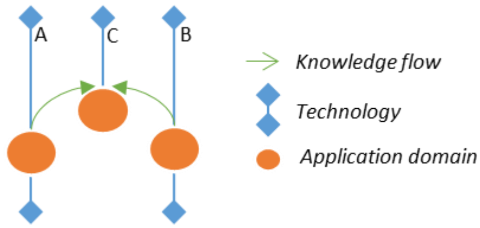

Figure 3 The combination of technology A and B resulted in technology C in a new application domain (Levinthal, 1998).

compared to the digital television have shifted, and a different minimum functionality was expected by smart TV customers due to it (Prabhala & Ganapathy, 2011, p. 312). Where initially the quality of video and size of the screen were the only attributes subject to minimum functionality, the new customers also wanted connectivity and software (i.e. an operating system). A company developing smart TV's thus had to widen its product development focus. In the (perhaps nearby) future, this minimum functionality is expected to shift more towards personalization, interaction, and socializing with people (Prabhala & Ganapathy, 2011, p. 317).

To further elaborate upon the relevant attributes, another example from consumer electronics follows. The personal computer has been given certain shapes, being, among others: desktop computer, laptop, and tablet. Each of the three mentioned have the same *set* of attributes because they are built from the same technology (i.e. same technological group), being PC technology. What makes each different is the *emphasis* that is laid on a *subset* of attributes of personal computer technology. With a desktop computer, for example, weight and size are much less relevant than with a laptop or tablet. And with a laptop, the built-in hardware input devices (e.g. keyboard and mouse) are considered relevant functional attributes above the touchscreen input from a tablet. Of course, within the market for desktop, laptop or tablet computers there is much variety of models available, but this remains a play of the same subset of relevant attributes. In this example, we also see that the attributes of a technological group can evolve. Touchscreen technology is, for example, later added to personal computer technology, resulting in the tablet computer. As a consequence of the addition of this attribute to the technological group, there are currently laptops on the market that, as well, incorporate touchscreen technology, the so-called "convertible" laptop. The addition of a new attribute can therefore open up new possibilities for other technologies part of the same group.

Knowing what application domain a technology belongs to is important in order for a company to know whom it is developing products for. What else is important is estimating the impact that the new technology, technology C, has on the customer in terms of how it is designed to be used, compared to the established technology. For example, when the sail of a ship was replaced by a steam engine, shippers suddenly required fuel to drive the engine, and to control the pressure in the kettle. The addition of this new technology required its users to learn a new approach to moving forth a ship, which is considered an impact on the accustomed way of propelling oversea transport. Being aware of the impact a new product can have on its customers' habits, could help in the developing of a strategy to smoothen the launch of the product. For instance, a company could develop complementary technology for the product to make it more appealing to customers, or make its technology compatible with another, or by initially developing a hybrid product such as a sail ship with steam engine.

In this paper we address changes in the set-up of the essential technologies of a technology over time, to which we will refer as the *interrelatedness of the essential technologies*, and the change in relevant attributes. We will not discuss industry co-evolution, a characteristic of technological convergence (Jonckheere, 2015) because we address technological cases which take place on a smaller time scale. Our unit of analysis is a single technology's development, leaving no place for analyzing co-evolution. From the perspective of the company with technology A, the interrelatedness of the essential technologies can be split into three episodes. These episodes are:

(i) Technology B is pulled towards technology A (same application domain → Figure 2)
(ii) The combination of Technology A and technology B is launched in a new application domain (Figure 3)
(iii) Technology A is implemented within a technology from the domain of technology B (new application domain → See "episode 3" in Figure 4)

They are called episodes because the order of the three identified episodes is not fixed. There are multiple scenarios through which a technology can continue its development, which we identify using these three episodes. Over time, a

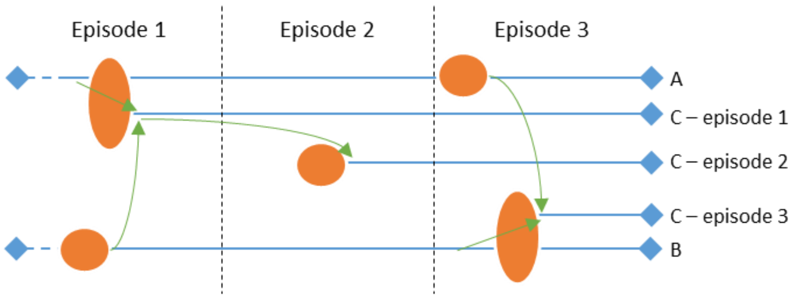

Figure 4 The different episodes of interrelatedness of technologies over time from the perspective of the company with technology A

technology is assumed to change episode when a certain point of interrelatedness is reached. By a better utilization of the functions that each of the essential technologies has, the amount of functions that technology C has can change. This, we would argue, can lead to a change of the relevant attributes and, in turn, a change of episode. One of the scenarios through which a technology can, in theory, move is shown in Figure 4. Here it is visualized that technology C started in episode 1 via a confluence of the base technology (technology A) and new essential technology B. The scenarios are always seen from the perspective of the company owning the base technology. The better integration of these technologies caused the customer's desired functionality to shift. At this point, we have two technologies on the market which either compete with, or complement each other. Think of the PDA phone (technology C – episode 1) and the smartphone (technology C – episode 2). Relative to the original domain of the base technology, technology C – episode 2 is in a new domain as the desired functionality has changed. Then, at some point the company may have gained a certain level of knowledge of technology B which it uses to develop a new technology in the original domain of technology B: technology C – episode 3. This company then combines its own base technology with technology B, but this time in the domain of technology B.

For each case discussed, a similar visualization as Figure 4 will be constructed, which will be further elaborated upon in the methodology chapter. First, the methodology will be discussed in which the analysis and case selection procedure will be elaborated upon, together with the unit of analysis. Next, the gathered case information will be presented followed by a chapter on the comparing of the cases. Then, a discussion follows in which the model will be developed and the different processes are presented. After this, the paper concludes with the different processes, and the remaining issues and limitations are given.

2. Research methodology

For this research an embedded multi-case study research design will be adopted in order to distinguish different types of combinations of technologies, and use this to develop the model (Yin, 1994, p. 41). This type of case study design is ideal when co-evolving variables are at play, distinct levels that influence each other (Yin, 1994, p. 41). A technology is continuously enhanced by the growth of understanding over time, causing products to as well improve over time, meaning that these are two separate, but dependent variables. Acquiring knowledge does not end when the product is first launched in the market, it is a continuing process however its *approach* is prone to change over time. For this study the following two levels of analysis are selected: first, the proximity and method of acquiring knowledge, and second, the evolution of the technology. Which will be further explained in this subsection.

The proximity of knowledge is related to whether technology C is launched in a different technology stream or not. The technology stream is the field of applied science that a technology is part of. When the field of applied science of technology C is different from the base technology, we speak of a new technology stream. A company that launches a technology in the *same* technology stream requires less new knowledge compared to launching it in a different stream (Ensign, Lin, Chreim, & Persaud, 2014). We think this is more important than whether technology B is from a different technology stream. Because when technology C is launched in a new stream, it likely says something about the degree of influence that technology B has on the technology as a whole. The CNC machine for example, where technology B is the PC, is launched in a new technology stream because technology B automated many of the functions earlier performed manually, and it also added new ones such as remote control via network connectivity. The entire translation from the drawing to a code understandable for the controller unit via manually creating punched cards, was now automated and much less time consuming than ever before. The CNC machine now belonged to the mechatronics technology stream, because the PC had a significant influence on the system as a whole. This means that effort is put into the embedding of PC technology in the NC machinery, because its developers wanted to automate many functions. Suppose it did not have such an influence, much less effort would be put into acquiring knowledge on the technology from a different stream, in this case being PC technology. The role that technology B plays in technology C therefore influences the technology stream technology C is part of.

Similarly this is the case with the application domain. In case the attributes of a technology remain the same, a company that already produced the base technology (technology A) is assumed to already have an important part of the entire knowledge required to create technology C.

A low cognitive proximity (i.e. to the company new technology stream or new application domain) is expected to require more development time because there is no, or little, knowledge present on the new technology in the company's established knowledge base. Take for example car manufacturer A, which has developed hybrid vehicles in the past, and wants to develop an electric vehicle. And car manufacturer B, which is looking into electric vehicles and has only developed combustion cars as of yet. Manufacturer A will experience a smaller knowledge gap due to its prior experience with electricity driven vehicles compared to manufacturer B. Manufacturer A stays within the same technology stream and knows already about electric motors, pulse-width modulation, electricity saving and generation methods, batteries, etcetera. Manufacturer B, on the other hand, enters a new technology stream, and it will therefore experience a larger knowledge gap than manufacturer A.

The process of acquiring the required knowledge is expected to be different as well; to fill a large knowledge gap it could for example be better to partner up with someone having an expertise in technology B, as suggested by both fusion (Kodama, 1992, p. 74) and convergence literature (Borés, Saurina, & Torres, 2003, p. 2).

The development time is thus expected to be influenced by the proximity and thereby the method of acquiring knowledge, and is considered the time span from the first proof of concept of the technology (invention) to the first product introduced in the market. Following the pattern of development and diffusion by Ortt & Schoormans (2004), this is called the innovation phase (see Figure 5).

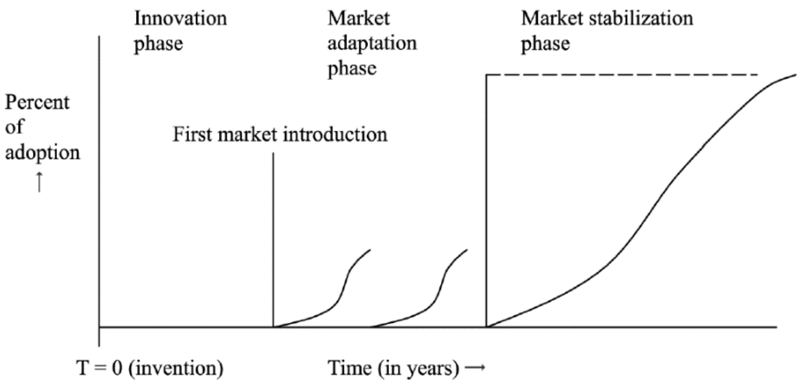

Figure 5 Three phases in the process of diffusion (Ortt & Schoormans, 2004)

The second unit of analysis in our research design is the evolution of a confluence technology. A confluence technology is considered a combination of different, previously unrelated technologies (Jonckheere, 2015, p. 3). Next, in Jonckheere (2015, p. 3), a single technology is defined as a certain technological principle that exists of a specific set of essential technologies, and is created to fulfill a certain function. A smart TV for example is a combination of television-, set-top box-, and personal computer (PC) technology; which make up its essential technologies. In turn, each essential technology follows the same definition and thus has its own set of essential technologies. Television technology for instance requires signal decoders for each type of input signal, a command receiver (remote control and control buttons), and an output (loudspeaker and display). Its function is to entertain, inform and educate, and the principle it uses to accomplish this is to receive an electric signal, decode it, display the information in the form of still or moving images, and output any accompanying audio. For a more elaborate description of an essential technology, and how it is different from a feature, we refer to Jonckheere (2015, p. 3).

Regarding the evolution of a confluence technology, we expect there to be different patterns of development and diffusion for different cases (i.e. technologies). The cases showing a similar pattern are grouped and compared to seek the factors that distinguish them from each other.

For each case a specific set of factors is analyzed, categorized into: context, essential technologies, application domain, stages of development, and remarks. Because we want to visualize the process through which a technology evolved, we need to know the changes that a technology has undergone. We do so by looking at the changes of the essential technologies over time, the method of acquiring knowledge, changes in the technology stream the technology belongs to, and changes in the application domain. A new application domain can for instance be entered when an essential technology is added. The contextual variables are important for the generalization of the study, and the selection of the cases. Lastly, the “remarks” category is there to capture interesting data that does not fit under any other category.

Table 1 contains an overview of the data collection categories, their variables, and in the most right column the selection criteria. Case selection is based on the timeframe, geography, accessibility of data, and, most importantly, the match with our unit of analysis of a technology. Only cases from 1950 and onwards are selected because, in the event of interviews, it is best to discuss a technology with someone who has experienced this technology in its early stages. This is more likely with technologies invented after 1950 as it is already about 65 years ago. Furthermore, it is since 1950 that the socio-economic impact of the Second World War was settled, meaning that stability in both consumers and firms had been found again (Steffen, Broadgate, Deutsch, Gaffney, & Ludwig, 2015, p. 92). Besides that, microprocessors have made an enormous impact in automation and digitalization around 1970, and can be found in an increasing amount of technologies. In an attempt to establish a heterogeneous list of cases, a date prior to the existence of microprocessors was required. With regard to the geography, cases from the western world (i.e. USA, Canada, Europe) are selected for a better accessibility of data in terms of literature and possible interviews, and to better be able to generalize the findings due to more similar economic and cultural characteristics.

Table 1 Data collection per case and variables for case selection.

Data collection groups	**Group variables**	**Range for selection**
Context	1) Timeframe (t)	1) 1950 < t <= 2015
	2) Geography	2) Western world (USA, Canada, Europe)
	3) Industry	3) N/A
	4) Essential technologies	4) At least two previously unrelated technologies
	5) Accessibility of data	5) Case is well documented in literature, or an interview can be held at a company
	6) Functions of the product	6) N/A
Essential technologies	1) Functions of each technology	1) N/A
	2) Components of each technology	2) N/A
	3) Technology stream	3) N/A
Application domain	- Changes in domain over time	N/A
Stages of development	- Timeline of the development, addition of technology(-ies), and method of acquiring knowledge	N/A
Remarks	N/A	N/A

We are aiming for a heterogeneous dataset, which follows from the exploratory nature of this study. A diverse set of cases from a variety of industries helps in finding the extremes so that the full range of situations that exist is represented better (Seawright & Gerring, 2008). Extremes are considered technologies with a different degree of complexity in terms of functions from a similar industry. We expect this complexity to influence the process of development and diffusion. The smartphone, for instance, is considered a complex technology for it has many functions, and Skype a more simple. Also, by considering cases from different industries, the population is not only represented better but also makes contrasting the cases more robust as industry specific characteristics are more easily spotted (Collier & Mahoney, 1996). Cases from the same industry may very well be more interwoven than expected, companies may, for example, be prone to similar characteristics, that potentially influence analyzed variables, such as: jargon, customers, development platform or approach to development, and speed of technological change.

For each case that follows from the case selection, a timeline will be constructed indicating major changes of a technology. A major change is considered a change in the set of essential technologies of the case under investigation, a better interrelatedness of the essential technologies, or a change in the method of acquiring knowledge. The interrelatedness is analyzed by comparing the functions that a technology over the course of its development employs, with the functions of its essential technologies. Back to the smart TV; early generations of this technology did not have an operating system (OS) or internet connectivity such as a personal computer did have. The current generation of smart TV's however does, and offers its user a greater ability to personalize and interact with the device much more similar to a PC. This means that the interrelatedness of the TV and PC has increased. So, how well an essential technology is integrated in the product of confluence, is defined by the functions this essential technology has in its own domain, compared to the functions that the product of confluence utilizes. For instance we ask ourselves: what are the functions an OS of a PC can perform compared to the OS of a smart TV? Incorporating one functionality from the OS does not instantly mean it has an OS similar to that of a PC. The OS of a PC has many more functions such as: program execution, memory management, networking, multitasking, and file management. The OS in a smart TV would be much more similar to that of a PC if it at least employed all of the functions that the OS of a PC has.

This timeline will start at the moment that the technology was first proven to work, thus showcasing its functionality using its technological principle and its specific set of essential technologies, up to June 2015, the date of this research. In some exceptional cases, the timeline starts earlier when an essential technology of the confluence product was integrated or changed before the conception of the confluence technology itself. The set-top box for example evolved, and incorporated basic PC technology before the smart TV was born. Looking from the perspective of the product of confluence, the developments of the essential technologies are analyzed and shown per time advance (time advance differs per case). A digital camera for example is split in the following essential technologies: analog camera, light sensor, storage, and a personal computer. The moment in time that the CCD chip was first introduced in the camera are for example such advances.

2.1. Process of constructing the timeline

Setting up the timeline starts for every case with acquiring synonyms of this case, because names are prone to change in the course of development. Information about the historical names is gathered from sites describing the history found via Google, and Wikipedia. Next, searches in Scopus and "ABI/INFORM Complete[1]" with these names are performed. In Scopus, the results are sorted by relevance, whereas for ABI/INFORM the oldest publications are shown first. In most cases the searches in Scopus did not result in usable literature, either because it did not exist, did not include a historical overview, or because the literature was not accessible due to library restrictions. Thus, the construction of the timeline for many cases mainly builds upon ABI/INFORM, and partly on hits in Google. A literature list is supplied at the end of every case report.

An example of the process of acquiring literature will be given for the smart TV case. The essential technologies of a smart TV are a PC, TV, and set-top box (STB). The STB (also called a demodulator, UHF converter, or Video receiver) is part of this list because it is found to be the device that enabled a TV to have an internet connection in the time that cable TV companies first started to upgrade their existing infrastructure to allow multiplexed signals (which is required for an internet signal). The STB was first a separate module for the digital TV, which preceded the smart TV. A search in Google and Wikipedia resulted in the following historical names: Smart TV, connected TV, IP TV, Web TV, interactive TV, internet TV, and digital TV (the acronym "TV" both spelled out and as is). Next, in ABI/INFORM these names are searched for. Often, depending on the amount of results per year and having found no interesting headlines or titles about new products or technological advances, articles are randomly opened and read as newspaper headlines are sometimes found to be less informative. Articles discussing the same new product or technology are only used once, follow-up articles are skipped.

After performing a study for each case, a cross-case analysis will be held of which the results will lead to the development of a model that distinguishes the different types of confluence. After this, an intersubjective experiment will be held in order to check the validity of the model with practitioners. Following up, the model is evaluated in the discussion.

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[1] A search engine ideal for business researchers which runs through a database of news articles, and professional publications.

2.2. Intersubjective experiment sample

The intersubjective experiment will thus be held after having performed the cross-case analysis and having developed an initial version of the confluence model. The sample of the experiment consists of three practitioners from different companies. Table 2 presents a general description of the participants. During the intersubjective experiment, the model that distinguishes the types of confluence is presented to a practitioner, together with a set of cards where each card contains the name of a case from our dataset. The practitioner is then asked to position each case within the model and explain their decision in order to check for intuitiveness and ambiguity of the cases and the model. Each practitioner will be interviewed and asked the following questions: (i) "What case did you find the hardest to position in the model and for what reason?", (ii) "Do you think there is a factor not in the model that should be there?", (iii) "Are there cases that you know of missing from the set?".

This semi-structured interview type is chosen to allow room for deeper, follow-up questions resulting from the three main questions. Or for instance when a relatively extreme deviation in the positioning of a case of the practitioner is noticed, compared to the researcher's or other practitioners positioning.

Table 2 Description of the participants.

N	Age	Gender	Occupation	Company
3	56	Male	Consultant sector Development & Engineering	ASML
	25		Developer and consultant	EVO-IT
	26		Software consultant and innovator	Cap Gemini

3. Case information

After the selection procedure of which the criteria are described in chapter 2, 10 cases were identified and the data from Table 1 is gathered for each case using the process described in chapter 2.1. Table 3 contains an overview of the selected cases, their respective industry[2], application domain, and technology stream. An application domain is new when the attributes that are important for a customer are different for technology C than the base technology, or when the main functionality changed. Similarly, the technology stream (i.e. field of applied science) is new when the technology is launched in a new stream relative to that of its base technology.

Of the 10 cases in Table 3, five started in a new application domain of which one in a new technology stream, and

Table 3 Overview of the selected cases.

Case	Industry	Application domain*	Technology stream*
Smart TV	Consumer electronics	New	Same
Smartphone	Consumer electronics	New	Same
CNC machine	Machine tools	Same	New
Skype	Software	Same	Same
Digital camera	Consumer electronics	Same	New
Satellite phone	Telecommunication	Same	Same
Multifunction printer	Computer peripherals	New	Same
Laser lithography	Semiconductor	Same	Same
CT scanner	Healthcare equipment	New	Same
Electric toothbrush	Consumer electronics	New	New
10 cases	**7 industries**	**5 new**	**3 new**

* State of the technology relative to the base technology at launch.

[2] Industry division based on the Dutch SBI (Standaard Bedrijfsindeling 2008).

five started in the same domain of which two in a new technology stream. From this dataset it seems to be more common to continue within the technology stream of the base technology, than to launch a technology in a new. For the application domain our dataset shows an equal tendency to launch a product in a new or the same application domain. “Our dataset” is emphasized because it is based mainly on a diverse set of cases, containing extremes instead of cases that statistically represent the population. This, because we are looking for variations of combinations of technologies, and factors that influence the process that such a variation moves through over the course of its development and diffusion. For each case, a report was made of which an example can be found in Appendix A.

4. Cross-case analysis

The first part of our cross-case analysis consists of analyzing the duration of the innovation and adaptation phases of confluence technologies. The duration of each phase will be established following the definitions of the hallmarks as presented by Ortt (2010). Second, we look at the proposition that the distance of knowledge has an impact on the duration of the innovation and/or adaptation phase. To recap, a high cognitive proximity is expected to have a shorter development time because of a smaller knowledge gap (Ensign, Lin, Chreim, & Persaud, 2014). Also, we look at whether the method of acquiring knowledge changes over time. The third part of this chapter is about the interrelatedness of the essential technologies of each case. Here, we identify the processes the cases moved through, and group them. Then, in the final part of this chapter we argue that before technologies can be combined, some form of “enabler” is required that couples one technology to another. We compare cases where technology is *added* to cases where technology is *replaced*.

On the basis of this information, we attempt to find the factors that have an influence on the process of development and diffusion, and the duration of these processes, in order to establish the model distinguishing the types of confluence.

4.1. Duration of the innovation and adaptation phases

In Appendix B an overview is given of the length of the innovation phase, and the length of the adaptation phase. The dates in Appendix B are put together following the definitions of the hallmarks presented by Ortt (2010). This overview also indicates whether a product started in a new or the same application domain, and whether it was launched in a new or the same technology stream.

Table 4 contains the means of the innovation and adaptation phases of all cases, indicating an average innovation phase duration of 6.3 years and average adaptation phase of 13.8.

Table 4 Total development time in years of the innovation and adaptation phase.

	Total of all cases
Mean length innovation phase	6.3 (6.3)
Mean length adaptation phase	13.8 (11.2)

* Values written as: “Mean value (std. deviation)”

For comparison Table 5 is added, which contains the durations of the same phases of 50 cases in five aggregated groups of industries as found by Ortt (2010). Two out of these 50 cases are confluence cases: CT scanner, and the digital camera. Interestingly, it now becomes clear that in our findings, a shorter average duration of the innovation phase is found: 6.3 (6.3) against 10.0 (13.5) years. Making it plausible that with technological confluence, the duration of the innovation phase is indeed shorter compared to other methods of innovation. The average duration remains shorter even when only considering the industries from Table 5 that our study has most cases from (seven out of 10): Telecom, media & internet (8.9), and Electronic equipment (7.2). Giving an average duration of 8.1 years compared to 6.3 in our study.

Table 5 Duration in years of the innovation and adaptation phases of 50 cases in five industries (Ortt, 2010).

	Chemicals, metals & materials	Pharma & healthcare equipment	Telecom, media & internet	Electronic equipment	Aerospace & defense	Total
Mean length innovation phase	4.9 (3.2)	21.6 (23.3)	8.9 (10.8)	7.2 (5.4)	7.6 (10.2)	10.0 (13.5)
Mean length adaptation phase	6.5 (5.8)	4.5 (6.2)	6.4 (7.1)	12.0 (11.2)	4.0 (4.3)	6.7 (7.6)

* Values written as: "Mean value (std. deviation)"

The shorter duration is perhaps best explained by the essential technologies of the confluence technology, which have already been introduced in the form of a product before being combined. Often, a company that develops the confluence technology already has knowledge of the base technology; a company developing a hybrid vehicle is likely to have already developed an internal combustion engine (ICE) vehicle earlier. Also, from our case studies it is found that the developers of Skype had prior knowledge of peer-to-peer networking, and the company developing the CT scanner had prior knowledge of X-ray imaging. This would also mean that companies know what they are developing when combining technologies, in other words, what the combination of technologies should look like, what it should do, and for whom they are developing it. We assume many will be able to imagine what a combination of technologies looks like, even if it is not invented yet. For the sake of the argument, let us do a small thought experiment: imagine a juicy orange, the fruit. And imagine this orange being combined with a water faucet. Perhaps you envision this as a new approach to getting the juice out of the orange, or as a design feature of the faucet itself, or even something else. The point is, there is a finite number of ways a basic version of the combination of technologies would look and function like, because we already know what the two objects in separate look and function like. This, in essence, is the same with the hybrid vehicle, Skype, CT scanner, and also the TV and PC technology in a smart TV. We know what a PC is capable of, and we have a concept of a TV in our minds which helps us develop a concept of a smart TV. Regarding the duration of the innovation phase, this may very well be a determining factor characteristic to confluence technologies. For further research we suggest interviewing companies that are innovating via technological confluence, and companies with other approaches to innovation, on their process of innovation. This will give more direction to the factors influencing the duration of the innovation phase.

The adaptation phase appears to be longer with confluence: 13.8 (11.2) versus 6.7 (7.6). What perhaps explains this longer duration best in relation to confluence technologies, is that existing environments and/or networks need to adapt to the new, hybrid, confluence technology. Previously separate networks therefore need to be changed to work with a new technology. This may cause a product of confluence of a competitive or even superior nature in terms of performance/price ratio compared to other technologies, to at first be negatively influenced by the fact that its environment is not ready. The satellite telephone was dependent on the availability of specially designed communication satellites orbiting the earth, and the development of base stations that the telephone could access to communicate with these satellites. It is rare finding someone who wants a telephone that you cannot contact anyone with, thus lengthening the adaptation phase. With the electric vehicle, an often used solution for charging are high current charging poles. But if these are nowhere to be found, charging can take a lot of time with the limited household currents, making the electric vehicle less appealing and causing the adaptation phase to lengthen.

Another factor that could influence the duration is the inferior performance of a technology compared to its competition. A company may know what a combination of technologies should look like, what it should do, and for whom it is developing it, but if the performance of the new system is inferior to the competition, it may have a short innovation period, but is up for a long adaptation period in which the technology needs to be further developed. The hybrid vehicle, for instance, is an invention from around 1900 by Ferdinand Porsche, which has a very long adaptation phase caused most likely because the performance of the ICE vehicle was for a long time far superior (Chan, 2002). However, this factor is arguably not characteristic for confluence technologies, but also for other technologies.

A study by Ortt & Delgoshaie (2008) on the factors that influence the length of the adaptation phase identified in total 30 factors, of which some appear to occur more often than others (Ortt & Delgoshaie, 2008, p. 7). The two most occurring factors in their dataset are the relative performance compared to alternative technologies, and the customer need. One of the factors recognized as well is the network effect (Ortt & Delgoshaie, 2008, p. 7), which we argued to be characteristic to confluence, because environments need to adapt to a new hybrid technology. Perhaps there is a mechanism to this factor that works different with confluence technologies, because it is about the adapting of an existing environment instead of the developing of a new one. The 30 factors have been categorized into four groups: the main organization, customers, technological system, and the market-environment (Ortt & Delgoshaie, 2008, p. 10). The duration of this phase thus seems to depend on the context regarding the factors in the four categories a technology is in. Therefore, what exactly influences the adaptation phase of confluence technologies is yet to be discovered. There is even a scenario where there is no difference between confluence technologies and other technologies regarding the adaptation phase.

For further research we suggest looking into whether there is a subsection of the factors by Ortt & Delgoshaie (2008) that has a bigger influence on the duration of the adaptation phase of confluence technologies than other technologies. And whether there are unidentified factors. Also, we suggest looking at the mechanisms of the network effect to possibly identify a mechanism characteristic to confluence technologies, because networks need to be adapted instead of developed. With regard to the innovation phase we suggest looking into the factors influencing the length of the phase, because very little is known about the influences. Regarding the duration of the innovation and market adaptation phases, this subsection is concluded with two hypotheses:

H1: The innovation phase is shorter when developing confluence technologies than other technologies.
H2: The market adaptation phase is longer when developing confluence technologies than other technologies.

4.2. Cognitive proximity and method of acquiring knowledge

Having compared the total durations of the two phases, in this subsection we compare the influence of a new versus the same technology stream, or application domain. Table 6 contains the duration of the innovation and adaptation phase for different combinations of the technology stream and application domain.

Table 6 Duration of innovation and adaptation phase in years of the application domain versus technology stream.

Application domain → **Technology stream ↓**	**Innovation phase**		**Adaptation phase**	
	Same	**New**	**Same**	**New**
Same	3.3 (2.5) [3]	5.3 (3.9) [4]	6.3 (7.8) [3]	10.5 (7.3) [4]
New	12.0 (14.1) [2]	8.0 (N/A) [1]	20.0 (4.2) [2]	37.0 (N/A) [1]

* Values written as: "Mean value (std. deviation) [number of cases]"

From the data in Table 6 it appears that the innovation phase is on average longer when knowledge from a new technology stream is required, compared to the same. Similarly, both phases appear to take more time when a new application domain is entered as well. There certainly seems to be a trend where the application domain and the technology stream cause a phase to lengthen, and even seem to reinforce each other.

There is one exception to this trend in Table 6, being the 8.0 years of the innovation phase, where a new application domain and new technology stream is entered. The fact the value of the innovation phase is lower compared to the same application domain, 8.0 versus 12.0 (14.1), can perhaps best be explained by it only being one case. In a mean of multiple values, the standard deviation indicates the upper and lower boundary of the most common values. Telling us that the most occurring values can be expected within this region. When there is only one value though, there is nothing known about the upper and lower boundaries, and the, in this case, 8.0 years, then becomes merely one of the values within an unknown region. However, looking at the trend of surrounding values, it is likely that either this cell's mean comes out higher than it currently is, or the mean left of it, the 12.0 (14.1), consists of values both at the upper boundary of its region. There will always be cases that, for a particular reason, have a different duration than others. Important is recognizing the factors that influence such a scenario. The innovation phase of the multifunction printer (MFP; new application domain, same technology stream) for instance took 11 years, which is about five years above average for a confluence technology. From what we found, it took longer because there were difficulties with the software regarding the multi-tasking of the MFP; the ability to for instance print and scan a document at the same time. What did not help the MFP's development was that multiple companies attempted to develop MFPs, but did not co-operate and ran their own internal R&D.

In relation to hypotheses *H1* and *H2* from the previous subsection, our findings around the technology stream and application domain on the duration of the phases suggests that new factors have been discovered. Regarding the adaptation phase, however, 30 factors have been found, which suggest several scenarios around these two factors:

(i) The application domain and technology stream are additional factors to the list of Ortt & Delgoshaie (2008), but only characteristic to confluence technologies. They can only be characteristic to confluence technologies because the application domain and technology stream are relative to the base technology and the resulting confluence technology, one is new when it is different from the base technology. If so, *H2* should be approved and the upward trend of the adaptation phase in Table 6 is legit.

(ii) There are undiscovered factors characteristic to confluence technologies, additional to the list of Ortt & Delgoshaie (2008), that explain the long duration of the adaptation phase. If so, *H2* should be approved and the upward trend of the adaptation phase in Table 6 is legit.

(iii) The duration of the adaptation phase of each technology in our dataset is only influenced by (some of) the 30 factors from Ortt & Delgoshaie (2008). This would mean that *H2* is rejected, and the upward trend in Table 6 of the duration of the adaptation phase is coincidental. Considering the high standard deviations of these values, indicating a large overlap in the most common durations, this scenario is plausible.

For further research, we suggest looking into the cases in the four groups of Table 6 (i.e. application domain–technology stream: same-same, same-new, new-new, new-same), and analyzing the influence of the factors from Ortt & Delgoshaie (2008) on the duration of the adaptation phase of these groups. When similar factors are found within a group, but different between the groups, this can be argued characteristic to a group, and the application domain and/or technology stream could be considered factors between the groups. When similarities are found between groups it could be concluded there is no reason to suggest that the application domain nor technology stream influence the duration of the adaptation phase.

Overall, it appears plausible that a low cognitive proximity (i.e. to the company new technology stream and new application domain), requires a longer innovation phase because it is likely there is no, or little, knowledge present on the new technology in the company's established knowledge base. This leads us to the following hypotheses:

H3: The innovation phase of a confluence technology takes longer when a new application domain is entered compared to the same.

H4: The innovation phase of a confluence technology takes longer when a new technology stream is entered compared to the same.

H5: When entering both a new application domain and technology stream, the two reinforce each other and the innovation phase of a confluence technology takes longer than with H3 and H4.

H6: The market adaptation phase of a confluence technology is influenced by the application domain and technology stream.

The last hypothesis needs some more explanation. H2 suggested the duration of the adaptation phase of a confluence technology takes longer than other technologies. In H6, we question the factors that are of influence on the duration of the adaptation phase. And because the values in Table 6 hint towards being influenced by the application domain and the technology stream, with the hypothesis we stay true to these findings. However, the high standard deviations together with the findings by Ortt & Delgoshaie (2008), leaves us to consider it may very well be more coincidental than it is a pattern.

4.2.1. Filling the knowledge gap

So, how do companies fill a knowledge gap? And what is known about the factors influencing a firms decision to follow this strategy? The knowledge gap is the difference between a company's base knowledge and the domain specific knowledge. To fill the gap, various ways are possible: one can make or buy the knowledge, cooperate with another company, or use a combination of these. In the combining of technologies, alliances with other firms are argued to be essential (Kodama, 1992, p. 70) (Lei, 2000, p. 733) (Harianto & Pennings, 1994, p. 293), which is why our emphasis is on factors leading to such a cooperation strategies.

Kodama (1992, p. 74) describes how Nippon Sheet Glass (NSG) in the 1970s developed a fiber-optic cable but the quality of transmission over long distances was poor, and it lacked mechanical strength. Together with Sumitomo Electric Industries (SEI), a coating technology was developed that reinforced the cable. Then, to solve the transmission loss problem, a joint research effort of Nippon Telephone and Telegraph (NTT) and SEI led to the use of longer wavelengths. In this example the base knowledge is the fiber-optic cable, of which elements were not functioning properly. In order to launch this product in the desired domain, the knowledge gap had to be filled which NSG did by consulting the expertise of SEI and NTT. Thus, initially a make strategy was used after which they stumbled upon a lack of knowledge, and adopted a co-operate strategy.

Lei (2000, p. 729) describes that throughout 1996 and 1997, Microsoft formed alliances with firms in the computer hardware, imaging, content, and cable television industries to extend its software-based competences into new areas. In this case, Microsoft immediately engaged in a coop R&D strategy after which in some cases a partner was acquisitioned (buy strategy), such as WebTV Networks. In our data this is similar to IBM and BellSouth, who too had a desire to extend into new areas, and complemented each other's knowledge to develop the first smartphone: the Simon personal communicator phone. ASML did the same with laser lithography; initially the light source was developed by Philips (mercury-gas discharge lamp). Then, in 1991, the light source was replaced by excimer laser technology; a technology introduced in the context of lithography at IBM in 1982. This technology was never researched by ASML itself, rather in cooperation with a supplier, being mainly Cymer, which has an expertise in excimer technology. Then, in 2013, ASML acquired Cymer to boost the development of their successor technology: extreme ultraviolet (EUV) lithography.

Another case is Computer Numerical Control (CNC) technology, which is developed by the MIT Servomechanisms Lab in the 1950s (MIT TechTV, 1959). Early versions of the CNC utilized a Flexowriter, eight-column paper tape, a tape reader, and vacuum-tube electronic control systems. A separate computer printed the code on punched tape which was then fed to the NC machine. A make strategy was opted for up to the point where knowledge lacked, then, development continued in co-operation with the Aircraft Industries Association, and Wright-Patterson Air Force. This coalition was especially needed for the development of the programming unit; the translation of the drawing into code.

Three of the previously described cases (NSG, Microsoft, MIT) have in common their approach to product development during the innovation phase. All companies developed a product that is launched in a new technology stream (relative to technology's prior stream), and stumbled upon a point where they could not continue without consulting another's expertise to fill the knowledge gap. This, however, is not always the case for technologies that enter a new technology stream. The electric toothbrush for example was launched in a new technology stream and is invented at Broxodent in 1956. Broxodent researched the domain specific knowledge themselves. Furthermore, the ASML case showed that a coop strategy is not exclusive to technologies launched in new technology streams.

The decision for a coop strategy is therefore not dependent solely on the proximity of knowledge in terms of the technology stream. A quantitative research on the driving forces for R&D strategies confirms this. Woerter (2011) analyzed survey results from 2555 firms in 28 industries, and one of the main conclusions is that external R&D activities are suggested for: *"non-price competition and/or technological uncertainty in the case of 'buy' and 'mixed', as well as price competition in the case of 'coop'"* (Woerter, 2011, p. 633). Meaning that when an environment is characterized by non-price competition, such as quality or service, a buy or mixed strategy is preferred. In contrast, a coop strategy is often followed when price is a competitive factor.

External knowledge resources are more appreciated by firms following the buy, coop, or mixed option rather than the make one. Another conclusion is that especially, a fast depreciation of knowledge and risky investments in learning are reasons for external R&D. Thus environments characterized by rapid technological change are common to opt for external R&D. An example of a company in such an environment is ASML, who has suppliers for many of the components in its lithography machines[3], while still also performing their own R&D, and being in a market characterized by non-price competition. ASML thus follows the theory of Woerter (2011), and opts a mixed strategy.

Finally, Woerter (2011, p. 626) found that a greater technological potential goes along with a coop strategy. The technological potential represents the importance of incoming knowledge spillovers to a firm. A firm valuing incoming knowledge is likely to choose a coop strategy. The technological potential stands for the scientific and technological knowledge relevant to the firm's R&D activity. A company may be using publically available knowledge spillovers from for example universities or research centers (Cassiman & Veugelers, 2006, p. 69), but also, aimed at more specific knowledge, it may join an alliance to try and maximize the spillovers from partners and non-partners

[3] Major suppliers: Agilent, Carl Zeiss, Cymer, and Philips. Data from ASML Corporate Fact Sheet: http://www.asml.com/

(Mowery, Oxley, & Silverman, 1996). These companies are likely to again choose a coop strategy once they have done so earlier (Woerter, 2011, p. 614).

Thus, where the domain specific knowledge (Ensign et al., 2014) defines the required knowledge, the technological potential together with the type of competition and a firm's environment influence a firm's approach to acquiring the knowledge. In addition, companies should choose a direction they wish to head, and join an alliance to enlarge the chance of receiving knowledge spillovers matching this direction, as discussed by Cassiman & Veugelers (2001; 2006). Furthermore, other motives for a strategic alliance include the urge of spreading the R&D cost, as well as risk of innovation (Mowery, Oxley, & Silverman, 1996, p. 79) (Woerter, 2011, p. 620). All prior mentioned factors are especially relevant for companies engaging in the combining of technologies, as they are often using technologies developed by others (Lei, 1997; 2000) (Kodama, 1992).

4.3. Interrelatedness of the essential technologies

Earlier, we discussed the theoretical situation of a combination of technologies in the same domain, of which the essential technologies start to cooperate which causes it to continue in a new domain relative to the base technology (technology A). During the analysis of the cases, empirical evidence was found for this theory via the digital camera case. The digital camera case shows that a confluence can start in the same domain, and by better utilization of the functions of its essential technologies it changes from domain. By the addition of a display on which the photo could be directly reviewed, there was no longer need to first transfer the photos to a computer in order to see them, and shoot multiple photos to make sure at least one of them was to a user's liking. A new application domain was entered because a new minimum functionality was expected from digital cameras, and the relevant attributes now included the immediately reviewing of photo and film.

In Table 7 in the left column the cases are listed and in the column beside it the change in the functions it utilizes is shown. The year of the *last* change in its functions, and the data point before are shown for a comparison of the utilization of the functions of its essential technologies. This data is gathered using the process described in chapter 2.1, and is described in the methodology as the amount of functions the confluence technology utilizes from its essential technologies. These essential technologies once were separate technologies with their own set of functions, the PC, and the mobile phone each have their own set of functions, but the smartphone did not immediately utilize all of these functions. Over time the utilization increased. Then, the column "missing functions" sums the functions of, for example, a PC or an OS, that have not (yet) been utilized by the confluence technology. The acronyms used in the table stand for functions of a PC or an OS, of which the meaning can be found in Appendix C. And lastly, the most right column indicates whether the case has changed its application domain over time, and summarizes how this change occurred. The table is based on the constructed timeline for each case following the process described in chapter 2.1. For the visual representations of the timeline of each case see Appendix D.

4.3.1. Processes occurring after the innovation phase

From the visual representations of the timeline of each case in Appendix D, we find that the most common processes are these where the new technology either starts in a new, or the same domain, and remains there. Often occurring in these situations is that, in time, a new essential technology is added which broadens the amount of functions this technology can utilize. This happened for instance with the CNC machine and Skype, where respectively PC and telephone technology were added later. The addition of PC technology for CNC resulted in, for example, the ability to connect the machine to a network, and to automatically translate a digital drawing of a component or product into a language understandable for the controller unit. Skype connected their service to the telephone network, allowing its users to make calls over the internet and the telephone network.

An episode 3 scenario that follows from the process of Figure 4 (page 3), where, after the confluence, the base technology is integrated in the domain of technology B, was not discovered. However, it could be argued that it did occur, depending from what point of view we look; looking from the perspective of technology B, IBM for example used their knowledge of PC's together with BellSouth's knowledge of phones to develop the first computer phone combination: the Simon personal communicator phone. IBM (technology B) thus integrated their knowledge in the domain of BellSouth, the base technology, to develop technology C. So instead of the company from the base technology pulling technology B to its domain, IBM "pushed" their technology to the domain of BellSouth.

Table 7 Utilization of the functions of the essential technologies by the confluence technology, and the related domain changes of each case.

Case	Change in functions it can fulfill[1]	Missing functions[4]	Changes in application domain[2]
Smart TV	2013: PC 5/5[3] (100%) - OS 7/8 (88%) 2014: PC 5/5[3] (100%) - OS 8/8 (100%)	2013: MULTI 2014: None	Yes – But new domain was opened from the start
Smartphone	2006: PC 5/5[3] (100%) - OS 7/8 (88%) 2007: PC 5/5[3] (100%) - OS 8/8 (100%)	2006: MULTI 2007: None	Yes – But new domain was opened from the start
CNC machine	1975: PC 0/6 - OS 0/8 1991: PC 5/6 (83%) - OS 7/8 (88%)	1975: All 1991: MULTI	No – Continued in the same domain even though new essential technology was added.
Skype	2003: 2/3 (67%) 2004: 3/3 (100%)	2003: PC to telephone calls 2004: None	No – Continued in the same domain even though new essential technology was added.
Digital camera	2010: PC 5/6 (83%) - OS 7/8 (88%) 2012: PC 6/6 (100%) - OS 8/8 (100%)	2010: APPS - MULTI 2012: None	Yes –By better integration of its essentials. People want to directly review their photo, changed the relevant attributes.
Satellite phone	1997: 1/1 (100%)	1997: N/A	No – Continued in the same domain
Multifunction printer	1991: PC 4/6 (67%) - OS 4/8 (50%) 1995: PC 4/6 (67%) - OS 6/8 (75%)	1991: APPS, storage - MULTI, FILE, SEC, UI 1995: APPS, storage - MULTI, FILE	Yes – But new domain was opened from the start
Laser lithography	1991: 1/1 (100%)	1991: N/A	No – Continued in the same domain
CT scanner	1967: PC 0/6 - OS 0/8 1971: PC 4/6 (67%) - OS 2/8 (25%)	1967: All 1971: APPS, output PER - PEXEC, MULTI, FILE,	Yes – But new domain was opened from the start
Electric toothbrush	2010: PC 3/6 (50%) - OS 1/8 (13%) 2014: PC 3/6 (50%) - OS 2/8 (25%)	2010: APPS, input PER, Storage – PEXEC, MEM, MULTI, FILE, IO, NET, SEC 2014: APPS, input PER, Storage - PEXEC, MEM, MULTI, FILE, IO, SEC	Yes – But new domain was opened from the start

1 It is said to fulfill the function if it does so even in its most primitive way. For example, it has IO when other hardware can be connected to the device, even though it does not have the same IO ports a PC has.

2 The application domain changes are relative to the domain of the base technology (technology A).

3 PC has six functions of which one of them is already present in the other technology (display in TV and not PC).

4 Many acronyms are used in the table of which the meaning can be found in Appendix C.

Interestingly, in 1983-1984, IBM partnered with, and later acquired, ROLM Corporation, a company based in computers and telecom (IBM, 2015). The question remains what part of the domain specific knowledge IBM together with ROLM was missing, that BellSouth did have? If it is at least related to knowledge, it could as well have something to do with for example the installed base BellSouth had, in order to gain an advantageous position when launching the new product (Van de Kaa & De Vries, 2015).

Even though the scenario of Figure 4 has not been found from the perspective of the base technology, the scenario is in theory possible; in this case, however, it would mean that cellphone technology is incorporated in the PC. This would be the case when the hardware to access the cellular network is embedded in the PC system, for example in portable computers. This is already possible using an external device (e.g. dongle) but it is not incorporated in the PC system as of yet. Considering the fact that 5G wireless networking will have a speed of around 10 Gigabits per second compared to 4G with 100 Megabits per second (Shankland, 2015), it is not extraordinary to think that if this trend of wireless transmission speeds continues, the currently used underground cables may become obsolete. Underground cables are more costly to maintain, but currently more reliable, compared to the wireless telecom stations.

Overall, it is interesting to see that seven out of 10 cases have a PC as essential technology, of which three are currently utilizing all of the functions a PC and an OS of a PC have. To what degree these functions are similar to a PC is not analyzed, therefore, some of them may only employ the bare minimum. This common PC base among various technologies also allows more devices to communicate with each other: each device utilizing PC technology functions can at some point communicate with either a PC itself, or one of the other devices incorporating a PC. A smartphone can for instance both communicate with a PC and with the smart TV, or even the electric toothbrush. By sharing such a technological base across devices, networks are integrating.

4.4. Enablers for adding technology versus replacing technology

When talking about the development of a confluence technology, we in essence talk about adding a new essential technology or replacing an essential technology. It is found that, when adding a technology, often an "enabler" is present. Such an enabler connects the existing technology to a new essential technology: a base technology to a technology B.

Because in most of our cases technology is added, additional cases are gathered in which technology is replaced. These are: steamship (steam engine replaced sail), electric vehicle (electric engine replaced combustion engine), microwave oven (electromagnetic radiation replaced resistor[4]), mobile telephone (antenna replaced wired base station[5]), and the transistor radio (transistor replaced vacuum tube). Table 8 shows the cases where technology is added versus where technology is replaced, and their respective enabler.

An enabler can be a technology that is present before the technology is added, and acts as an intermediary through which the combination is made possible. For some, this enabler is more obvious than for others. For example, the combining of PC technology with the camera was made possible by the CCD light sensor together with flash storage. Similarly, the photon detector could digitalize the input data for the CT scanner, which enabled the PC to be integrated in the CT scanner. In other cases, such as the multifunction printer and smartphone, similar hardware architectures were found which made the whole easier to combine. Each application of the multifunction printer either includes the scanning or printing of paper. The early smartphone was in terms of hardware very similar to a mobile phone. One could argue the software of a mobile phone was enhanced with functionalities from PC technology. Together with hardware improvements, such as a better processor and faster/more memory, this resulted in the smartphone.

In the case of Skype, an enabler could not be identified. In this case, the technology was developed similar to replacing a technology: by developing technology from available or acquired knowledge. With Skype, knowledge of Peer-to-peer networking was gained, or improved, via an earlier project named Kazaa, a file sharing application.

[4] There are multiple types of ovens, here we compare to an electric oven, in which resistors are used to radiate heat energy.

[5] Here as well there are different types of fixed phones. Our comparison assumes a cordless phone to contain a display and keypad, and the base station connects the phone to the fixed telephone network.

Table 8 Availability of "enablers" in cases where essential technology was added versus essential technology replaced.

Technology added	Enabler	Technology replaced	Enabler
Multifunction printer	Copier and fax contain printer and scanner. Similar architecture (Kodama, 2014)	Steamship	-
Smartphone	Similar hardware architecture compared to mobile phone (Kodama, 2014)	Electric vehicle	-
CT scanner	Digital photon detector	Microwave oven	-
Smart TV	Set-top box technology	Mobile telephones	-
Electric toothbrush	Timer	Transistor radio	-
Digital camera	Flash storage + CCD technology	Satellite telephone	-
CNC machine	APT technology	Laser lithography	-
Hybrid vehicle	Transmission, batteries		
Skype	-		

In our findings it appears to be much more common to require an enabler when adding technology, than replacing technology. This may be because when adding a technology, technologies from different knowledge domains are often combined. The enabler then acts as a "hybrid" of these knowledge domains, connecting the domains. Looking at Table 8, we find in our case studies that, for instance, the set-top box (STB) of the smart TV, the APT of the CNC machine, and the transmission of the hybrid vehicle are such hybrids, build from an understanding of two different knowledge domains. Before the smart TV, the STB allowed users to watch the regular television channels, but also for video-on-demand streaming purposes via the internet. The STB thus already contained bits and pieces from PC technology.

With the CNC machine, the automatic programming tool (APT) automated the process of creating the punched cards, and PC technology was partly integrated in the APT in order to do so. Later, the punched card was removed from the process, and the entire programming was done digitally. Lastly, with the hybrid vehicle, the transmission combined the power from the electric engine with the combustion engine, allowing the two to complement each other.

With Skype, an enabler was not necessary because the domain specific knowledge of each of the essential technologies, had, arguably, much overlap. They were both from the same technology stream, and the developers had worked together before on another project.

5. Distinguishing types of technological confluence

Our goal is to distinguish different types of confluence that lead to different processes through which the confluence technology moves, and evolves. Up to now, we have found that literature and our data regarding the duration of the innovation phase point in the same direction, and knowledge proximity can therefore be considered a factor of influence on this duration. Overall, with confluence technologies, the innovation phase is found to be shorter compared to that of other technologies, and the adaptation phase longer. Furthermore, we hypothesized that when entering a new application domain, or a new technology stream, a longer innovation phase is to be expected. And finally, we hypothesized that in case *both* a new application domain and technology stream are entered, the two reinforce each other causing an even longer duration.

Also, we have found that the knowledge acquiring strategy depends not only on whether a technology is in a new or the same technology stream, and we found that this strategy may change over time. The decision to join or start an alliance also has to do with the type of competition (price or non-price), a company's technological environment, and the value a firm gives to incoming knowledge spillovers. For the combining of technologies, incoming spillovers are a great asset, on the condition they match the direction a company wishes to head: the domain specific knowledge.

Thirdly, it is discovered that by a better utilization of the functions of the essential technologies, the application domain of the confluence technology can change. Also, by the addition of technology even the technology stream that a technology belongs to may change.

And to conclude, it is found that when adding a technology to another, an enabler often ought to be present in the form of another technology that acts as an intermediary, or in the form of the essential technologies having a similar architecture.

There is, however, one addition: the technological principle of the new technology compared to its predecessor. In case the technological principle of a known technology changes, such as microwave oven technology compared to heat oven, how this technology is designed to be used often changes as well, influencing a user's habits. The two often go hand-in-hand. In chapter one, the example was given of the sail ship, where the sail was then replaced by a steam engine. This forced shippers to learn a new approach to moving forth a ship. Being aware of the impact a new technology can have on its customers' habits, can help in the developing of a strategic roadmap to smoothen the launch. For instance, a company could develop complementary technology to make the technology more appealing to customers, make its technology compatible with another, lecture its users, or by initially developing a hybrid version such as a sail ship with steam engine. Change, however, does not always come with such an impact. With Skype, the addition of peer-to-peer networking was not found to affect a user's accustomed way of using internet telephony because the relevant attributes remained the same, rather it changed the architecture. This architectural change resulted in Skype being able to deliver its internet telephony service free of charge. Due to the fact that computers directly talked to each other (peer-to-peer), instead of via servers, the costs of running an internet telephony service decreased significantly while maintaining the same service as its competitors. Another example is the addition of multi-tasking to the smartphone, a function transferred from PC technology. In contrast to Skype, multi-tasking did change the user-end by allowing a user to run multiple applications and switch between them. Multi-tasking, however, did not interfere with any other function or habit a user may have had. A user was still able to do everything the way this user was accustomed to, the only difference being the fact that applications were kept "alive" in the memory of the phone, in the background. Therefore, this expanded the capabilities of the smartphone, without influencing a user's accustomed behavior, and, in the meantime, increasing the interrelatedness of the essential technologies of the smartphone. Because of this, we find that the only way that a user's habits can be interfered with, is when the attributes of a technology that a user values are changed: which are the relevant attributes of a technology. Besides the influence on a user's habits, a change in the technological principle is also expected to cause a more lengthy innovation phase because a base technology is influenced at its core by the change of essential technologies. This suggests it becomes harder to develop the new technology by the firm owning the base technology.

The preceding factors are found to have an influence on either the process that a confluence technology moves through, or the duration of the innovation or adaptation phase, or on both. Because of their influence, these factors are selected and embedded in our confluence model, which is displayed in Figure 6. The aim of the model is to distinguish different types of confluence based on factors influencing the process of development and diffusion, in order to aid a manager of a firm in their strategic decision making. There are different situations in which a company developing a confluence technology can find itself in. Each situation is referred to as a "type of technological confluence", and is defined by a specific combination of factors, with the factors with the biggest influence being shown in Figure 6.

On the horizontal axis we have positioned the technology, consisting of the technological principle and change in essential parts of this technology. And on the vertical axis the knowledge proximity together with the application domain have been positioned. The knowledge proximity is based on whether a technology is launched in a new or the same technology stream, because this caused the biggest distinction in the duration of the innovation phase and, as discussed earlier, the adaptation phase as well. How each factor is defined, and other guidelines to using this model is described in section 5.1.1. The application domain, we found, is for each technology dependent on the main functionality it fulfills, and the attributes a customer considers to be important of this technology. The main functionality of a car is for example transportation, and that of an electric toothbrush is oral hygiene. The relevant attributes of an electric toothbrush are for instance: bristle type, movements per second, and battery life, which are different from the regular toothbrush.

In the confluence model, 16 cases have been positioned; 10 from our dataset and the other six are these collected in chapter 4.4 because our cases mainly added essential technology, and we lacked cases where technology was replaced (see also Table 8). The additional set of cases from Table 8 are written in *Italic*.

Figure 6 is the result of six experiments with three practitioners from different companies. At the beginning of each experiment, practitioners were given 16 cards with the names of the 16 cases, and asked to position these in the model. During the experiment, hard to position, ambiguous cases were discussed. In some cases, this led to the removal of a case from the dataset, such as the smart watch because it was argued not to be a combination of technologies, and, in other cases, new insight was gained in certain variables by debating where a case should belong, and explaining why so. Each time, practitioners appeared to struggle with the relevant attributes; are they the same or not as its base technology? It is often argued by practitioners it depends on a person's preferences what attributes are important, making it a rather subjective variable. When, however, discussing the desktop – laptop – tablet example from chapter

			Technological principle			
			Same		New	
			Essential technologies		Essential technologies	
Technology stream of the new technology	Main functionality	Relevant attributes	Technology replaced	Technology added	Technology replaced	Technology added
Same	Same	Same	Laser lithography, Satellite telephone, *Transistor radio*			CT scanner, Skype
Same	Same	New			*Mobile telephone, Microwave oven, Steamship, Electric vehicle*	*Hybrid Vehicle*, Smart TV
Same	New	Same				
Same	New	New				MF Printer, Smartphone,
New	Same	Same				CNC machine
New	Same	New				Digital camera, Electric toothbrush
New	New	Same				
New	New	New				

Figure 6 Model distinguishing types of confluence. Written in *italic* are the additional cases from Table 8.

one, where the three belong to the same technological group but each emphasizes a different subset of attributes, we always came to an agreement when a certain set of attributes is different from its base technology.

We agree, it remains a bit of a subjective variable for which discussions are necessary. But a company often has a certain product based on a certain combination of technologies in mind to develop, by adding the relevant attributes to the model of confluence, the envisioned product is linked to the development of its required technology.

Other discussions arising during the experiments were caused by differences in knowledge on a specific case, leading to different positions of a case in the confluence model. The digital camera, for example, is currently part of the mechatronics technology stream, where it first was part of the mechanical stream. Not knowing this caused practitioners to position it under the "same technology stream", instead of a "new technology stream". However, when asked if a technology would be developed within the practitioner's company, whether it would be easier to identify a change of technology stream, practitioners said they most likely would.

Having performed these six experiments with practitioners, we can be much more certain about the validity of the model, and its practical application. It becomes more valid in that external audits with people active in the field share their experience, which each time helped the development of the model to progress, together with the definition of the variables. Yet, we wish to emphasize the model is not ready for practical use by managers. Even though we have identified, what we argue to be, the major determinants for the process of development and diffusion and its duration, this complex process is not exclusively determined by these factors. In addition, we have not been able to analyze and formulate recommended strategies for each type of confluence. Further research should point out what other factors influence the shape and duration of a process per type of confluence. And, in order to make it applicable for managers, for each type of confluence a matching strategic recommendation should be formulated.

5.1.1. Guidelines to using the model

In the model, we continuously compare a company's base technology with the product of confluence (read: technology C). We will walk through some practical guidelines to using the confluence model, especially in the definition of each of the variables on the axis. We start with the horizontal axis, where the technology is positioned, and continue with the vertical axis, in which the knowledge proximity and application domain are positioned.

A technology is defined by its technological principle, and its essential technologies. The technological principle is derived from the abstract process that a technology embeds in order to carry out its main function. A vacuum tube radio, for instance, receives radio waves and passes on the signal of a, by its user set, frequency, and transforms these back into their original form, after which it amplifies the signal, and outputs audio. This level of abstraction leaves room for the replacement of a part, in this case, allowing the vacuum tube to be replaced by a transistor without altering the principle by which a radio works. A contrasting example is the mobile telephone, in which, simply put, the base station of a fixed telephone was replaced by an antenna, and a battery. This changed the process by which the telephone signal was received, thereby changing the technological principle.

The other variable on the horizontal axis is "essential technologies of a technology". Essential technologies are the components of a technology that are required to make the technological principle work (Jonckheere, 2015, p. 3). Vacuum tube technology in the radio is such an essential technology, which was replaced by transistor technology. Because in defining the essential technologies the technological principle is followed, this in essence means that via the process a technology works with, the components that are essential can be identified. For a more elaborated explanation and more examples of essential technologies we refer to Jonckheere (2015, p. 3).

On the vertical axis, the first variable is the technology stream of the product of confluence. The technology stream is synonym to the field of applied science a technology belongs to. When the field of applied science of the base technology is different from the new technology, the technology stream is considered new. The NC machine, for example, is developed under the field of Mechanical engineering. Later, when PC technology was added as an essential technology, the NC machine became an essential technology of the CNC machine, and continued under the header of Mechatronic engineering. This occurred mainly because PC technology significantly influenced the essential technologies of the NC machine.

The second variable on the vertical axis is the main functionality, which is similar to the customer need that a technology fulfills. A car, for example, is made for transport purposes, a telephone for telecommunication, and an electric toothbrush to cleanse your teeth with.

And the last factor, the relevant attributes of a technology. The relevant attributes are the rudiment properties of a technology that a customer values. For the digital camera, for example, these are determined as: size, weight, quality of photo, display to review photos, and storage size.

The latter two variables together define the application domain that a technology belongs to. A new application domain is entered when either or both of the variables is changed. In the model, the application domain has been split into these two variables because a change in the main functionality of a technology suggests a more difficult to develop product of confluence, and thereby possibly a different process pattern and/or duration. Furthermore, when a change in the technological principle of a technology leads to a change of the relevant attributes, a customer's habits are often influenced. Whether this is a positive influence or not, depends on the nature of the change. As discussed earlier, the addition of a display to the digital camera changed the relevant attributes, but has, arguably, been a positive influence. This, because its users could now immediately review a taken photo, instead of first having to develop a photo or copy it to a PC with the added risk of not knowing whether the photo was successful.

Lastly, there are two side notes to be mentioned when using the model. First, it could occur that essential technologies are both added and replaced. In this case, position the technology under "technology added", because when adding a technology, often, an enabler either needs to be present or be developed. This is not the case when replacing a technology (see also section 4.4). And second, as discussed in the previous subsection after Figure 6, the subjective variable "relevant attributes" is in the model because a product is often in mind that exists of a combination of technologies, via the relevant attributes, a company's product is linked to the technology that it requires.

6. Discussion and conclusion

In this chapter, each type of confluence will be discussed, based on what separates them in terms of their process of development and diffusion. To begin with, each type has been given a name, respective to their degree of complexity from the perspective of a company. In Figure 7, the names of the types are shown, and are given from the perspective of the company. Therefore, an incremental confluence, for example, indicates the least complex confluence for a company, in terms of the distance of knowledge, and application domain the technology is developed in. The gray colored areas on the left half of the model are argued to be unlikely situations for each their respective reason, which is described in the field itself.

As said, the types of confluence are seen through the lens of a company. What makes each type unique is the varying distance of knowledge, and distance of a new technology's application domain relative to that of its base technology, which leads to different processes of development and diffusion of a confluence technology. As can be seen in the model, rows of the "relevant attributes" are combined and given a name together. This is done, for now, because more impact on the process of development and diffusion is caused by a change of main functionality. When changing the main functionality, an entire new area is entered from the perspective of the firm. In this area they likely have little or no experience, which potentially lengthens both the innovation and adaptation phase because they have to, respectively, gain new knowledge and find out what relevant attributes to focus on, and adapt to new customers. A new set of relevant attributes indicates a new group of products that fulfill the same main functionality, such as the desktop-, laptop-, and tablet computer. The addition of the relevant attributes to the model is, however, important because it links the product that a company wishes to develop, which has undergone a discussion on the relevant attributes, with the confluence technology.

In Figure 7, the names vary depending on the degree of complexity from: "Incremental confluence", to "Progressive confluence", "Reconfigurative confluence", "Transfer confluence", and lastly, "Revolutionary confluence". In the coming sections, each of the types is elaborated upon. In the figure, for each type of confluence the duration of the innovation and adaptation phases are added.

			Technological principle			
			Same		New	
			Essential technologies		Essential technologies	
			Technology replaced	Technology added	Technology replaced	Technology added
Technology stream of the new technology: Same	Main functionality: Same	Relevant attributes: Same	**Incremental confluence** [2] - Innovation length: 4.5 (2.1) - Adaptation length: 9.5 (7.8)	**Unlikely situation #1** The addition of an essential technology goes hand-in-hand with a change of technological principle.	**Progressive confluence** [3] - Innovation length: 2.7 (1.5) - Adaptation length: 7.3 (10.2)	
		Relevant attributes: New				
	Main functionality: New	Relevant attributes: Same	**Unlikely situation #2** A change of main functionality is unlikely to occur when the technological principle remains the same. For every attempt in making a technology suitable for a new purpose, a new technological principle results.		**Reconfigurative confluence** [2] - Innovation length: 7.0 (5.7) - Adaptation length: 10.0 (5.7)	
		Relevant attributes: New				
Technology stream of the new technology: New	Main functionality: Same	Relevant attributes: Same	**Unlikely situation #3** Similarly to above, a change of technology stream is found to be the result of the addition of a technology from a different technology stream, that influences the technological principle. A change of technology stream is therefore unlikely to occur when the technological principle remains the same.		**Transfer confluence** [3] - Innovation length: 10.7 (10.3) - Adaptation length: 25.7 (10.3)	
		Relevant attributes: New				
	Main functionality: New	Relevant attributes: Same			**Revolutionary confluence**	
		Relevant attributes: New				

Figure 7 Reviewing the model and naming the types of confluence. Indicated between brackets is the amount of cases the values are based on.

In the top left of the figure we find "*Incremental confluence*". A technology is advanced by replacing a technology in the base technology, leading to a new technology. Examples are laser lithography, and the satellite telephone. From the perspective of the company this means that because the technological principle remains the same, the only thing required is to gain knowledge from the replacement technology. Regarding the evolution of such a technology (Figure 8), we find that the new technology stays within the same application domain, and products based on this technology further incrementally improve because a higher efficiency in the cooperation of the essential technologies is reached. With our dataset, the duration of the innovation phase is found to be on average 4.5 (2.1) years, and the adaptation phase 9.5 (7.8) years.

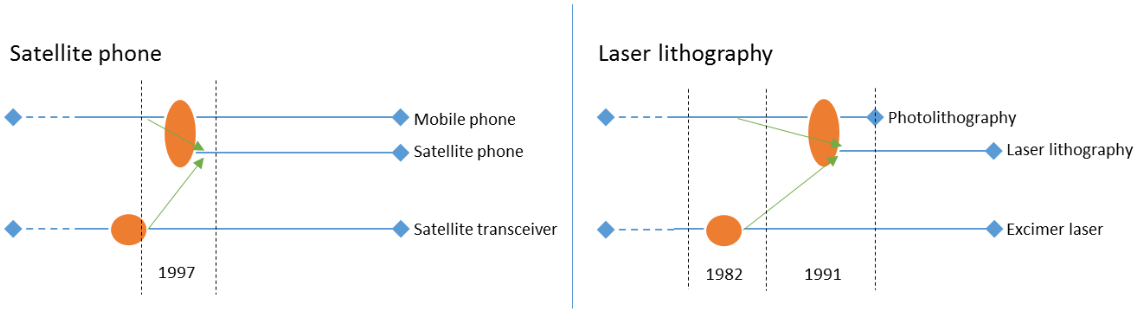

Figure 8 Incremental confluence pattern of evolution

The second type of confluence is "*Progressive confluence*". Which is given this name because the technology advances in a different way than its base technology (new principle, different composition of essential technologies), while doing so within a much similar environment as its base technology (same technology stream, same main purpose it fulfills). Thus, within its own field, it advances by attempting a different approach, which we consider progressive. Examples are Skype, the CT scanner, and smart TV of which the evolution of each technology is shown in Figure 9. A progressive confluence can both result in products in a new application domain and the same, based on a change of the relevant attributes. A difference between the digital television and the smart TV is the added attribute of connectivity that customers may consider important. Smart TV users want the ability to, for example, stream videos from the internet. What makes this type different from an incremental confluence is the fact that by the addition or replacement of an essential technology, the technological principle changed. This adds to the complexity of the development. For early versions of the CT scanner it took a PC a couple of days to calculate the 3D image from the separate X-ray images. Furthermore, the quality and precision of this 3D image was poor due to programming errors, and a low amount of photon detectors. The fact that the technological principle had changed caused researchers to re-design many of the elements of the technology. With Skype, the entire architecture of the software was redesigned compared to other internet telephony software. Similar with the smart TV, in which the role of PC technology increased over the years. All these technologies, however, remained within the same context as their base technology, and advanced by changing the very nature of the base technology by altering the essential technologies. Our dataset indicates an average duration of the innovation phase of 2.7 (1.5) years, and for the adaptation phase 7.3 (10.2).

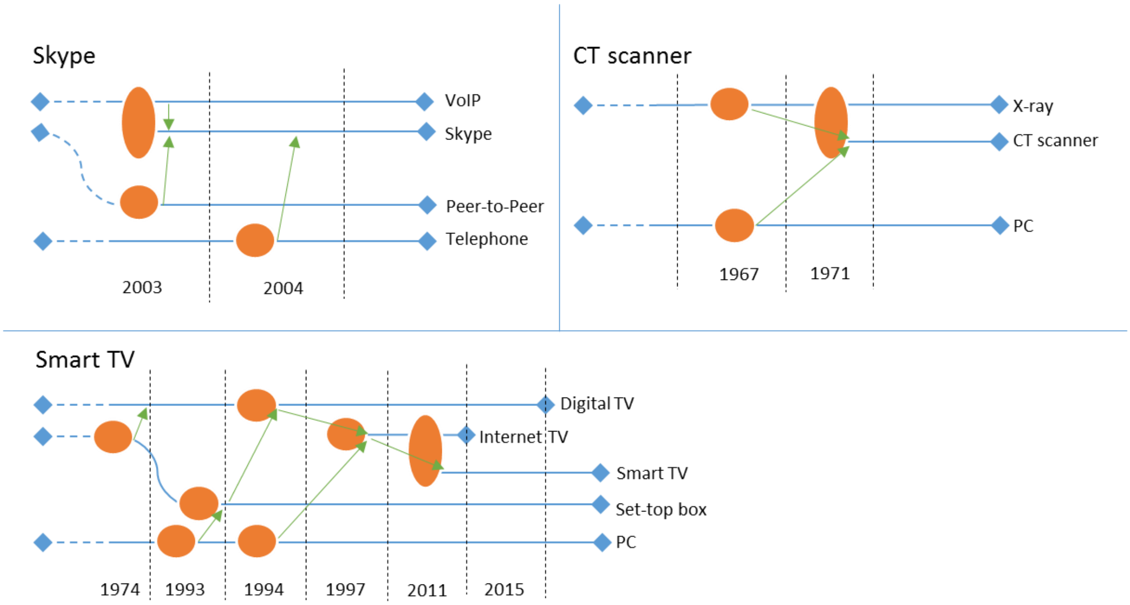

Figure 9 Progressive confluence pattern of evolution

The third type is *"Reconfigurative confluence"*. This type has been given this name because a base technology is reconfigured to fulfill a new purpose. A change in the essential technologies not only leads to a new technological principle that the technology operates via, it also grants it a new purpose, a new main functionality. This automatically causes it to enter a new application domain, this time independent of a change of relevant attributes. We expect that with this type of confluence, the relevant attributes are always new because with the change of main functionality, a technology is developed that is new to the world but complementary to its base technology.

From our dataset it appears that technologies of this type of confluence have an intermediate step, likely because of the newness of this type of technologies to the customer, and a company therefore is possibly searching for the right combination of relevant attributes (see Figure 10). What is now called a multifunction printer (MFP), was first called an intelligent copier/printer. Similarly, what started as the personal digital assistance (PDA), is later on renamed a smartphone. A name change appears to go hand-in-hand with a focus on a larger audience and a change in the functions that a technology has by a better interrelatedness of the essential technologies. The PDA was first directed to the business users and focused on for instance e-mail, group conversations, and the calendar. When renamed, the smartphone added media functions which caused it to become more mainstream. The intelligent copier/printer was an early attempt to develop an all-in-one printer with the ability to multi-task scanning, printing, copying and faxing. However, the software was troublesome and scanning documents to a computer was not possible yet, let alone multi-tasking. During this troublesome period, the media called it a "Hydra", for it had many "heads" and remained mythical for quite some years. A new name was being used after scanning was added and software issues were mitigated, marking the start of the MFP. With this type of confluence, a relatively longer adaptation phase of on average 10.0 (5.7) years is found. The innovation phase appears to be on average 7.0 (5.7) years.

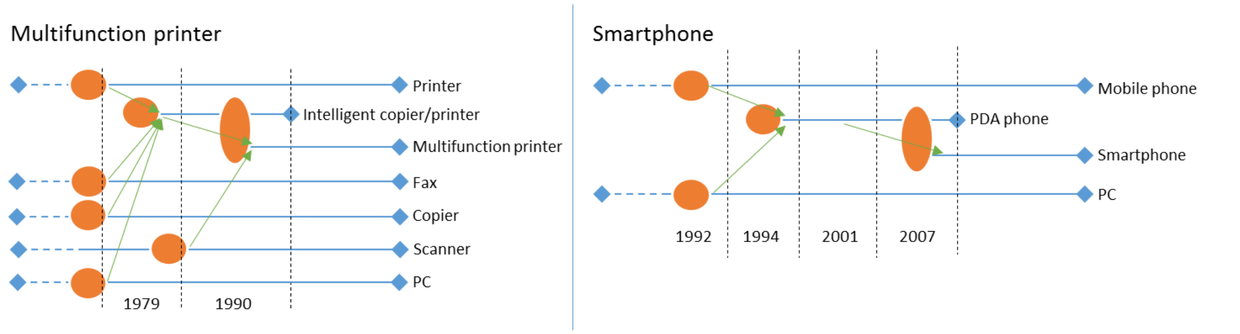

Figure 10 Reconfigurative confluence pattern of evolution

Next, with a "*Transfer confluence*", technology from a different technology stream is used in the base technology, causing the entire technology to change from technology stream while the main functionality remains the same. Developing a technology as part of a new technology stream is earlier hypothesized to lengthen the duration of the innovation and adaptation phases. From the perspective of a company, knowledge needs to be transferred from a new stream to the firm, where the required domain specific knowledge has less overlap with a company's knowledge base (assuming it only developed the base technology). Examples of this type of confluence are the CNC machine, electric toothbrush, and the digital camera. These cases indicate a duration of the innovation phase to be 10.7 (10.3) years on average and the adaptation phase even 25.7 (10.3) years, both longer durations than prior mentioned types of confluence. Similar to progressive confluence, a new application domain can be entered when the set of relevant attributes changes. With the electric toothbrush, battery life and rotations per minute were new attributes, and with the digital camera it was the ability to immediately review a taken photo or video. Looking at the process of development and diffusion in Figure 11, most characterizing is the addition of multiple technologies over time. Where the basic principle was often reached by the first addition, it was later on enhanced and made more efficient by the addition of another technology, often being PC technology. The role of the technology enabling the confluence to take place (the "enabler") is much more visible in the process, and is bigger with this type of confluence than with the formerly mentioned types.

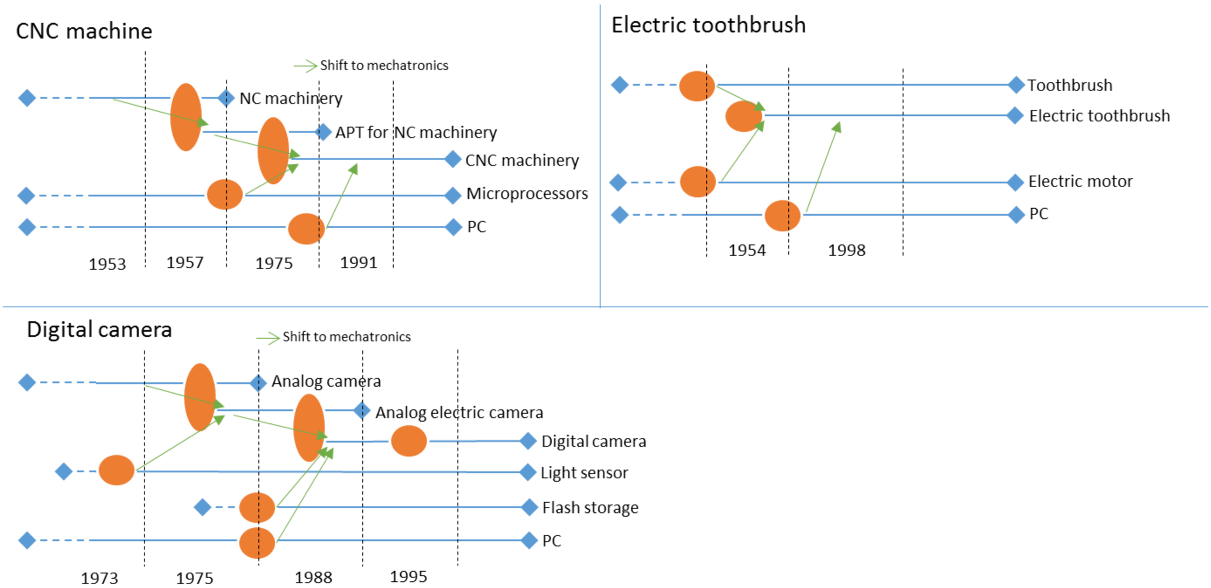

Figure 11 Transfer confluence pattern of evolution

And lastly, a *"Revolutionary confluence"* stands for the most complex type of combining technologies. This type is in essence similar to a reconfigurative confluence, in that the base technology is reconfigured to fulfill a new purpose, a new main functionality, and because of this, a new application domain is entered as well. With a revolutionary confluence, however, the new technology is part of a new technology stream. Looking at the factors influencing the duration of the innovation and adaptation phase, this type of confluence is expected to have the longest duration of all. This is mainly due to the overall distance of knowledge relative to the base technology. A fictive situation in which this type of confluence can occur is when, for example, a company that develops satellite transceivers starts to develop satellite telephones. From this perspective, thus with the satellite transceiver as base technology, the product of confluence starts to fulfill an entirely new purpose via a new technological principle as part of a new technology stream. Again, the example with the satellite telephone is fictive, and is actually developed by telephone company Bell labs. We have not been able to identify cases that match this type of confluence.

Overall, it is fascinating to see that, on average, the innovation phase is shorter for confluence technologies than other technologies. This difference, however, does seem to become smaller when moving towards more complex types of technological confluence. A transfer confluence, for example, is found to have an average duration of the innovation phase of 10.7 years, where the average length of the innovation phase of other technologies is found to be 10.0 years. Most technologies engaging in technological confluence, however, are incremental confluence, progressive confluence, or reconfigurative confluence, which all have shorter lengths of the innovation phase than the average of other technologies. On top of that, even though our data indicates that the adaptation phase takes longer with confluence technologies, we have reason to believe that the adaptation phase is not different for confluence technologies than for other technologies. Further research should point out what factors are characteristic to confluence technologies. If this turns out to be the same factors for confluence- and other technologies, this indicates very favorable conditions regarding the influence of technological confluence on the process of development and diffusion of technologies. It would mean that the innovation phase is shorter, while the adaptation phase remains unaffected. If this turns out to be the case, it means that a company starts earning money earlier by innovating via technological confluence, than other means of innovation that also result in new products.

In addition, looking at Figure 7, it is interesting to see that the durations of the innovation and adaptation phase of each type of confluence is different, and shows an upward trend. This certainly makes the influence of the factors identified more plausible, as the data found turned out to be in accordance with the expected outcome. All in all, there is yet much to unravel in this new overarching perspective on the combining of technologies, and we suggest the following six hypotheses:

H1: The innovation phase is shorter when developing certain types of confluence than other technologies.

H2: The market adaptation phase is longer when developing confluence technologies than other technologies.

H3: The innovation phase of a confluence technology takes longer when a new application domain is entered compared to the same.

H4: The innovation phase of a confluence technology takes longer when a new technology stream is entered compared to the same.

H5: When entering both a new application domain and technology stream, the two reinforce each other and the innovation phase of a confluence technology takes longer than with H3 and H4.

H6: The market adaptation phase of a confluence technology is influenced by the application domain and technology stream.

Besides this, we have learned about the ways of filling a knowledge gap, and the antecedents leading to a certain strategy. By opting an embedded multi-case study design, we have gained knowledge on the interplay of knowledge and the process by which a technology evolves. Via the two units of analysis in this study, we were able to visualize the evolution of a technology, and consider the distance of knowledge a factor influencing the overall process.

A limitation to this study that we unfortunately found hard to mitigate is the amount of cases, namely, the overall amount of technologies existing of combinations of technologies matching our unit of analysis is limited. That, at least, have been successful on the market. Which leads us to the pro-innovation bias of our case selection. Cases that engaged in the combining of technologies, but failed on the market have not been added to this study because too little data is available on these cases. Also, because of the limited availability of confluence cases, we have not been able to gather data from all industries, and industry specific characteristics could therefore not be identified. We also do not know if a certain type of confluence is specific to an industry due to such specific characteristics. Another consequence of this inability is investigating the co-evolution of industries, which comes forth from the perspective of technological convergence (Jonckheere, 2015, p. 9). It would be interesting to see if not only technologies reach out to other technologies and become intertwined, but whether entire industries tend towards the same. And lastly, during the process of development and diffusion of a confluence technology, different actors may join and leave the process, affecting the duration or the process. For future research we also leave the search to factors influencing the process of the innovation phase, and the developing of recommendations for managers at companies for each type of confluence. All in all, a thrilling new field of research has opened up with technological confluence, and we are very eager to see how this further develops into a practically employable strategic tool for innovation for managers.

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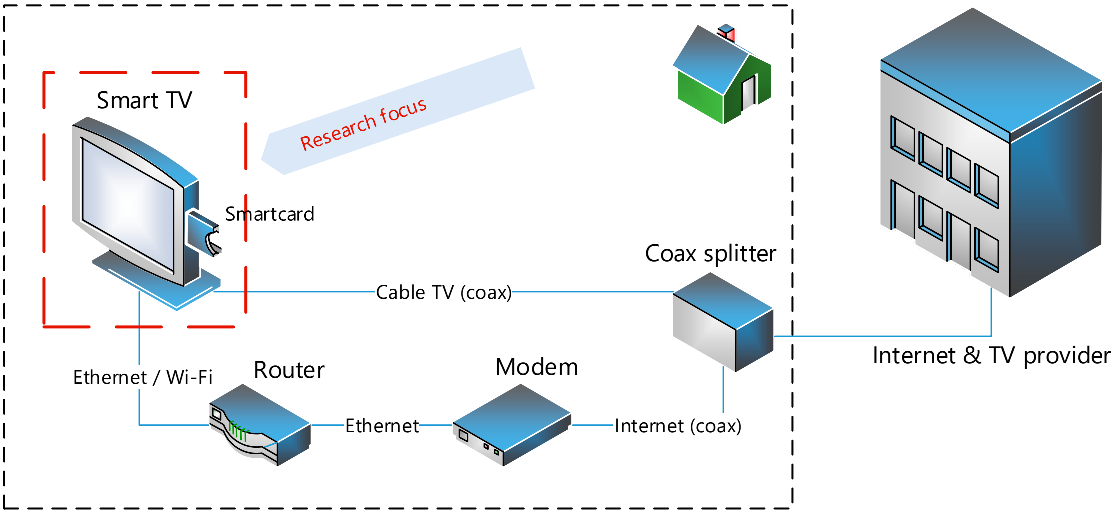
Appendix A: Case study report of the Smart TV

1. Smart Television

1.1. Context

Variable	Value
Proof of technology (year)	1994
Geography of first proof	France
Industry	Information and Communication / Consumer electronics
Technology stream	Electronic engineering
Technological principle	Display still or moving images by decoding an electrical signal of which access is granted. Software operating system user interface allows the user to switch between the TV signal and the intra- and/or internet connection.



1.1. Product essential technologies

Essential technologies	Technology description			
	Technology stream	**Technological principle**	**Function**	**Parts**
Television	Electronic engineering	Receiving via an analog electric signal, decoding and displaying of still or moving images.	Entertain, educate, inform	Signal decoder for different types of electric input signals, command receiver (controller & buttons), output (loudspeaker & display)
Set-top box	Electronic engineering	Receiving via a digital or encrypted analog electric signal, decoding and output the decoded signal via a certain protocol (e.g. HDMI, SCART, optical).	Decode an encrypted signal and send it in a, for the connected device, understandable language.	Signal decoder for a specific type of electric input signal (e.g. UHF, satellite, IPTV, cable), command receiver (controller & buttons)
Personal computer	Computer science	Electronic calculating, storage, and display device that only uses 1's and 0's as data.	Input, store, process, display data	Operating system, applications, input and output peripherals, processor(CPU&GPU), storage

1.2. Application domain Television and Smart Television

	Application domain			
Case	**Customer need (function)**	**Customer group**	**Technology**	**Relevant attributes**
Television	Entertain, educate, inform	Consumer TV	Television	Video quality, size
Smart Television (early = internet TV)	Entertain, educate, inform	Technology enthousiasts	Internet TV	Video quality, size, connectivity, software
Smart Television (current)	Entertain, educate, inform	Consumer TV	Smart television	Video quality, size, connectivity, software

1.3. The product over time

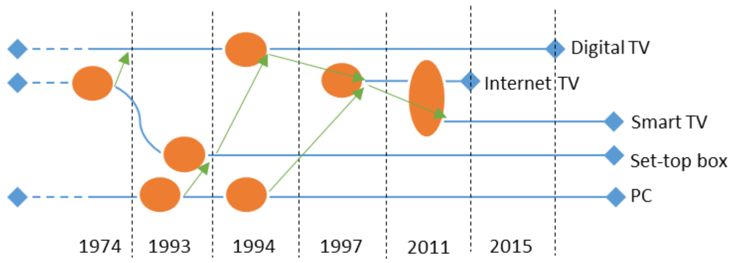
		Interrelatedness of the essential technologies		
Product name	**Year**	**Television**	**Set-top box**	**Personal Computer**
Digital Television	1974	Cathode ray tube (CRT) color TV	Originally called a “Video receiver”, “UHF converter” or “Demodulator”. Device decodes digital channels into for a TV understandable data.	
Internet TV	1993		Internet access for computers via cable instead of telephone line. Mentioning of “interactive TV”.	
Connected TV / Internet TV / WebTV	1994	Patent filed indicating the integration of a TV with set-top box and networking with computers to, for example, store information transmitted or received by the television.. Uses a CPU, could be used for internet shopping, and has IO module for connecting to peripherals such as a printer or a bar code reader.		
WebTV / Internet TV	1997		WebTV comes with separate box that connects to the internet over the phone line	WebTV is a terminal with a web browser and e-mail client. Supports regular computer keyboard (wired or wireless). Subscription of $19.95 p/m is required.
Connected TV / Internet TV / Interactive TV	2000	LCD TV	Built-in for internet connectivity, but cable companies often deliver as separate box with same purpose	Powered with Microsoft TV platform. Access the internet for: email, online shopping, stocks, sports, news and weather.
Connected TV / Internet TV / Interactive TV	2006			PhotoShowTV (software program) where photos can be send to and viewed on other devices supporting Microsoft’s Windows Media Center such as television, Xbox 360, and PC.
Connected TV / Internet TV / Interactive TV	2008			TV can access the internet (wired) for: news, weather, stock, YouTube, support DLNA, USB for photos music and videos, pre-loaded movies and games.
Connected TV / Internet TV / Interactive TV	2009	LED TV	Movies on demand	Wi-Fi support, widgets (+ SDK for developers) to access the internet (e.g. weather, stocks, share photos, watch movies, simple e-commerce).
Connected TV / Internet TV / Interactive TV	2010	Full HD 3D LED TV		Internet access same as before but via downloadable apps instead of pre-installed widgets. Connect PC and mobile phone to TV wirelessly. Addition of a web browser.
Smart TV	2011		Video on demand (built-in)	Local & internet smart search function (search files on connected devices), social networking,

Smart TV	2012		Voice control, motion control, Cloud connection (for content stored on TV & access this content via other devices)
Smart TV	2013		Voice control enhanced, Automatic software updates, software learns a user's customs & recommends content
Smart TV	2014	Ultra HD LED TV	Image recognition (identify & capture big moments in soccer game), multi-tasking.
Smart TV	2015	Super ultra HD LED TV	Quick connect smart devices, content optimized TV, domotica with other (samsung) smart devices, personal data can be viewed on TV (email, alarms, schedules, etc.)

1.4. Remarks

- Consumers want Personalized TV, Continuous entertainment, Content interaction, Advanced forms of interaction (Prabhala & Ganapathy, 2011).
- Since 2015 Samsung only produces smart TV's, all other types of televisions are discontinued (Samsung, 2015).

Smart TV



Smart Television													
	Television				Set-top box			Personal computer					
	Decoder	Command	Loudspeal	Display	Decoder	Internet	Command	Operating	APPS	Input peri	Output pe	CPU	Storage
1974		x	x	x	x								
1993		x	x	x	x								
1994		x	x	x	x								
1997		x	x	x	x	x		x		x		x	
2000		x	x	x	x	x		x		x		x	
2006		x	x	x	x	x		x		x		x	
2008		x	x	x	x	x		x		x		x	x
2009		x	x	x	x	x		x	x	x		x	x
2010		x	x	x	x	x		x	x	x		x	x
2011		x	x	x	x	x		x	x	x		x	x
2012		x	x	x	x	x		x	x	x		x	x
2013		x	x	x	x	x		x	x	x		x	x
2014		x	x	x	x	x		x	x	x		x	x
2015		x	x	x	x	x		x	x	x		x	x

Smart Television										
	PERSONAL COMPUTER									
	OPERATING SYSTEM								STORAGE	
	PEXEC	MEM	MULTI	FILE	IO	NET	SEC	UI	INTSTOR*	EXTSTOR*
1974										
1993										
1994										
1997	x	x								
2000	x	x					x	x		
2006	x	x					x	x		
2008	x	x			x	x	x	x		x
2009	x	x			x	x	x	x	x	x
2010	x	x			x	x	x	x	x	x
2011	x	x		x	x	x	x	x	x	x
2012	x	x		x	x	x	x	x	x	x
2013	x	x		x	x	x	x	x	x	x
2014	x	x	x	x	x	x	x	x	x	x
2015	x	x	x	x	x	x	x	x	x	x

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Appendix B: Duration of the Innovation and Market adaptation phase of the cases

Case	Innovation phase	Adaptation phase	Total time	Technology stream
Smart TV	1994-1997: 3 years	1997-2015: 19 years	22 years	Same
Smartphone	1991-1994: 3 years	1994-2007: 14 years	17 years	Same
CNC machine	1953-1975: 22 years	1975-1991: 17 years	39 years	New
Skype	2003-2003: 1 year	2003-2004: 0 year	1 years	Same
Digital camera	1973-1975: 2 years	1975-1997: 23 years	25 years	New
Satellite phone	1976-1979: 3 years	1979-1994: 15 year	18 years	Same
Multifunction printer	1979-1990: 11 years	1990-1995: 6 years	17 years	Same
Laser lithography	1982-1988: 6 years	1988-1992: 4 years	10 years	Same
CT scanner	1967-1971: 4 years	1971-1973: 3 years	7 years	Same
Electric toothbrush	1954-1962: 8 years	1962-1998: 37 years	45 years	New
Mean value:	**6.3 years**	**13.8 years**	**20.1 years**	

* Marked rows are technologies that started in the same application domain as their base technology.

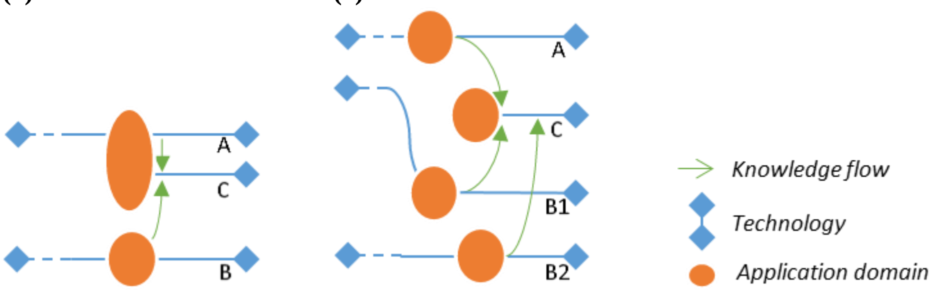
Appendix C: List of acronyms for the functions a PC has.

- **OS**: Operating system
  - Kernel
    - **PEXEC**: Program execution (load / unload applications, schedule tasks)
    - **MEM**: Memory management (memory allocation)
    - **MULTI**: Multitasking (multitude of programs can run at the same time, user can switch between them)
    - **FILE**: Disk access and file systems (file management)
    - **IO**: Device drivers (I/O management)
  - **NET**: Networking (connect to an existing system of devices)
  - **PER**: Input and Output peripherals (e.g. keyboard, mouse, display)
  - **SEC**: Security
  - **UI**: User interface (OS has a ‘desktop’)
- **INTSTOR**: Internal storage
- **EXTSTOR**: External storage support (e.g. USB drive or SD card)
- **CPU**: One main processor
- **APPS**: User manageable applications (user is free to install and remove software programs)

Appendix D: Confluence case processes

There are two basic differences distinguishable in the visualization of the confluence of each case. A technology can be pulled towards an existing domain (visual 1 below: technology A and B lead to C), or the combination of technologies opens up a new domain (visual 2: Technology A and B1 lead to C). Either one of these or a combination of the two principles can always be identified in a constructed timeline.

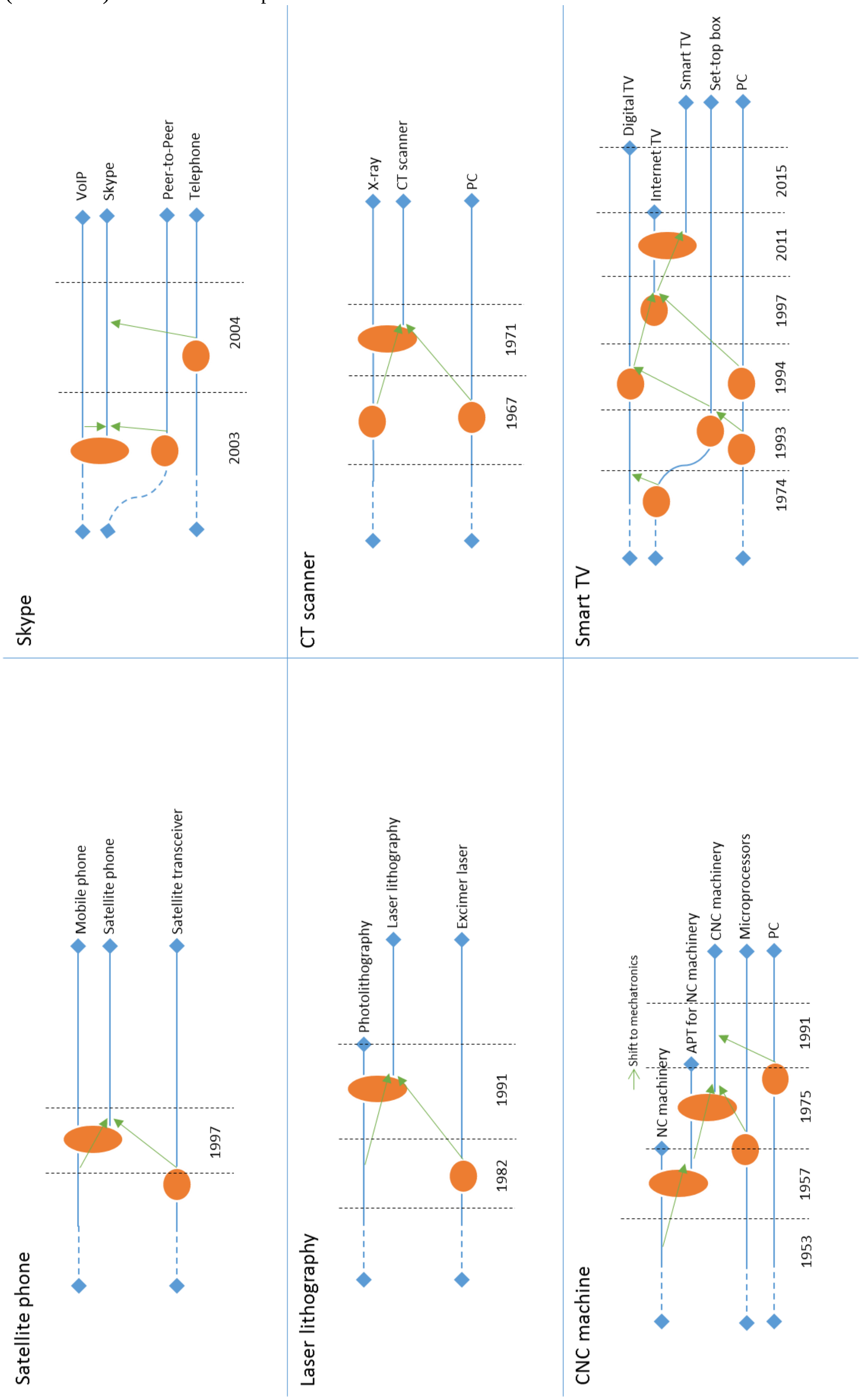
(1) **(2)**



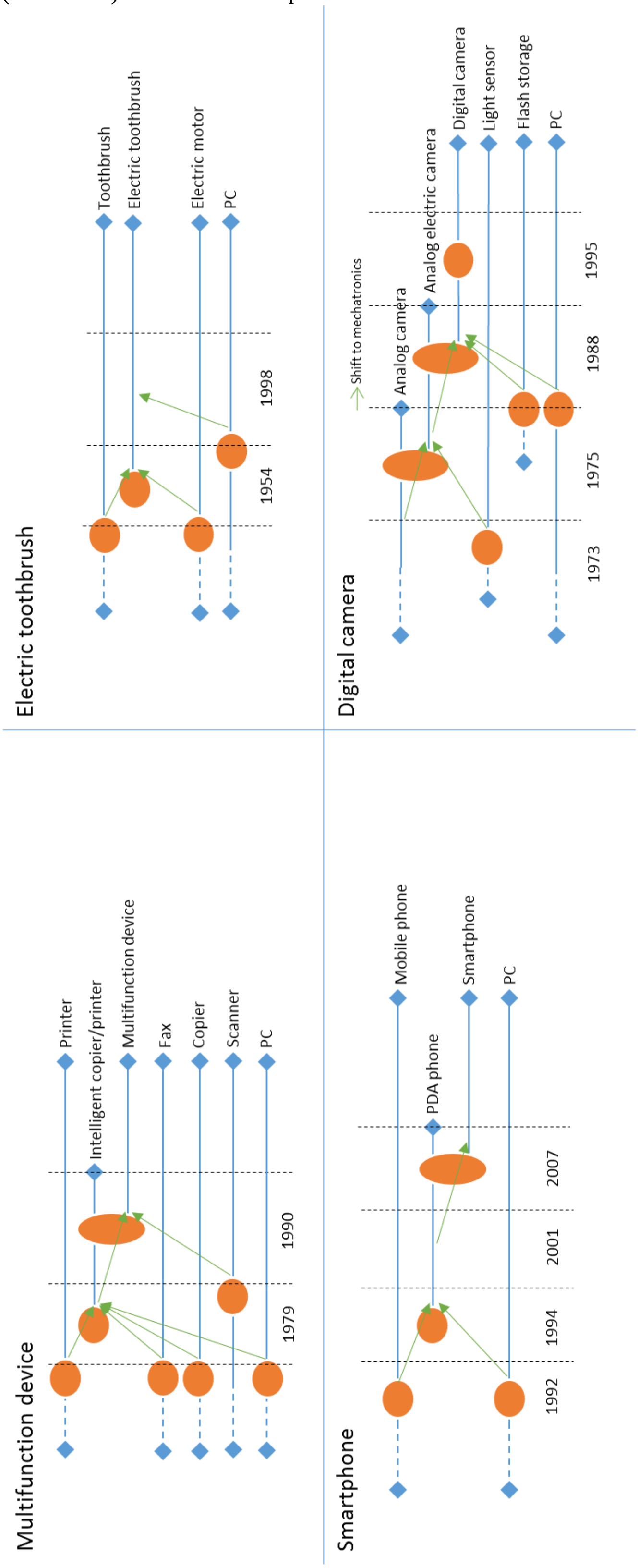
The proof of concept of a technology is marked by the diamond shape at the start, after which the dotted line indicates that we focus on a section of its entire lifespan. The diamond at the end of the line either marks the discontinuity of a technology, if it is stopped earlier compared to other timelines, or indicates that the advances have been analyzed up to the time of the analysis, if a dotted line at the end is missing. The circle and oval shapes on each line indicate the application domain of the technology, and the arrow shows the knowledge flow. Often, an arrow will be drawn over time to show the first notion of a (new) technology, and the moment it has been implemented.

As can be seen in visual 2, the timeline of technology B1 is bend towards technology A. This indicates that the two technologies are from the same technology stream. The word “technology stream” is used as a synonym to “fields of applied science”. Over time, other technologies may be added such as technology B2 in visual 2. This sometimes causes a technology to shift domain which will be indicated by a new, separate circle. On the next two pages the timelines of the cases can be found.

Appendix D (continued): Confluence case processes



Appendix D (continued): Confluence case processes



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“Conclusion, Discussion, Reflection”

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1. Conclusion

In this study, we set out to answer the question: *"What is the effect of innovation via the combining of technologies on the process of development and diffusion?"*. This question we split into five sub-questions of which an overview is given in the table below. In this chapter, our findings regarding the sub-questions are presented after which the main question is answered in the discussion.

Table 1 Formulation of the research sub-questions

>> SUB-RQ1: What perspectives to the combining of technologies can be identified?
>> SUB-RQ2: How are these perspectives different from each other?
>> SUB-RQ3: How can the overarching perspective "technological confluence" be defined?
>> SUB-RQ4: What types of technological confluence can be recognized?
>> SUB-RQ5: What process(es) of technological confluence can be identified?

In finding an answer on our main research question, we first set out to identify all perspectives on the combining of technologies. Then, a systematic literature review on these perspectives is performed which led to insight in the boundary of each perspective, and the differences among these perspectives.

As a result, three perspectives have been identified: Technological convergence, Technology fusion, and Technology integration.

The term "Technological convergence" was first mentioned by Rosenberg (1963), who described that companies from different industries, from the perspective of their final product, started to cooperate to solve a common issue with their metal-cutting machinery. From our literature review, the majority of literature agrees on technological convergence being about the process of combining two or more technologies from distinct industries. A consequence of such interdisciplinary cooperation is argued to lead to co-evolution (Lei, 2000). This, because companies from different industries start to rely more on each other's technology, by which they grow closer and stimulate each other. An example can be found in the software and hardware industry, where an improvement in one industry stimulates the other to innovate faster. From the perspective of the software industry, video game developers, for example, desire to develop ever more complex games with better visual experiences, which asks for more demanding hardware, thereby stimulating the hardware industry (Lei, 2000, p. 705).

Kodama (1986) described another phenomenon in the combining of technologies, which he named "Technology fusion". Technology fusion is about innovating in a non-linear and complementary way (Kodama, 1992, p. 70). It is found non-linear and complementary because technologies from previously separate technological fields are combined, resulting in a new, hybrid, technology. Also characteristic to technology fusion is the cooperative aspect that, Kodama (1992, p. 76) argues, is essential to the success of innovating via technology fusion. A reciprocal and substantial strategic alliance in which partners are together committed to a R&D project, may that be exploratory research or product development, and in which they have mutual responsibilities and benefits.

Technology integration focuses on developing or positioning a technology to fit in an existing environment, by making the technology compatible with other technologies in the environment (Stock & Tatikonda, 2004) (Iansiti, 1995). Also, technology integration is used in the context of incorporating a technological *product*, instead of a technology, within an existing environment. The difference being that a technology is developed to fit in an environment, whereas incorporating a product is about acquiring the knowledge required to optimally use this product. An example of a technology is a software development tool that is developed to complement other software development tools so that the aggregate efficiency of developing software increases. Thus, a product is *being developed*. After having finished this product, it is incorporated within a business environment. This is where the second context of technology integration steps in: product integration. This part of technology integration focuses on helping a firm get acquainted with the product by transferring knowledge from an expert to the firm.

Up to now, the main concept as described at the first introduction of each perspective has been summarized. Over time, however, the scope of each perspective has widened and concepts have sometimes been interpreted differently. Table 2 shows a summary of the differences among the terms, in the coming sections we will address the overlap of the terms from which the outer boundaries of the combining of technologies will also become apparent.

Technological convergence is introduced as an interdisciplinary, or differently put, inter-industry phenomenon, in which, over time, intra-industry convergence was added. A first example where intra-industry convergence takes place can be found in the telecom industry, between the fixed telephony and mobile telephony (Vrdoljak, Vrdoljak and Skugor, 2000). A second example can be found in the software industry, today's operating system, such as Windows, embeds a variety of once separate applications, such as: word processing, virus detection, spreadsheets, internet browsers, cloud computing, and media players (Lei, 2000, p. 705). This, however, appears similar to the perspective of technology integration. Namely, in both intra-industry convergence and technology integration, there is an aggregate environment in which various technologies/products complement each other. The only difference between the two appears to be the actor, with intra-industry convergence the aggregate environment (e.g. Windows) embeds other products and technologies, whereas with technology integration, a product or technology is developed to fit such an aggregate environment (e.g. software development tool). Another widening of the scope of convergence occurred with the publication of Schnaars, Thomas and Irmak (2008), who state that often an entirely new product or entirely new industry results from the process of convergence. Schaars et al. define a new product as revolutionary products that shift market structures, require consumer learning and induce behavior changes such as the electric vehicle or personal computer. With this, the scope of convergence now included innovation that leads to new industries and revolutionary products, whereas first, a combination of technologies resulted in new products within the context of the base technology. This widening of scope resulted in an increased overlap with technology fusion, where a combination of technologies as well results in products in a new context (Figure 1, left visual).

Another finding indicated that, in this case, technology fusion is open to interpretation of a researcher. Rao,

Table 2 Differences among the three perspectives

	Technological convergence	**Technology Fusion**	**Technology Integration**
Main concept	Co-evolution of industries that stimulate and influence each other. Inter- and intra-industry.	Reciprocal strategic alliances to develop new complementary technologies by combining.	Embedding products in an existing environment.
Unit of analysis	Technology	Technology	Product, partly technology
Perspective	Industry	Firm	Firm
Combinations of (original)	Replacing a component in your technology with this from a different industry	Adding technology from different technological fields	Develop a technology for a certain environment. Implement a product within a certain environment.
Combinations of (current)	*Adding* or replacing a component in your technology with this from a different *or the same* industry	Adding *previously unrelated* technology	Has not changed.
Drivers	Deregulation, innovation in complementary products, integrative technological platforms	Open architecture technologies	From a company's perspective, external products
Strategies	Strategic alliances, co-specialization, focus on core competences	Reciprocal and substantial strategic alliances, knowledge gathering competences, market-driven R&D	External technology integration, complementary product integration
Resulting application domain	Mostly same	Mostly new	Same
Knowledge flow	Bidirectional	Bidirectional	Directional

Angelov & Nov (2006) describe Skype to be a technology fusion case in which two technologies, Peer-to-Peer (P2P) networking and Voice over IP, are combined of which Skype resulted. Skype certainly disrupted the internet telephony market because by the addition of P2P networking, servers were no longer required as clients directly talked to each other leading to a significant decrease of the cost of running an internet telephony service. The technologies Skype exists of, however, are from the same technological field, they both originate from the software field. Furthermore, the combination of the two technologies did not result in a technology being launched in a new context, or new application domain. The fact that the application domain remained the same shows that the perspective of technology fusion is interpreted differently compared to Kodama (1992), causing an increased overlap with the field of convergence. And in particular intra-industry convergence due to two technologies being combined from the same industry.

Looking at Figure 1, convergence currently entails both the left visual as well as the right, where it first only considered the right visual. Since the publication by Rao et al. (2006), technology fusion moved vice-versa, from the left visual to also including the right visual.

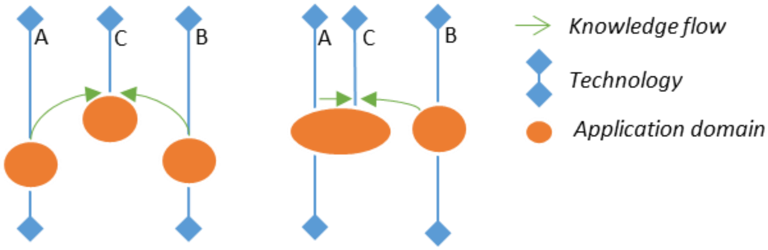


Figure 1 Entering a new application domain or continuing within the same.

From each of the three perspectives it is shown what type of combinations are originally discussed, versus what is currently discussed. Current convergence literature is found to currently have broadened its view by both allowing components to be added and replaced, and by adding intra-industry convergence. Technology fusion is broadened by letting loose the requirement of a technology being from a different technological field by discussing combinations of previously unrelated technologies. The field of technology integration is the youngest of the three, and does not appear to have changed over time. In addition, the perspective through which each perspective approaches is given. Convergence looks at industries, where fusion and integration at firms. Thus, where convergence and fusion have in common their unit of analysis and type of combinations, fusion and integration share the perspective from which they look. This together results in all perspectives moving in closer to each other, a process characterized by the figure below.

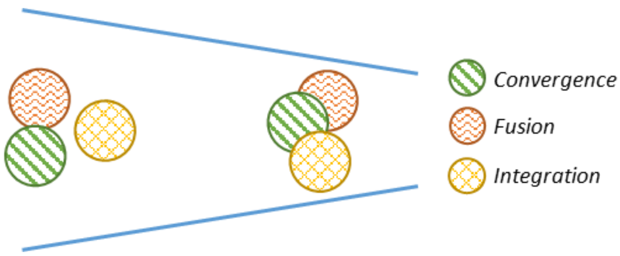


Figure 2 Changing overlap of the perspectives over time

Also interesting to see is the amount of references that the various perspectives share with one another (Jonckheere, 2015, p. 13). A cross-reference analysis indicated that about 20% of the references from the fusion literature is shared with convergence literature, that is, literature in our dataset. Fusion shares less with integration with 12%. This is interesting because it again indicates convergence and fusion are more alike than integration is. Fusion and convergence are found to be approaches to innovation, whereas integration entails the implementation of a technology or product in an environment.

A final difference identified between the fields of convergence and fusion, and integration, is the direction of knowledge flow. The knowledge flow in convergence and fusion is bidirectional because industries either stimulate each other (convergence), or a strategic alliance is argued essential (fusion). With integration on the other hand, a directional knowledge flow is present due to the implementation aspect. Knowledge on, for instance, a product (e.g. Enterprise Resource Planning system) is acquired from a company with expertise on this product. Also, when integrating a technology (e.g. software development tool) to fit in an existing environment and complement other tools, knowledge flow is also not bidirectional, unless developed in a strategic alliance. An alliance is, however, not a condition to technology integration.

>> SUB-RQ3: How can the overarching perspective "technological confluence" be defined?

Knowing the core concept of each perspective and their mutual differences and boundaries, we can develop our definition of technological confluence. We have defined Technological confluence as: innovation by changing the set of essential technologies of a system, where unrelated technology replaces an essential technology in the system, or a technology is added to this system (Jonckheere, 2015, p. 15).

A technology is defined as a specific set of essential components, that via its technological principle fulfills a certain main functionality. A basic electric oven, for instance, consists of a temperature sensor, thermostat, resistor, fan, screws, bolds, electric wire, and a housing. The bill of materials of such an oven may exceed 100 items, of which many are, however, not *essential* components to the *technology*. The essential components are these that are required in the *process* of the technological principle. When an electric current flows through the system, the resistor starts to emit heat energy. The electric current will continue to flow through the heat element (resistor) until the temperature sensor measures the upper threshold, or preferred temperature, set by the thermostat. Then, the thermostat will attempt to keep the oven at the same temperature by iterating the process when the temperature drops below a certain threshold. Via this description of the technological principle, we find that the essential components are the resistor, temperature sensor, and thermostat. The other items on the bill of materials therefore indirectly influence the system via added functionality, such as the fan. Screws, bolds, and the housing on the other hand are essential to the product, rather than the technology. This definition of a technology can be applied widely to many technologies. When *combining* technologies, however, we have chosen to refer to the essential components as "essential technologies" because often a base technology is present to which another technology is added. Both technologies in turn have their own set of components. When referring to a technology it is more intuitive to think of the aggregate of components that a combination exists of. This way, a smart TV is said to exist of TV technology and PC technology, that in turn each have their own set of components.

The combining of technologies is about changing the set of essential technologies that a base technology (initial technology, such as the electric oven) consists of. Such a change can occur when adding a technology to an existing base, or when replacing a technology in a base. When changing a composition of essential technologies, the technological principle and main functionality that a technology consists of can change as well. When, for instance, replacing the resistor in the mentioned electric oven with microwave technology, the technological principle of the oven changes, while its main functionality remains the same. Another consequence of changing the composition is that the application domain that a technology is part of changes.

With this definition, an overarching perspective on the combining of technologies is created. This is required in order to systematically distinguish the different types of combining technologies that have a different process of development and diffusion. Our fourth research sub-question focuses on identifying the various types, which we refer to as types of technological confluence, and the fifth sub-question focuses on the process that each of these types follows.

>> SUB-RQ4: What types of technological confluence can be recognized?

Five types of technological confluence have been recognized which are found to differ in terms of their process of development and diffusion. From a case study of 10 cases, three main variables have been identified to influence this process, being: technological principle, technology stream, and the main functionality, and two sub-variables, being: essential technologies, and relevant attributes. How each variable influences the process is part of the fifth research question. The five types of technological confluence have been named based on the level of complexity from the perspective of the firm owning the base technology. The identified types are called, from least to most complex: Incremental confluence, Progressive confluence, Reconfigurative confluence, Transfer confluence, and Revolutionary confluence. Table 3 shows an overview of each type including a description of the main concept of the type, its characteristics, the average durations of the innovation and adaptation phase, and the cases that we analyzed belonging to this type. What makes each type different is the interplay of the variables, causing the resulting confluence technology to be unique in terms of its process of development, and its process of diffusion in the market.

For a revolutionary confluence we have not been able to establish the process characteristics and the average durations of the phases. In a case of this caliber, a company is challenged to bridge an intriguing knowledge gap, the largest knowledge gap there is in the combining of technologies. In such a situation, a company has a certain base technology, which when combined with another technology results in a technology with a new technological principle, new main functionality and is part of a new technology stream. Technology B in this case, is far away from a company's knowledge base, but is going to define a large part of the functionality of the confluence technology. A technology will only be part of a new technology stream when the added technology significantly influences the system as a whole. This type of confluence would occur, for example, when a company that develops computer processors decides to develop a microwave oven, washing machine, or mobile phone under its own brand. Or when a company developing satellite transceiver modules starts to develop a satellite telephone.

>> SUB-RQ5: What process(es) of technological confluence can be identified?

To start off with, the duration from the invention of a confluence technology up to its first market introduction (innovation phase) is found to be, on average, shorter than other types of innovation: 6.3 years compared to 10.0. The adaptation phase, on the other hand, is found to be longer with confluence technologies: 13.8 compared to 6.7. We have argued it is plausible that the innovation phase is shorter, because with technological confluence, the combined technologies have, often, been applied in the form of products before. Because it is already known what the technologies in separate look and function like, it is easier to sketch an image of what the combination would be like. This, however, currently applies to incremental confluence, progressive confluence, and reconfigurative confluence. Because a transfer confluence is found to have an average duration of 10.7 years, which is above the average duration of other means of innovation. Also, the duration of a revolutionary confluence is not known due to the lack of cases identified, but is, due to the distance of knowledge, expected to take longer than a transfer confluence. The following hypothesis is left for future research:

H1: The innovation phase is shorter when developing certain types of confluence than other technologies.

When the technology is first introduced in the market in the form of a product, the market adaptation phase starts. The market adaptation phase is found to take longer with confluence technologies (13.8 years). An explanation for this phase to take longer could be that existing networks need to adapt to the new technology. Networks need to converge, which possibly takes longer than building an entire new network. Another reason could be that a confluence not directly results in a technology of a competitive price/performance ratio to incumbent technologies. Which has, for example, likely been the case for a long time with the hybrid vehicle. This is, however, not a variable characteristic to confluence technologies, as followed from a study by Ortt & Delgoshaie (2008) on factors influencing the adaptation phase. Likewise, the network effect is also a factor identified by Ortt & Delgoshaie, however, related to building an environment of a technology, or network, instead of adapting. It is therefore questionable whether the longer adaptation phase is characteristic to confluence technologies, as our data suggests. For future research we formulated the following hypothesis:

H2: The market adaptation phase is longer when developing confluence technologies than other technologies.

Having described the average durations, next step is the influence of the variables found on the duration and the

Table 3 Different types of technological confluence.

	Incremental confluence	Progressive confluence	Reconfigurative confluence	Transfer confluence	Revolutionary confluence
Main concept	Innovating by replacing a technology from the base technology with another.	Progress a technology by changing the technological principle while fulfilling the same main functionality as the base technology. Confluence technology is launched within the same context as the base technology.	The essential technologies of the base technology are changed and reconfigured for a new main functionality. A new market is entered, often in a new context.	Technology from a different technology stream makes a significant impact on the new confluence technology, shifting the new technology to a new technology stream.	A base technology is given a new purpose by changing its essential technologies. Similar to Reconfigurative confluence, however, the product of confluence is part of a new technology stream.
Process characteristics	Evolution of the technology is characterized by increased effectiveness of the cooperation of the essential technologies.	Short innovation phase after which it either disrupts the market or eventually replaces the base technology.	After innovation phase the new technology either disrupts the market it is launched in or eventually replaces the base technology.	Often, an enabler is yet to be added to the base technology. Characteristic is the addition of multiple technologies due to this.	-
Mean duration innovation phase	4.5 years	2.7 years	7.0 years	10.7 years	-
Mean duration adaptation phase	9.5 years	7.3 years	10.0 years	25.7 years	-
Technological principle	Same	New	New	New	New
Main functionality	Same	Same	New	Same	New
Technology stream	Same	Same	Same	New	New
Example cases	Satellite telephone, laser lithography	CT scanner, Skype, smart TV	Multifunction printer, smartphone	CNC machine, digital camera, electric toothbrush	-

process of development and diffusion. How long the innovation phase takes is found to depend on the distance of knowledge relative to the company. The distance of knowledge is defined by the technology stream and application domain. A technology stream is defined as the field of applied science that a technology belongs to, such as mechatronics, automotive, semiconductor physics, computer engineering, and aerospace engineering. The application domain is defined by the main functionality that a technology fulfills, together with the relevant attributes. Relevant attributes are the functional attributes of a technology, of which a subset is found more important in a certain group of products. When, for instance, looking at the desktop computer, laptop, and tablet we find that different attributes are found "relevant" in each of these groups. With the laptop emphasis is on mobility with built-in hardware input devices, and with the tablet the same but without such hardware devices. For a desktop computer, on the other hand, mobility is a lot less relevant.

Looking at the different types of confluence, we found that the duration of the innovation phase differs per type. And because the duration differs, the variables identified are argued to have an influence on this phase. This is similarly the case for the market adaptation phase. For future research we hypothesized that when entering a new application domain, a new technology stream, or both, the duration of the innovation phase is longer. For the market adaptation phase the hypothesis is differently formulated following up on the questionable duration of this phase with confluence technologies relative to other technologies (see *H2*). The hypotheses are formulated as follows (see also Table 4 for a visual representation of the hypotheses):

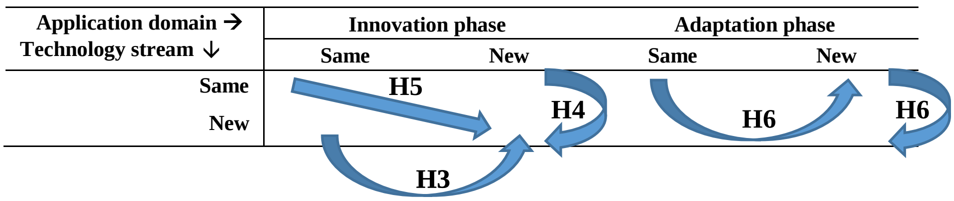
H3: The innovation phase of a confluence technology takes longer when a new application domain is entered compared to the same.

H4: The innovation phase of a confluence technology takes longer when a new technology stream is entered compared to the same.

H5: When entering both a new application domain and technology stream, the two reinforce each other and the innovation phase of a confluence technology takes longer than with H3 and H4.

H6: The market adaptation phase of a confluence technology is influenced by the application domain and technology stream.

Table 4 Illustration of the hypotheses



Thus, the application domain (combination of main functionality and relevant attributes) and the technology stream are argued to influence the two phases in terms of duration, but also in terms of its process.

A transfer confluence, for instance, is characterized by the addition of an essential technology by which the technological principle changes, and the resulting technology is launched in a new technology stream (see also Table 3). We found that an intermediate step is often required before reaching the desired technology of a transfer confluence. Most likely because technology from a different stream is starting to affect the entire base technology, and an enabler is necessary to bridge the two different streams. With the NC machine, the process of creating the punched cards was automated with a computer, creating the Automatic Programming Tool (APT), which led to the early version of the CNC machine. The punched cards were generated and placed in the machine. It was only later that the punched card was removed from this process, and the computer started to integrate in the machine. APT enabled this transition. With the electric toothbrush the digital timer connected the hardware with PC technology, and flash storage did so for the digital camera.

2. Discussion

"What is the effect of innovation via the combining of technologies on the process of development and diffusion?"

Our objective has been to find the effect of innovation via the combining of technologies on the process of development and diffusion. In unraveling this effect we focused on two phases, being the innovation phase and the market adaptation phase as shown in Figure 3 (Ortt & Schoormans, 2004).

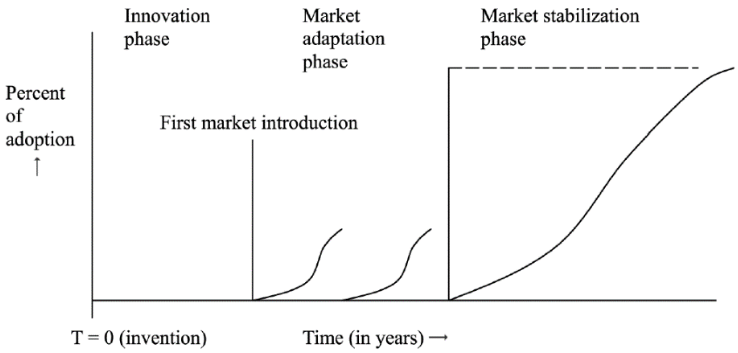


Figure 3 Three phases in the process of diffusion (Ortt & Schoormans, 2004)

What we found is that the perspectives on the combining of technologies were never systematically reviewed, leading to our overarching perspective of technological confluence. With this new perspective we set out to distinguishing the different approaches and processes of confluence, and identified five types of technological confluence. These five types are found to differ in terms of their duration of the two phases, and in terms of their process. The effect of innovation via the combining of technologies therefore differs per type of confluence.

A confluence starts with the addition of a technology to a system's set of essential technologies, or the replacement of an essential technology in this system. This, in turn, *can* influence the confluence technology in terms of its technological principle, main functionality, attributes, and the technology stream. We call them attributes here because a technology has all of them, whereas the *application* of a technology in the form of a product (group) lay emphasis on a *subset* of attributes, which make these attributes relevant for this product (group). Because a company is likely to have a certain type of product in mind when developing a certain technology, we in general refer to relevant attributes.

Looking at the duration of the types of confluence in Table 3, we see that the innovation and adaptation phase becomes longer when the complexity of a confluence technology increases with each consecutive type of confluence. Each type of confluence follows this trend nicely, one type, however, does not. An inconsistent result can be seen with incremental confluence, showing an average duration of the innovation and adaptation phase of respectively: 4.5 and 9.5 years, which is longer than the average duration of the next type, progressive confluence.

We identified two incremental confluence cases on which the average duration is based: laser lithography and satellite telephone. With laser lithography, the duration of the innovation phase is above the average of a progressive confluence (the consecutive type of confluence) with six years, where the satellite telephone took only three years. And with the adaptation phase, it is the other way around, laser lithography took four years and the satellite telephone 15 years.

What exactly caused the development of the laser lithography to take longer than the expected duration we do not know, and we can only theorize about the why. The first working principle of lithography with an excimer laser was shown at IBM in 1982, in a publication by Jain, Willson, & Lin (1982), we find that the performance in terms of resolution was comparable to state-of-the-art lithography using conventional lamps. In terms of speed the excimer laser technique proved ~2 orders of magnitude faster and thereby outperformed the conventional lamp. Jain et al., however, manifests laser lithography as a *"potentially practical technique"* (Jain, Willson, & Lin, 1982, p. 55), but does not state any remaining issues. It is possible that, due to the high precision required for lithography, issues lay in replicability. Lithography machines have two main specifications: resolution and overlay, where overlay stands for the tolerance that the overlay can be positioned with, time after time. So, it could still have been a challenging performance issue. Another explanation could be that after the potential of the technique was proven at IBM, other manufacturers started their own internal R&D instead of using that of IBM. If this is the case, every company has done their own prototyping and developed their own understanding of the excimer laser technique. The market of lithography machinery is characterized by non-price competition, which, we found, is an incentive for a buy or mixed strategy (Woerter, 2011, p. 633). ASML co-operated with Cymer to develop their own version using the same excimer laser technique. This means that, because there is non-price competition and manufacturers do not co-operate with each other to solve a common issue, the innovation phase is slowed down and thereby explaining the longer duration of the innovation phase.

Perhaps the best explanation for the longer adaptation phase is a technology's type of system (Tushman & Rosenkopf, 1992). Our case selection is partly based on the complexity of a technology. This was, however, formerly addressed by looking at the distance of knowledge of a technology relative to that of the base technology. Another approach to the complexity of a technology is to look at the type of system a technology is. Tushman & Rosenkopf identified four degrees of complexity: non-assembled products, simple assembled products, closed assembled systems, and open systems. Non-assembled products consists of one material or substance, such as glass, aluminum, and wood. A simple assembled product consists of a multitude of materials that are joined together, or linked, such as an aluminum can which has four components (top, bottom, side, opener). Next, a closed assembled system is an enclosed system with a clear boundary, such as a watch, bicycle, automobile, and an airplane. Lastly, we have open systems, for example: power systems, telephone, internet, and railroad. In developing open systems many more actors have a stake compared to closed systems, there are networks of organizations. An open system consists of a multitude of linked closed systems, where these closed systems are developed to fit in such an environment.

With the combining of technologies, previously separate systems or products come together by which a new system or product results. With our current dataset this resulted in a new closed system, or a new open system. The satellite telephone, an incremental confluence technology, is dependent on (the amount of) communication satellites orbiting earth. The satellite telephone itself is a closed system that is dependent on an open system. The innovation phase only took three years and focused on the development of this closed system, the adaptation phase, on the other hand, lasted 15 years. The most likely explanation for the longer average duration of the adaptation phase of an incremental confluence is therefore the dependency of the closed system on the open system of the satellite telephone, which is also referred to as the network effect (Ortt & Delgoshaie, 2008, p. 4).

Looking at a case under progressive confluence, the open system that a smart TV, for example, is part of was present long before the first smart TV appeared. In the early 1990's, after deregulation took place in the United States of America, cable companies upgraded their networks to allow internet signal using the existing TV cable infrastructure. Since then, an internet connection is present in a significant amount of households. The open system that a smart TV is part of has thus been ready for this new closed system for years, and did not need any further adjustment. A technology's type of system is therefore said to moderate the influence that a type of technological confluence has on the process of development and diffusion. The interplay of the identified variables on the process of development and diffusion is shown in Figure 4.

When a system changes from a closed to an open system, a longer duration of the adaptation phase can be expected. Because it then requires or becomes part of an open system, a multi-actor stage is entered which is likely to influence the knowledge acquiring strategy. This due to the requiring of additional knowledge to develop or adjust this open system. Other situations where the type of system could influence the duration of the adaptation phase is when two or more open systems are combined via a new, hybrid, closed system. This means that the previously separate systems need to adapt to each other's environment. Whether adapting takes more time compared to developing a new system is therefore worth investigating in a follow-up research.

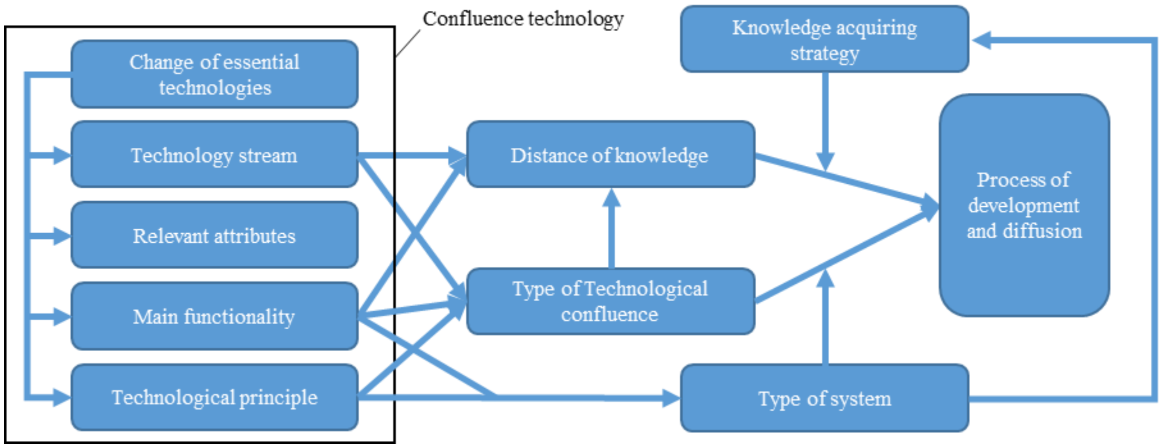


Figure 4 Variables affecting the process of development and diffusion of confluence technologies

2.1. Interplay of variables shaping development and diffusion

Other factors influencing the duration of the innovation and adaptation phase than these in Figure 4, are not ruled-out, in fact, in the previous subsection we highlighted some: network effect, performance of the new versus incumbent technology, and opting a strategic alliance depending on the type of market competition. Further research should further investigate the influence of these factors, and attempt to determine other factors influencing both the duration and process of the innovation phase.

Looking at Figure 4, we have identified what we consider to be the factors most characteristic to the combining of technologies. On the left, the factors that give shape to a confluence technology are positioned. This all starts with a change of essential technologies of a system, which can, in turn, influence the technology stream that this technology is part of, the relevant attributes that the technology has, the purpose it fulfills (main functionality), and the technological principle via which it operates. Overall, we see that the distance of knowledge together with the type of technological confluence influence the process of development and diffusion. Two moderating factors here are the knowledge acquiring strategy, and the type of system, both of which we discussed earlier. The distance of knowledge is dependent on the technology stream that the confluence technology is part of, and the main functionality. We consider the main functionality as well in the distance of knowledge because it indicates the degree to which technology B influences the purpose of the confluence technology. Relative to the base technology, a main functionality only changes when a new technology is added that starts to play a significant role in the system as a whole. The smartphone received a new main functionality because of the role that PC technology, technology B, played in the system. When the main functionality changes relative to the base technology, it indicates that the company owning the base technology has put effort into developing a system in which the, to this company unfamiliar, technology plays an integral role.

The type of technological confluence is determined by the technology stream, main functionality, and technological principle, and influences the process based on the necessity of an enabler or not. When an essential technology is added, an enabler is often found to be present, whereas when replacing technology this is not the case. For a progressive confluence and a reconfigurative confluence, the process does not appear influenced by the enabler. While its presence is required, the innovation and adaptation phase did not suffer under this requirement. With a transfer confluence, on the contrary, we analyzed three cases: CNC machine, digital camera, and electric toothbrush, and an enabler is found to influence the duration of the adaptation phase. In all cases, a confluence occurred with PC technology but before this confluence could take place, a hybrid, intermediary technology is added that enabled the confluence. With the CNC machine the confluence was enabled by developing the Automatic Programming Tool, with the digital camera flash storage was first required which could only be added after the integration of the CCD light sensor, and with the electric toothbrush the timer was first added before PC technology. For this reason, the type of technological confluence directly influences the process of development and diffusion.

2.2. Relating to other literature

In this subsection, the relation of our study to other literature will be discussed, where mainly the link between confluence and the former three perspectives is emphasized.

Ortt (2010) identified three scenarios of development and diffusion through which breakthrough technologies move (see Figure 3). Ortt found that, with breakthrough technologies, either: (i) the innovation phase takes longer than the adaptation phase, (ii) the adaptation phase takes longer than the innovation phase, or (iii) after the innovation phase large-scale diffusion immediately takes off. Considering the durations of the innovation phase and market adaptation phase of the confluence technologies analyzed in the second paper (see appendix B in paper 2), we find that, on average, the first and second scenario occur equally often over the entire dataset. Looking at the scenarios occurring within specific types of confluence, we find that with transfer confluence the second scenario is common, after which an, in comparison to other types of confluence, very long adaptation phase can be expected. With a reconfigurative confluence this varies, and both scenarios one and two can be expected here, where with a progressive and incremental confluence, scenario two appears again more common.

Furthermore, in our study on the combining of technologies, we combined the knowledge from three perspectives: technological convergence, technology fusion, and technology integration (see Table 2). These perspectives have remained close to technological confluence.

Technology fusion is the field that shares most aspects with technological confluence. Technology fusion discusses the combining of technologies from previously unrelated technological fields, with emphasis on the adding of essential technology and much less on the replacing. With technological confluence, we address the distance of knowledge relative to the base technology. The confluence technology can be part of a new technology stream (technological field in fusion literature), and can also result in products in new markets. Because of this, the field of technology fusion is most represented by the types transfer confluence and revolutionary confluence (both new technology stream).

With technological convergence, combinations of technologies are launched often within the same context as their base technology, replacing their position (see Figure 1 right visual). This is much like incremental and progressive confluence in that the context (i.e. main functionality, technological principle, relevant attributes) does not differ far from the base technology’s context. Furthermore, the industry aspect of convergence is partly represented in technological confluence in the form of the distance of knowledge. An industry tends to consist of technologies from the same (set) of technology stream(s). Therefore, a company looking to pull a technology from a different industry to itself, can come into contact with another technology stream. From the perspective of the company, the distance of knowledge in technological confluence then is similar with inter-industry convergence. With intra-industry this is different. Because an industry already contains a set of technology streams, it is perhaps easier for companies within the same industry to share knowledge. This, because (perhaps to a certain extent) they share the same industry specific characteristics, such as: jargon, customers, development platform or approach, speed of technological change. Whether this is of significant influence on the duration or complexity of confluence product development is a point for further research. And to conclude, a convergence can as well lead to a reconfigurative confluence, as follows from convergence literature stating that new products or even new markets can result (Schnaars, Thomas, & Irmak, 2008).

Regarding technology integration this is currently less the case. This research is due to time constraints limited to the analysis of the different processes and durations of the innovation and adaptation phase of each type of technological confluence. Strategies to handle these different types are left for further research. In defining these strategies for companies engaging in technological confluence, the role of the field of technology integration will become evident. The very nature of technology integration is to analyze an environment, and to develop a product that integrates well with this environment to improve its position, as well as the environment itself. The perspectives of convergence and fusion are as well great sources in finding these strategies due to their link with the types of technological confluence. Other fields of study relevant in defining the strategies are: new product development (Montoya-Weiss & Calantone, 1994), knowledge transfer and knowledge management (also includes knowledge distance, cognitive proximity) (Ensign, Lin, Chreim, & Persaud, 2014). Another very interesting field of study that is likely going to influence a wide variety of industries, is the digital factory, in which product development and production processes are enhanced via simulation and optimization (Kuehn, 2007).

2.3. Limitations

The population to which we see the types of technological confluence fit, are technologies on the degree of complexity of a closed type of system, closed system that is part of an open system, and technologies that match our definition of a technology. We defined a technology as a technological principle that requires certain essential technologies to fulfill a certain main functionality (Jonckheere, 2015, p. 3). Thereby excluding technologies that do not exist of a multitude of technologies. Our analysis towards the confluence typology is based on 10 cases from seven different industries, all closed systems of which some are part of an open system. Little can, however, be said about industry specific characteristics, for this we recommend further research by enlarging the amount of cases per industry, and identifying possible similarities. Problematic here, however, is that currently only few cases are available, besides the 10 addressed in this study. The coming years, however, we expect, the amount of cases to increase following the trend of integrating more and more technologies with PC technology. Another great influence that is likely to stimulate confluence is the desire to connect technologies to each other via the internet, RFID technology, and wireless communication technologies. This is also referred to as the “Internet of Things”, where many, currently closed systems, will become part of an open system by combining technologies.

Another limitation of this study can be found in its methodology, in which we defined the degree of complexity of a case based on the distance of knowledge. In addition we could have looked at the complexity of a technology as a system as well. The type of system a technology is, appeared to greatly influence the duration of at least the adaptation phase which came forth from the longer duration of an incremental confluence. It would have been interesting to investigate its interplay with the technology stream and application domain in our second paper. In the typology and the confluence model that we developed it would, however, not have made any difference due to the importance of the distance of knowledge relative to the base technology. It would, however, have contributed to our insight in the factors influencing the duration of the various phases in an earlier stage of research, which would have helped in some explanations in our second paper.

A next limitation of this research is that interviews with companies that have developed a combination of technologies lacked due to time constraints. In practice, interviews on the cases are partially held during the execution of the experiments with practitioners. Interviews dedicated to the process that a company goes through in order to develop such a technology, could, however, have contributed to the overall analysis. The data of this research is acquired from publications (media and journal publications) on the internet, and partly on the findings of the six experiments.

2.4. Further research

As stressed before, these findings are not yet applicable to a managerial environment due to the lack of a strategy specific to a type of technological confluence. When recommended strategies have been formed, implications are that a manager can position their desired confluence technology in the confluence model, after which this manager gains insight in the expected duration and evolution of such a combination of technologies. Furthermore, this manager is informed on the possible strategies to mitigate specific elements of this type of combination of technologies, such as the duration of the innovation or adaptation phase. With regard to academic implications, top priority is identifying the strategies specific to a type of technological confluence, and identifying the factors influencing the innovation phase. In addition, it will be interesting to investigate whether developing a new network, a new open system, takes longer than the adapting of one, and under what conditions. And besides that, the confluence model gives insight in the different types of combining technologies on which researchers can focus their studies on the development and diffusion of a technology, and on new product development. By referring to a (group of) type(s) in the model, the scope of future studies can be defined much clearer. In time, the adoption of this model possibly boosts research in the field of combining technologies because there is only one, clear, overarching perspective that entails all types of combining technologies. There would no longer be need for a researcher to put effort in the understanding of all different perspectives on the combining of technologies before selecting one and continuing research, our model will guide in doing so. When using our model, the difficulty of actually finding the current definition of a perspective via a meta-synthesis, such as convergence, is a step that can finally be left out of the research process. This will make focusing research more easy because performing this meta-synthesis has shown to be quite challenging as shown in the first paper of this research due to the versatility of the definitions used. In addition, when using our model there is much less room for interpretation due to the fixed set of variables that influence the process.

We suggest continuing research building forth on the bedrock of technological confluence and its typology, and using the same definition of essential technologies as in this study. Furthermore, our work is based on the three phase pattern of development and diffusion from Ortt & Schoormans (2004), which we also suggest adopting so that the definitions of the innovation-, market adaptation-, and market stabilization phase, together with the hallmarks that define the start and end of each phase, remain the same over the course of the further development of the perspective of technological confluence.

The potential of the confluence model in terms of the management of innovations, the developing of roadmaps, and forecasting is significant, and its aptitude has in this study been proven. Technological confluence has shown it is capable of building forth on the known fields of technological convergence, technology fusion, and technology integration, and has demonstrated it captures the essence of the combining of technologies in a systematic way, as it has never been done before. The core of technological confluence together with its scope have been developed, and it is now for future research to unravel its remaining mystique and make it practically employable. To give a head start on the subjects left for further research, the roadmap as shown in Table 5 is suggested. The "Related to" column indicates theories, hypotheses, sections in this thesis, or other items in the table (via the numbers) relating to the subject.

Table 5 Suggested roadmap for further research.

No.	Subject	Related to	Description
#1	The duration of the innovation phase with technological confluence.	Innovation phase of three phase model by Ortt & Schoormans (2004). Hypothesis 1.	More empirical evidence is required before claiming technological confluence is an approach to innovation that is less time-consuming than other approaches to innovation of the same caliber. We suggest performing additional case studies on the duration of this phase.
#2	The duration of the market adaptation phase with technological confluence	Market adaptation phase of three phase model by Ortt & Schoormans (2004). Hypothesis 2.	More empirical evidence is required in order to confirm or reject the hypothesis that the market adaptation phase is longer with technological confluence. We suggest performing additional case studies on the duration of this phase.
#3	Influence of distance of knowledge on the duration and shape of the innovation phase.	Innovation phase of three phase model by Ortt & Schoormans (2004). No. #1, #2. Hypothesis 3, 4, 5.	We hypothesized that when a confluence technology is launched in a new application domain, the innovation phase takes longer. Similarly so when a technology changes from technology stream. In addition, the two reinforce each other (*H5*). However, more empirical evidence is required. We suggest combining this study with the study on the former two subjects because the same dataset is applicable.
#4	Factors influencing the innovation phase of confluence technologies.	Innovation phase of three phase model by Ortt & Schoormans (2004). Paper 2, section 4.1, 4.2, 4.3.	Little is known about the factors influencing the duration and process of the innovation phase. We have identified the distance of knowledge, defined by the technology stream and application domain, to be one of the major determinants. In addition, we have found the lack of a strategic alliance to lengthen this phase. Development of, for instance, the MFP took longer because it was developed by various separate companies instead of in an alliance. However, the decision for a strategic alliance for a large part depends on the type of market competition that the company is active in. Regarding the innovation phase, there are expectedly other factors of influence on the duration and shape of the innovation phase as well. We suggest interviewing multiple companies engaging in technological confluence on their process of development and the type of confluence that they adopt. This is required before being able to formulate strategies on the innovation phase per type of confluence.

Table 5 Continued.

No.	Subject	Related to	Description
#5	Influence of distance of knowledge on the duration and shape of the market adaptation phase.	Perform after #2. Market adaptation phase of three phase model by Ortt & Schoormans (2004). Hypothesis 6.	We questioned whether a change in the application domain and/or technology stream influences the duration of the market adaptation phase. More empirical evidence is required. We suggest starting this research by analyzing the influence of the 30 factors from Ortt & Delgoshaie (2008) on the market adaptation phase of confluence technologies, and focus on whether there is a subsection of these factors specific to technological confluence compared to other means of innovation of the same caliber. Most important here is the question whether there are differences in the factors among the various types of technological confluence. When these factors explain the duration of the market adaptation phase there is reason to suggest that the distance of knowledge is not of influence on the adaptation phase.
#6	Does developing and building a new environment / network take longer than adapting an existing environment / network?	Network effect (Ortt & Delgoshaie, 2008, p. 10). Paper 2, section 4.1, p. 11.	When combining technologies, two previously separate environments or networks are combined as well and we wonder whether setting up a new network takes longer than the adapting of one? And what factors is this dependent on?
#7	Industry specific characteristics and co-evolution	Convergence literature on co-evolution of industries, see also paper 1, p. 9. Paper 2, chapter 6, p. 25.	Due to a lack of cases we are left with the question whether there are certain types of technological confluence specific to a certain industry. If so, strategies may need to be directed towards industries due to industry specific characteristics such as process of development, co-operation culture, company culture, type of customer, etcetera. In addition, we wonder whether co-evolution of industries occurs over time. Co-evolution possibly occurs on three distinct levels: industry, technology stream, and knowledge and literature.
#8	Strategies regarding the market stabilization phase specific to technological confluence.	Market stabilization phase of three phase model by Ortt & Schoormans (2004).	Analysis of this phase was excluded from this research because we expected most differences among the approaches to innovation to occur in the first two phases of the three phase model. For the formulation of strategies regarding this phase, however, we ask ourselves whether there are factors specific to technological confluence in comparison to other approaches to innovation that result in new products? And are there factors characteristic to a type of confluence? This is required to formulate strategies regarding this phase for each type of confluence.
#9	Linking the strategies of the three phases to develop a coherent model.	Perform after all items on this agenda. Prior research to the strategies regarding the innovation, market adaptation, and stabilization phase. Also see the final paragraph of section 2.2 in this document and section 2.4 the first paragraph.	Combine the knowledge on the findings on the former items on this list into strategies of all three phases for each type of confluence, including the conditions under which this strategy holds, and creating a holistic model that gives a manager insight in all types of confluence including their processes, durations, and approaches to mitigating via the strategies.

3. Reflection

At the end of the first paper, we developed the perspective of technological confluence as a perspective that overarches the current three perspectives, by this we chose to vertically aggregate these perspectives instead of horizontally complement. We chose to do so because this way, the entire field of combining technologies could be systematically reviewed, and the various approaches to combining technologies as a means of innovation could be revealed. With a perspective that resides on the same level as the other three perspectives this would not have been possible. A complementing perspective would, on the other side, have allowed the other perspectives to stay intact, whereas we bundled them leading to redundancy of perspectives, a risky decision that possibly leads to resistance in the adoption of the confluence model. Currently, technology fusion and technological convergence have been bundled within confluence and could eventually become obsolete. In addition, when the model of the types of confluence is finished with strategies recommended per type of confluence, the field of technology integration overcomes the same. In a time of "*less is more*", pursuing the development of the perspective of technological confluence has been the best move. With an eye on the future, we hope that confluence enables firms to engage in innovation via the combining of technologies in an easier and well-informed manner, and that academics can better focus research.

In the next section the quality of research is judged on the basis of four variables, after which a personal reflection concludes this report.

3.1. Judging the quality of research

In order to judge the quality of this qualitative exploratory case study research, four logical tests are performed (Guba, 1981) (Lincoln & Guba, 1985) (Shenton, 2004). Any qualitative research can be judged using these four logical tests:

(i) *Credibility:* Involves establishing that the results of qualitative research are credible or believable from the perspective of the participants in the research, and concerns the research methodology.
(ii) *Transferability:* The degree to which the results of qualitative research can be generalized or transferred to other contexts in terms of: times, settings, situations, and people.
(iii) *Dependability:* Account for the ever-changing context within which research occurs by describing the changes that occur in the setting, and how these changes affected the way the research approached the study.
(iv) *Confirmability:* Confirmability concerns the degree to which the results could be confirmed or corroborated by others.

In Table 6 it is made explicit how these four logical tests have been operationalized and employed in practice.

Table 6 Operationalization of the four logical tests for judging the quality of qualitative research and their implication in practice.

Test	**Determining factor**	**Phase of research**	**Implication in practice**
Credibility	Adoption of well-established research methods	Research design	Embedded multi-case study design (Yin, 1994), systematic literature review, operationalization of variables for data collection and selection, weighing different types of experiments. Intersubjective experiment performed with practitioners from different companies.
	Use of multiple sources of information	Data collection	Scientific literature, various acknowledged websites, interviews during experiments.
	Negative case analysis	Verifying model types of confluence, final discussion	Theoretically contradicting cases are discussed in paper 2 and in the final discussion.
	Debriefing sessions	All phases	Frequent sessions with superiors in which findings are discussed and in which the work is reviewed.
	Background, qualifications and experience of the investigator	All phases	The topic under investigation remained close to the researcher's MSc field of study and personal specialization within the MSc.
	Examination of previous research findings	Systematic literature review, final discussion	Perspective of Technological confluence is developed from the fields of Technological convergence, Technology fusion, and Technology integration. Afterwards, it is related back to these perspectives.

Table 6 Continued.

Test	Determining factor	Phase of research	Implication in practice
Transferability	Operationalization of the research design	Research design, systematic literature review, experiment	Information is made explicit about the: units of analysis, experiment and its sample size, other data collection methods as well as the raw data itself, and the time period over which data was collected also in terms of this project (up to June 2015). Further generalization has been discussed in the final discussion.
	External confirming audits	Experiment	Intersubjective experiment has been held to improve the research's connection with situations in practice by learning different perspectives from practitioners.
Dependability	Explicit research process	Data collection and selection, systematic literature review, theory development and testing	During the project, the research attempted to make all steps from observation to interpretation and theory development as explicit possible via text, tables, and supporting figures. Variables for data collection and selection have been operationalized.
	Multiple research methods	Research design	A multitude of overlapping research methods have been employed in order to add rigor to the research: systematic literature review, meta-synthesis, theory development, embedded multi-case study design, intersubjective experiment.
Confirmability	Objectivity of the research	Research design, data collection, personal reflection	Multiple sources have been addressed (see "credibility") to mitigate investigator bias, research process is made explicit, personal reflection has been written in which the reader is informed about strengths and weaknesses characteristic to the researcher.

3.2. Personal reflection

My thesis has been quite the ride from which I have learned a lot about combining technologies as a means for innovation, as well as its consequences. On a personal level I found this thesis challenged me to do things in a different way than I was used to. In general, I can say that it has helped my personal development by widening my perspective on the complexity of already one aspect in this world, and the depth through which this can, and needs to be unraveled in order to comprehend its nature. During my research I bumped into many topics related to the combining of technologies, and often had a hard time staying within my scope.

I consider myself a pragmatic worker, I feel comfortable to continue when the preceding is finished. This has both positive and negative consequences. On the positive side, this way of working helped me to break down the project into smaller bits that I could grasp better, in order to solve these issues and continue with the next. This helps remember why I am doing certain things. This was especially helpful in developing the model where I attempted to keep in mind the process of development and diffusion that follow, and differ per type of technological confluence. However, often this research forced me to deviate from my accustomed way of working because I had to sometimes continue the research *without* fully understanding the preceding. This was especially the case between the first and second paper. When writing the first paper, the whole subject was very new to me and I did not see the bigger picture at all. In fact, when I thought I had finished the first paper and started the research for the second paper, I soon figured that I had not concluded the first at all. It was most surprising when I noticed I never *actually* described and thereby defined what "technological confluence" is. I simply did not see then what I see now. Looking back, I continued my research with a hunch I had that I could not yet comprehend or see its essence of. This has also influenced my approach to the second paper; where in the first paper I often just started typing, I now started with building blocks that were more easily changed. Nonetheless, the second paper has just as well undergone many revisions, it just took less time to change the content.

On the other side, I must say that my pragmatic approach in hindsight may not have been the most fruitful, for example, I planned on doing an intersubjective experiment with the model at one company per case. In an early stage I had asked around in my environment whether they knew people in certain companies that could support my findings, and they did! Before I talked to anyone, however, I wanted to have finished my model. Perhaps to not make a fool out of myself by reserving someone's time for something that, in my opinion, was not worthy of this person's attention. I postponed the experiments and before I knew, my time was almost up. When I realized this, I contacted three persons that I personally knew from different companies, who were willing to reserve time to do the experiment. Having done the experiments, I realize that I should have done so earlier as it would have boosted my research. Before each meeting I positioned the cases in the model myself and when a case was positioned somewhere else we discussed the reason for it. Experiment after experiment this helped me refurbish the model, and establish the rules of the game. In addition, they shared some interesting things about some of the cases that I did not knew from my literature research. It is not that I did not consider it would help my research that I waited with doing the experiments, both interviews for data gathering and the intersubjective experiment have been part of my methodology since the beginning. It is perhaps more my personal uncertainty about the topic in the earlier stages that held me back. I felt stupid stepping towards a company while being unable to completely grasp the essence of confluence. But even when I thought I grasped the concept and stepped towards a company I nevertheless bumped into perspectives or information I had not considered or found before. In future researches I will remember this and step towards the actors in the field earlier because even when I thought I was done, I actually was not.

To wrap up, I want to thank Roland Ortt for his positivity, stimulation and constructive feedback towards my work, and especially to me as a person. Even though I sometimes had to revise (large) parts of the work I had done, I never left a meeting with a bad feeling, on the contrary really: I felt energized! It is his way of giving feedback, thinking with me, and afterwards reminding me what I am doing it for that stimulated me to continue.

I also want to thank Mark de Bruijne for his critical and straight forward, but always constructive feedback on my work. Having you as a part of my team gave me more certainty about the direction I was heading. You have been a great addition to the brainstorm sessions and I greatly appreciate your contributions as they gave me new perspectives.

During my thesis, Roland at some point described me as a steamship; it takes time to start up, but when I am going I will not stop easily. My thesis may be over, but it is not done yet. There is lots more to discover and unravel in this complex world. And that is exactly what I plan on doing (starting with a trip through Asia)!

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Appendix 1

“Raw case study information”

TUDelft

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Defining the context of the case

This research focuses on end-user products, may that be a product developed for consumers or firms. Each product operates within a specific system in which it is integrated. Such as Skype, which is integrated in the voice over IP (VoIP) system, and the telephone system. A user with a computer running the Skype client may connect via a Skype service to the telephone network in order to communicate with a phone. When this phone has the ability to support the Skype software and an internet connection, the computer user may also choose to connect to the same person via the internet. The Skype system offers a variety of methods to communicate with other people. For this research focus lies on the end-user product; the Skype client. However, developments in its system enabled Skype to evolve to what is it is today.

Another example is the satellite telephone of which in essence two types exist. The first connects directly to a satellite using its own base station, and the second transmits the data to a nearby large satellite dish which amplifies and transmits the data to a satellite. The latter is therefore dependent on the proximity of a land-based satellite dish, whereas the former is not and can be used in remote areas. A single case can have a variety of approaches to the same principle which emphasizes the need of defining the system in which the case is analyzed. Similarly to the Skype case, the network enabled the development of the satellite phone. An infrastructure of communication satellites such as the Telstar 1 first had to be put into orbit, and terrestrial satellites were required and connected to the public switched telephone network (PSTN) before a telephone call could be realized. For every case the context of the end-user product will be visualized and the focus of the research will be indicated.

Understanding essential technologies

We define the essential technologies by looking at what technologies the technological principle requires to fulfill its function. This, however, depends on what level of abstraction the principle is defined. The technological principle is derived from the process that a technology embeds to carry out its main function. For a mobile phone, for example, the technological principle can be described as: establish a wireless multiplex connection with the telephone network to allow voice-, and short text communication to be transmitted and received, the user can control the technology via a keypad, and the outcome of any form of input is shown on a display or turned into sound waves. From this technological principle we derive the following components: signal transceiver, input keypad, audio receiver, audio emitter, and a display. Using this method, the indirect components of the technology are left out, such as the battery, FM receiver, and photo camera. Often, indirect components are found to be features, and therefore not essential to fulfilling a technology's function.

Because the combining of technologies is about 'major' changes that a technology undergoes, an, as systematic as possible, distinction needs to be made between features and essential technologies. The second approach to defining essential technologies appears to do so best in our situation, and will be used during this research. To further elaborate this approach, another example will be discussed.

One of the currently most complex technologies to define is the smartphone due to the versatility of functions it fulfills. It can both be used as a 'pocket computer' as well as a mobile phone, also it has such a variety of sensors inside that expand this functionality even more. A smartphone can be used to browse the internet, telecommunicate with other people via the telephone network, play videogames, view media, act as a navigation system in a car, capture photos or film, and much more. Some of the prior mentioned functions will often be categorized a feature, and not essential to the main functionality, such as most sensors. What is troublesome is that the main functionality of a smartphone is ambiguous, and heavily depends the perspective through which the smartphone is looked at. Because we are interested in the combining of technologies, we have attempted to split the essential technologies of a smartphone into two aggregated groups: personal computer (PC) technology, and mobile phone technology. Figure 1 is a visualization of what we consider the essential technologies of a PC and mobile phone, which, in turn, are the essential technologies of the smartphone.

The functions that today's smartphone can fulfill is not exactly the same as a PC, but nears that of a PC, while still being able to access the cellular network. A computer's basic function is to input data, store, process, and output data. A PC expands this with the functions an operating system (OS) fulfills such as: resource management, multitasking, and a user interface. In order to use these functions, the PC is dependent on a set of technologies being: the OS, central processing unit (CPU), storage, input and output peripherals, and software applications. For a large part, the hardware is controlled by software; called drivers. The OS 'talks' to these drivers to employ the hardware for its user. Furthermore, the OS allows the user to adapt the system to a user's needs via software applications, thus allowing a user to manage the applications installed on the system, and therefore as well the amount of functions the

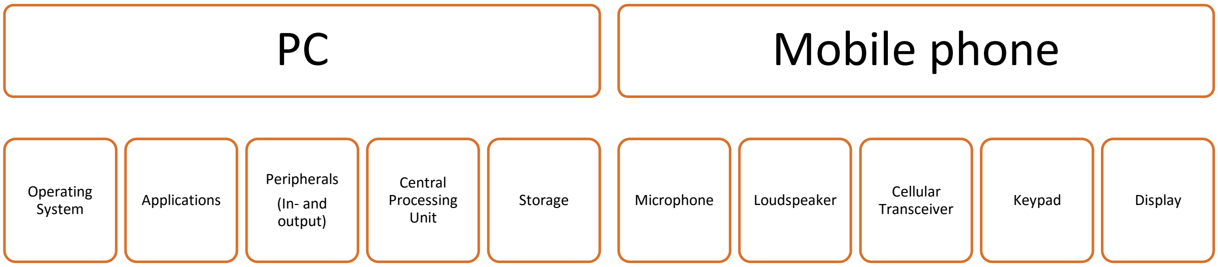


Figure 1 Decomposition of the essential technologies of a smartphone: a PC and a mobile phone.

PC can fulfill. When a user wants to play a game, he or she will have to install a game on the system after which it can fulfill this function. In a smartphone, the same technologies as a PC has can be found, however, less elaborated versions. A smartphone offers for example less freedom in networking with other devices, and in file management. For this reason it nears a PC, but is, as of yet, not similar to one.

For complex products key is recognizing groups of technologies that originate from a different technology, to then go one step deeper into each of these groups to recognize their essential technologies. In short, the rule for essential technologies is that all technologies that are required for a technology to exercise its basic functions according to its technological principle, are considered its essential technologies.

Analyzing the product over time

For every case a timeline is constructed of the technological advances over time, starting at the first proof of concept of the technology up to June 19, 2015, when the timeline is constructed. Looking from the perspective of the product, the developments of the essential technologies are analyzed and shown per time advance (time advance differs per case). A digital camera for example can be split in an analog camera, lens, storage, and a personal computer. The moment in time that auto-focus or the CCD chip was first introduced in a camera are for example such advances. The advance that changed the camera to a digital camera was flash memory, which started the confluence of the PC with the camera. Images were now stored digitally on flash memory in a computer readable file format and could be downloaded by one.

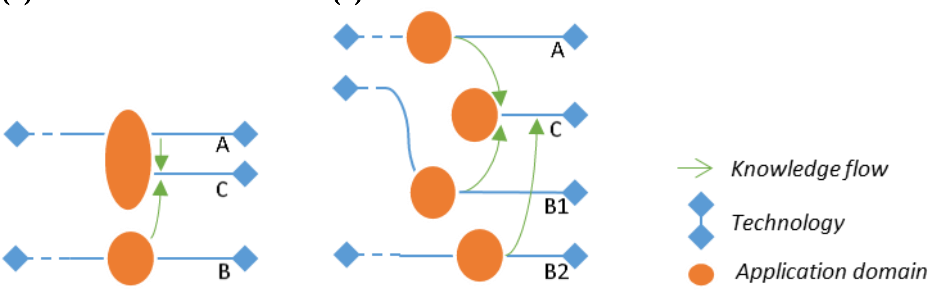
For every case, setting up the timeline starts with acquiring synonyms of the same case as names are prone to change in the course of development. Information about the historical names is gathered from sites describing the history found via Google, and Wikipedia. Next, a search in Scopus and ABI/INFORM Complete with these names are performed. For Scopus the results are sorted by relevance, whereas for ABI/INFORM the oldest publications are shown first. In most cases the searches in Scopus did not result in usable literature, either because it did not exist, include a historical overview, or because the literature was not accessible. Thus, the construction of the timeline for many cases mainly builds upon ABI/INFORM and partly on Google results. A literature list is supplied at the end of each case.

An example follows for the smart TV case of which the essential technologies are a PC, TV, and set-top box (STB). The STB (also called a demodulator, UHF converter, or Video receiver) is part of this list because it is found to be the device that enabled a TV to have an internet connection in the time that cable TV companies first started to upgrade their existing infrastructure to allow multiplexed signals (which is required for an internet signal). The STB was first build-in the digital TV, which preceded the smart TV. A search in Google and Wikipedia resulted in the following historical names: Smart TV, connected TV, IP TV, Web TV, interactive TV, internet TV, and digital TV (the acronym “TV” both spelled out and as is). Next, in ABI/INFORM all names are searched for in separate. Often, depending on the amount of results per year and having found no interesting headlines or titles, articles are randomly opened and read as headlines are sometimes found to be incomplete. Articles discussing the same new product or technology are only used once, follow-ups are skipped.

Understanding the visual timeline of the confluence

There are two basic differences distinguishable in the visualization of the confluence of each case. A technology can be pulled towards an existing domain (visual 1 below: technology A and B lead to C), or the combination of technologies opens up a new domain (visual 2: Technology A and B1 lead to C). Either one of these or a combination of the two principles can always be seen in a constructed timeline.

(1) (2)



The proof of concept of a technology is marked by the diamond shape at the start after which the dotted line indicates that we focus on a section of its entire lifespan. The diamond at the end of the line either marks the discontinuity of a technology if it is stopped earlier compared to other timelines, or indicates that the advances have been analyzed up to the time of the analysis in case a dotted line is missing. The circle and oval shapes on each line indicate the application domain of the technology, and the arrow shows the knowledge flow. Often an arrow will be drawn over time to show the first notion of a (new) technology, and the moment it has been implemented. As can be seen in visual 2, the timeline of technology B1 is bend towards technology A, this indicates that these two technologies are from the same technology stream. The word “technology stream” is used as synonym to “field of applied science”. Over time, other technologies may be added such as technology B2 in visual 2, this sometimes causes a technology to shift domain or remain in the same.

Reading the interrelatedness tables

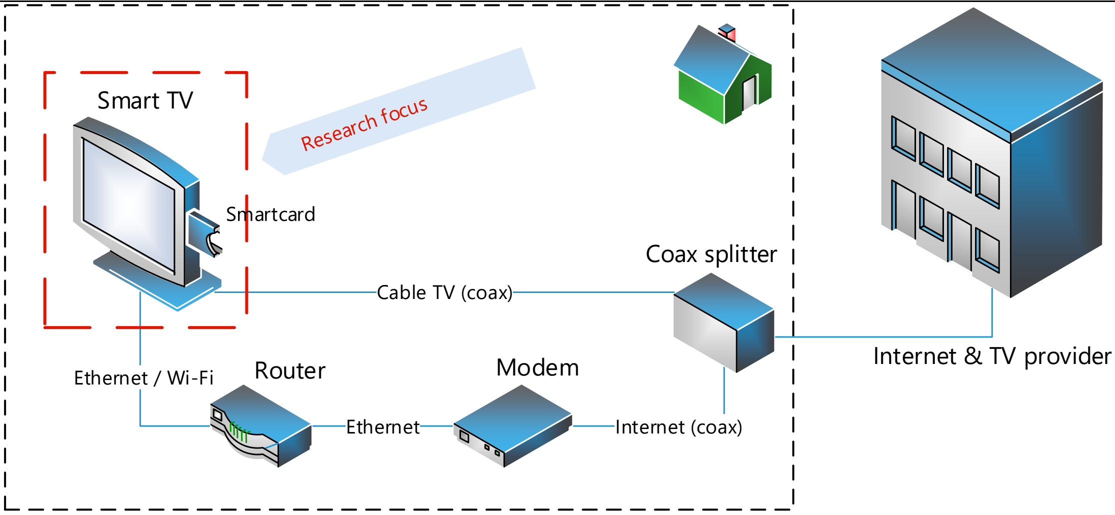
Many cases include a table that indicates at what point in time a specific part of a product’s (read: the case) essential technology is added. As discussed earlier, each essential technology can again be broken down into parts: the smartphone exists of a PC and a cellular phone where the PC too has its specific parts. The first table describes the interrelatedness on this level. A cross in every column means that for example the PC and the cellular phone are fully integrated with each other as all the parts are implemented in the smartphone. A question mark means that the information could not be found. Certain parts of an essential technology, such as a PC’s operating system, require another breakdown because implementing one part of an operating system does not mean that this device now has an operating system similar to a PC. To clarify this, a second table of interrelatedness is added to cases where this is applicable. To keep the size of the tables to an acceptable level acronyms are used, for example for the personal computer:

- Operating system
  - Kernel
    - **PEXEC**: Program execution (load / unload applications, schedule tasks)
    - **MEM**: Memory management (memory allocation)
    - **MULTI**: Multitasking (multitude of programs can run at the same time, user can switch between them)
    - **FILE**: Disk access and file systems (file management)
    - **IO**: Device drivers (I/O management)
  - **NET**: Networking (connect to an existing ecosystem of devices)
  - **SEC**: Security
  - **UI**: User interface (OS has a ‘desktop’)
- **INTSTOR**: Internal storage
- **EXTSTOR**: External storage support (e.g. USB drive or SD card)
- **CPU**: One main processor
- **APPS**: User manageable applications (user is free to install and remove software programs)

1. Smart Television

1.1. Context

Variable	Value
Proof of technology (year)	1994
Geography of first proof	France
Industry	Information and Communication / Consumer electronics
Technology stream	Electronic engineering
Technological principle	Display still or moving images by decoding an electrical signal of which access is granted. Software operating system user interface allows the user to switch between the TV signal and the intra- and/or internet connection.



1.1. Product essential technologies

Essential technologies	Technology description			
	Technology stream	**Technological principle**	**Function**	**Parts**
Television	Electronic engineering	Receiving via an analog electric signal, decoding and displaying of still or moving images.	Entertain, educate, inform	Signal decoder for different types of electric input signals, command receiver (controller & buttons), output (loudspeaker & display)
Set-top box	Electronic engineering	Receiving via a digital or encrypted analog electric signal, decoding and output the decoded signal via a certain protocol (e.g. HDMI, SCART, optical).	Decode an encrypted signal and send it in a, for the connected device, understandable language.	Signal decoder for a specific type of electric input signal (e.g. UHF, satellite, IPTV, cable), command receiver (controller & buttons)
Personal computer	Computer science	Electronic calculating, storage, and display device that only uses 1's and 0's as data.	Input, store, process, display data	Operating system, applications, input and output peripherals, processor(CPU&GPU), storage

1.2. Application domain Television and Smart Television

Case	Application domain			
	Customer need (function)	**Customer group**	**Technology**	**Relevant attributes**
Television	Entertain, educate, inform	Consumer TV	Television	Video quality, size

Smart Television (early = internet TV)	Entertain, educate, inform	Technology enthousiasts	Internet TV	Video quality, size, connectivity, software
Smart Television (current)	Entertain, educate, inform	Consumer TV	Smart television	Video quality, size, connectivity, software

1.3. The product over time

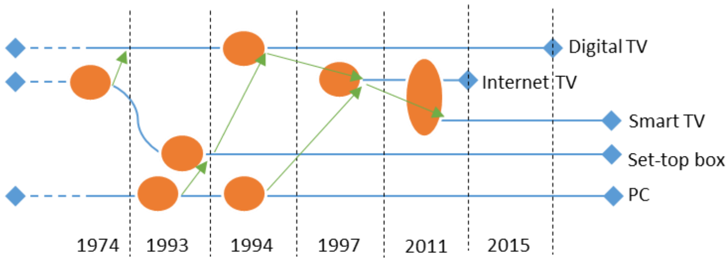
		Interrelatedness of the parts		
Product name	**Year**	**Television**	**Set-top box**	**Personal Computer**
Digital Television	1974	Cathode ray tube (CRT) color TV	Originally called a "Video receiver", "UHF converter" or "Demodulator". Device decodes digital channels into for a TV understandable data.	
Internet TV	1993		Internet access for computers via cable instead of telephone line. Mentioning of "interactive TV".	
Connected TV / Internet TV / WebTV	1994	Patent filed indicating the integration of a TV with set-top box and networking with computers to, for example, store information transmitted or received by the television.. Uses a CPU, could be used for internet shopping, and has IO module for connecting to peripherals such as a printer or a bar code reader.		
WebTV / Internet TV	1997		WebTV comes with separate box that connects to the internet over the phone line	WebTV is a terminal with a web browser and e-mail client. Supports regular computer keyboard (wired or wireless). Subscription of $19.95 p/m is required.
Connected TV / Internet TV / Interactive TV	2000	LCD TV	Built-in for internet connectivity, but cable companies often deliver as separate box with same purpose	Powered with Microsoft TV platform. Access the internet for: email, online shopping, stocks, sports, news and weather.
Connected TV / Internet TV / Interactive TV	2006			PhotoShowTV (software program) where photos can be send to and viewed on other devices supporting Microsoft's Windows Media Center such as television, Xbox 360, and PC.
Connected TV / Internet TV / Interactive TV	2008			TV can access the internet (wired) for: news, weather, stock, YouTube, support DLNA, USB for photos music and videos, pre-loaded movies and games.
Connected TV / Internet TV / Interactive TV	2009	LED TV	Movies on demand	Wi-Fi support, widgets (+ SDK for developers) to access the internet (e.g. weather, stocks, share photos, watch movies, simple e-commerce).
Connected TV / Internet TV / Interactive TV	2010	Full HD 3D LED TV		Internet access same as before but via downloadable apps instead of pre-installed widgets. Connect PC and mobile phone to TV wirelessly. Addition of a web browser.
Smart TV	2011		Video on demand (built-in)	Local & internet smart search function (search files on connected devices), social networking,
Smart TV	2012			Voice control, motion control, Cloud connection (for content stored on TV & access this content via other devices)
Smart TV	2013			Voice control enhanced, Automatic software updates,

			software learns a user's customs & recommends content
Smart TV	2014	Ultra HD LED TV	Image recognition (identify & capture big moments in soccer game), multi-tasking.
Smart TV	2015	Super ultra HD LED TV	Quick connect smart devices, content optimized TV, domotica with other (samsung) smart devices, personal data can be viewed on TV (email, alarms, schedules, etc.)

1.4. Remarks

- Consumers want Personalized TV, Continuous entertainment, Content interaction, Advanced forms of interaction (Prabhala & Ganapathy, 2011).
- Since 2015 Samsung only produces smart TV's, all other types of televisions are discontinued (Samsung, 2015).

Smart TV



Smart Television													
	Television				Set-top box			Personal computer					
	Decoder	Command	Loudspeal	Display	Decoder	Internet	Command	Operating	APPS	Input peri	Output pe	CPU	Storage
1974		x	x	x	x								
1993		x	x	x	x								
1994		x	x	x	x								
1997		x	x	x	x	x		x		x		x	
2000		x	x	x	x	x		x		x		x	
2006		x	x	x	x	x		x		x		x	
2008		x	x	x	x	x		x		x		x	x
2009		x	x	x	x	x		x	x	x		x	x
2010		x	x	x	x	x		x	x	x		x	x
2011		x	x	x	x	x		x	x	x		x	x
2012		x	x	x	x	x		x	x	x		x	x
2013		x	x	x	x	x		x	x	x		x	x
2014		x	x	x	x	x		x	x	x		x	x
2015		x	x	x	x	x		x	x	x		x	x

Smart Television										
	PERSONAL COMPUTER									
	OPERATING SYSTEM								STORAGE	
	PEXEC	MEM	MULTI	FILE	IO	NET	SEC	UI	INTSTOR*	EXTSTOR*
1974										
1993										
1994										
1997	x	x								
2000	x	x					x	x		
2006	x	x					x	x		
2008	x	x			x	x	x	x		x
2009	x	x			x	x	x	x	x	x
2010	x	x			x	x	x	x	x	x
2011	x	x		x	x	x	x	x	x	x
2012	x	x		x	x	x	x	x	x	x
2013	x	x		x	x	x	x	x	x	x
2014	x	x	x	x	x	x	x	x	x	x
2015	x	x	x	x	x	x	x	x	x	x

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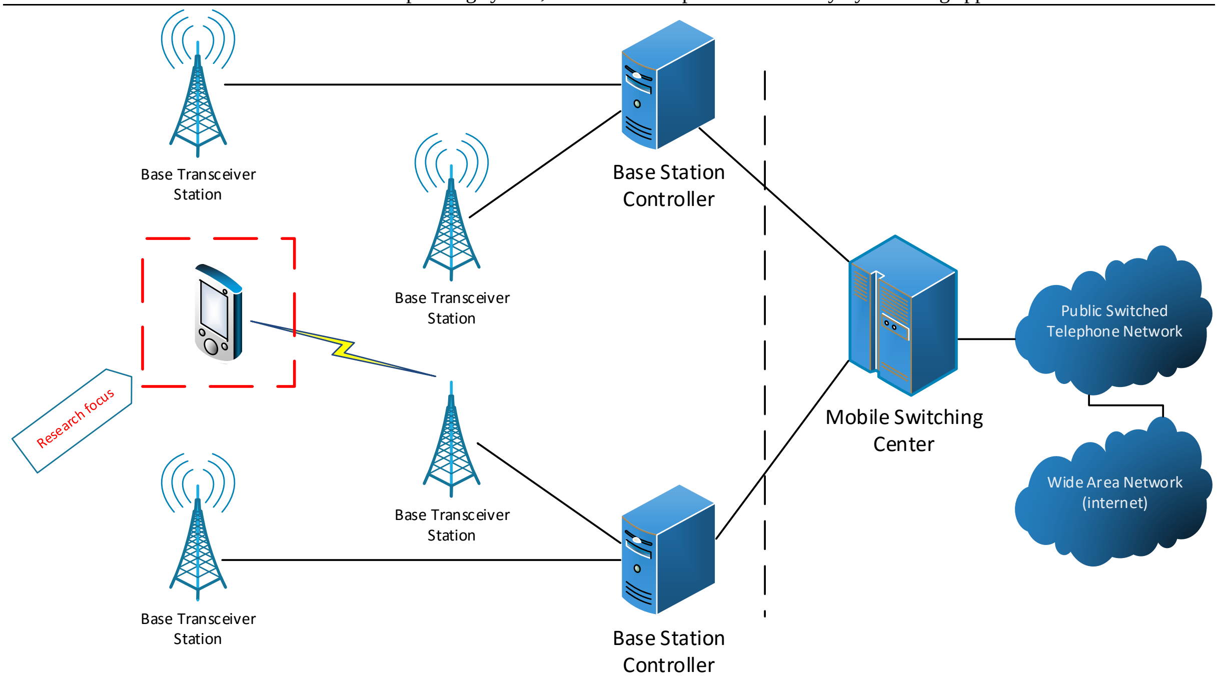
2. Smartphone

2.1. Context

Variable	Value
Proof of technology (year)	1992
Geography of first proof	USA
Industry	Information and Communication / Consumer electronics
Technology stream	Telecom engineering, Electronic engineering
Technological principle	Establish multiplex connection with the telephone network to allow voice-, video-, and short text communication with other telephone users, connect to the intra- or internet, allow a user to interact with the operating system, and allow to expand functionality by installing applications.



2.2. Product essential technologies

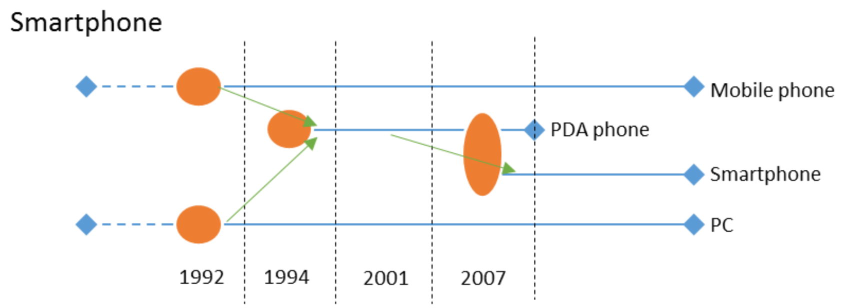
Essential technologies	Technology description			
	Technology stream	**Technological principle**	**Function**	**Parts**
Mobile telephone	Telecom engineering, Electronic engineering	Establish multiplex connection with the telephone network to allow voice-, video-, and short text communication. Interaction with the device is enabled by a user interface.	Voice-, and short text communication	Sender (encoder), Receiver (decoder), loudspeaker, input keypad, display, microphone
Personal computer	Computer science	Electronic calculating, storage, and display device that only uses 1's and 0's as data.	Input, store, process, display data	Operating system, applications, input and output peripherals, processor(CPU&GPU), storage

2.3. Application domain Mobile telephone and Smartphone

Case	Application domain			
	Customer need (function)	**Customer group**	**Technology**	**Relevant attributes**
Mobile telephone	Voice- and short text communication	Mobile telephone users	Mobile telephone	Battery life, size, weight, connectivity
Smartphone (early)	Online communication, web browsing, and voice- and short text communication.	Business customers	PDA phone	Battery life, size, weight, connectivity, software
Smartphone (current)	Online communication, web browsing, and voice- and short text communication.	Smartphone users	Smartphone	Battery life, size, weight, connectivity, software

2.4. The product over time

Product name	Year	Interrelatedness of the parts	
		Mobile telephone	**Personal computer**
Simon personal communicator	1994	Monochrome touchscreen, stylus, charging base station	Send and receive emails and faxes.
Nokia 9000	1996	Monochromatic display (no touchscreen), handheld device.	QWERTY keyboard, email, fax, web browsing, word processing, spreadsheets
Ericsson GS 88 'Penelope'	1997	Similar to Nokia 9000 but with touchscreen and stylus	Introduction of Symbian as first Operating System for smartphones
Blackberry color 7200	1999	First color screen	Innovation in data-network (speed up to 9.6 kbps) allowed better internet connectivity (always online principle)
PDA phone, Ericsson R380	2000	Resistive touchscreens with stylus became popular. Addition of digital camera (first: J-SH04). Ericsson R380 the first phone referred to as "smartphone".	Instant messaging: AOL, Yahoo-, and MSN Messenger. Addition of Bluetooth. Development up to 2007 focused on internet software (email and web browsing) and camera.
Kyocera 6035	2001		Phone has dual-software: cellphone firmware and PalmOS operate independently. E-mail and web browsing.
HP iPAQ H6315	2004		First phone with Wi-Fi connectivity. Also featured instant messaging and external storage slot..
Blackberry curve 8100	2006		Enabled email, instant messaging, and HTML browser, external storage slot.
iPhone	2007	Capacitive touchscreen, multi-touch. Dominant design: phone shaped as a slab with capacitive multi-touch touchscreen.	Only four hardware buttons, no longer dumbed-down versions of webpages, instead full webpages (as displayed on a PC), also support for HTML email. More focus on multimedia instead of work (e.g. calendar, email, fax). Connect phone to iTunes for downloading audio and video.
Smartphone	2008	Addition of GPS, accelerometer, (barometer), gyroscope, lightmeter, (temperature), magnetometer, proximity sensor.	Further developing software (e.g. operating system and its parts) and enhancing hardware (CPU, GPU, RAM, flash memory size, camera). Integration of social media (facebook, twitter). Fingerprint to unlock (iPhone 5S). Introduction of application stores to extend functionality by downloading and installingsoftware.



Smartphone												
	Mobile telephone						Personal computer					
	Sender	Receiver	Loudspeal	Keypad	Display	Micropho	Operating	APPS	Input peri	Output pe	CPU	Storage
1994	x	x	x		x	x	x		x		x	x
1996	x	x	x		x	x	x		x		x	x
1997	x	x	x		x	x	x		x		x	x
1999	x	x	x		x	x	x		x		x	x
2000	x	x	x		x	x	x		x		x	x
2001	x	x	x		x	x	x		x		x	x
2004	x	x	x		x	x	x		x		x	x
2006	x	x	x		x	x	x		x		x	x
2007	x	x	x		x	x	x		x		x	x
2008	x	x	x		x	x	x	x	x		x	x

Smartphone										
	PERSONAL COMPUTER									
	OPERATING SYSTEM								STORAGE	
	PEXEC	MEM	MULTI	FILE	IO	NET	SEC	UI	INTSTOR*	EXTSTOR*
1994	x	x					x	x	x	
1996	x	x					x	x	x	
1997	x	x					x	x	x	
1999	x	x					x	x	x	
2000	x	x				x	x	x	x	
2001	x	x				x	x	x	x	
2004	x	x			x	x	x	x	x	x
2006	x	x		x	x	x	x	x	x	x
2007	x	x	x	x	x	x	x	x	x	x
2008	x	x	x	x	x	x	x	x	x	x

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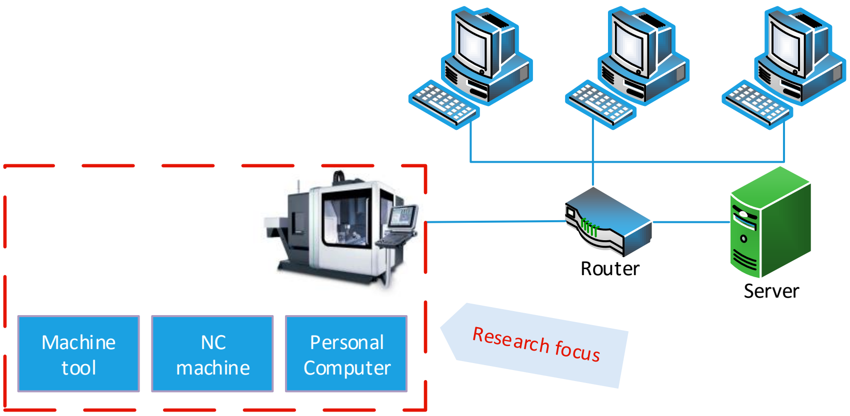
3. CNC Machinery

3.1. Context

Variable	Value
Proof of technology (year)	1953
Geography of first proof	USA
Industry	Machine tools
Technology stream	Mechatronic engineering
Technological principle	Machine parts using automated tools which can be moved in different dimensions controlled by a software program that translates a user's required part into for the driver unit understandable commands.



3.2. Product essential technologies

Essential technologies	Technology description			
	Technology stream	**Technological principle**	**Function**	**Parts**
NC machine	Mechanical engineering	Control mechanical tools using encoded commands on a storage medium	Automate machine tools	Program encoder, controller unit
Machine tool	Mechanical engineering		Machine parts by either drilling, cutting, sanding, printing, or a combination of the aforementioned	Tool
Personal computer	Computer technology	Electronic calculating, storage, and display device that only uses 1's and 0's as data.	Input, store, process, display data	Operating system, applications, input and output peripherals, processor(CPU&GPU), storage

3.3. Application domain NC machinery and CNC machinery

Case	Application domain			
	Customer need (function)	**Customer group**	**Technology**	**Relevant attributes**
NC machinery	Automate machine tools with higher precision, speed and for more complex pieces	Manufacturers	NC	Precision, speed, tools, complexity of pieces
CNC machinery (early)	Automate machine tools with higher precision, speed and for more complex pieces	Manufacturers	CNC	Precision, speed, tools, complexity of pieces
CNC machinery (current)	Automate machine tools with higher precision, speed and for more complex pieces	Manufacturers	CNC	Precision, speed, tools, complexity of pieces

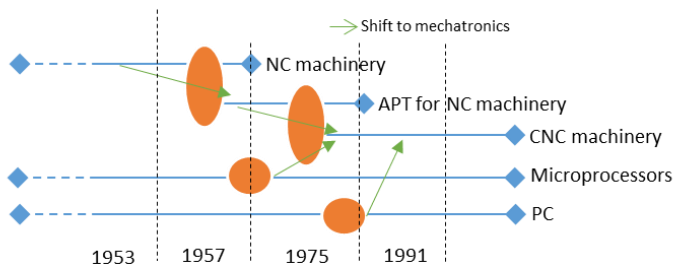
3.4. The product over time

Product name	Year	Interrelatedness of the parts: NC machinery	Interrelatedness of the parts: Machine tool	Interrelatedness of the parts: Personal computer
Automatically Programmed Tools	1953	MIT Servomechanisms Lab developed first start of a CNC machine. It utilized a Flexowriter, eight-column paper tape, a tape reader, and vacuum-tube electronic control systems. A separate computer printed the code on punched tape which was then fed to the NC machine. Further development to stabilize the system went in co-operation with Aircraft Industries Association and Wright-Patterson Air Force.		
Automatically Programmed Tools	1957	First NC machines began to appear on the workfloors of aircraft companies. APT automates the process of encoding the numerical values on the punched tape. But it is not integrated in the NC machine itself and operates as a separate device.		
CNC machinery	1975			Incorporating microprocessor unit in NC architecture
CNC machinery	1985	Hardware modularity achieved. Modules: Communications, Tape storage, automatic programming, drive module and FANUC bus as communication method		Each module has its own microprocessor unit
CNC machinery	1991	Innovative mounting technology resulted in enhanced ability to densily mount electronic parts which helped another modularization of modules in the NC architecture: display, computing, drivers. Connected by FANUC bus		Display unit contained ported PC functions: database & networking. This allowed managing of tool files, customize operation screens, and freely build human interfaces. Networking function allowed remote control.
CNC machinery	1997	NC further exists of display and computing units combined into one module, and a driver unit		

3.5. Remarks

1991 is chosen as the date where the PC was first integrated because in that year, the separate microprocessors were replaced by a single CPU for the entire system.

CNC machine



CNC Machinery									
	NC machine			Personal computer					
	Program e	Controlle	Machine t	Operating	APPS	Input peri	Output pe	CPU	Storage
1953		x	x						
1957	x	x	x						
1975	x	x	x						
1985	x	x	x						
1991	x	x	x	x		x	x	x	x
1997	x	x	x	x		x	x	x	x

CNC Machinery										
	PERSONAL COMPUTER									
	OPERATING SYSTEM								STORAGE	
	PEXEC	MEM	MULTI	FILE	IO	NET	SEC	UI	INTSTOR*	EXTSTOR*
1953										
1957										
1975										
1985										
1991	x	x		x	x	x	x	x	x	x
1997	x	x		x	x	x	x	x	x	x

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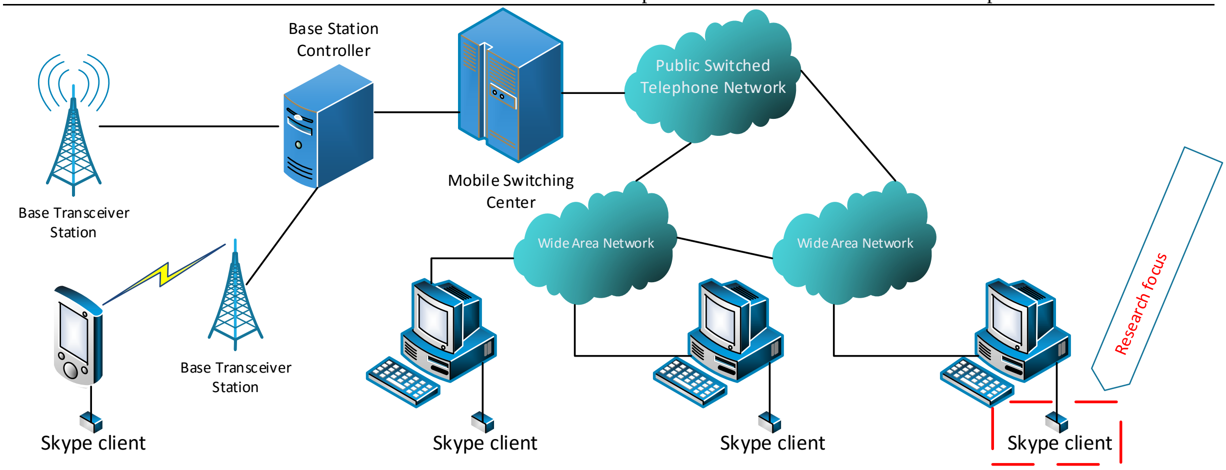
4. Skype

4.1. Context

Variable	Value
Proof of technology (year)	2003
Geography of first proof	USA
Industry	Software
Technology stream	Software engineering (currently telecom engineering as well)
Technological principle	Transmission of voice and video data packages directly between two or more Skype clients. A Skype client can also communicate with telephones via a server connected to the telephone network.



4.2. Product essential technologies

Essential technologies	Technology description			
	Technology stream	**Technological principle**	**Function**	**Parts**
Voice over Internet Protocol	Software engineering	Transmission of voice data packages over the internet protocol, similar to classic digital telephony	Voice- and data communication over the internet (computer-computer)	Analog to digital encoder and vice versa, encode/decode IP packages, signaling, channel setup,
Peer-to-Peer networking	Software engineering	Nodes/peers talking directly to each other instead of through an intermediating server	Decentralize networking	N/A
Telephone	Telecom engineering	Establish multiplex connection with the telephone network to allow voice-, and short text communication.	Voice- and data communication over the telecom network	Microphone, loudspeaker, signal transceiver, input keypad or keyboard

4.3. Application domain Skype vs Voice over IP

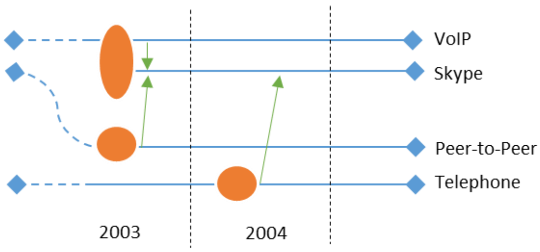
Case	Application domain			
	Customer need (function)	**Customer group**	**Technology**	**Relevant attributes**
VoIP	Alternative to telephone communication (cheap, especially internationally)	Business, consumers	VoIP	Video-, and voice calling, quality and price of service
Skype (early)	Alternative to telephone communication (cheap, especially internationally)	Business, consumers	Skype	Video-, and voice calling, quality and price of service

Skype (current)	Alternative to telephone communication (cheap, especially internationally)	Business, consumers	Skype	Video-, and voice calling (internet + telephone), quality and price of service

4.4. The product over time

		Interrelatedness of the parts		
Product name	**Year**	**VoIP**	**P2P Networking**	**Telephone**
Skype	2003	All parts of VoIP and P2P are integrated from the start for audio and video calls. Only incremental improvements followed.		
Skype	2004			Added SkypeOut for calling from a computer to a normal telephone
Skype	2005			Added SkypeIn and Skype Voicemail for calling from a normal telephone to a computer. Also SMS support to and from a normal phone added.

Skype



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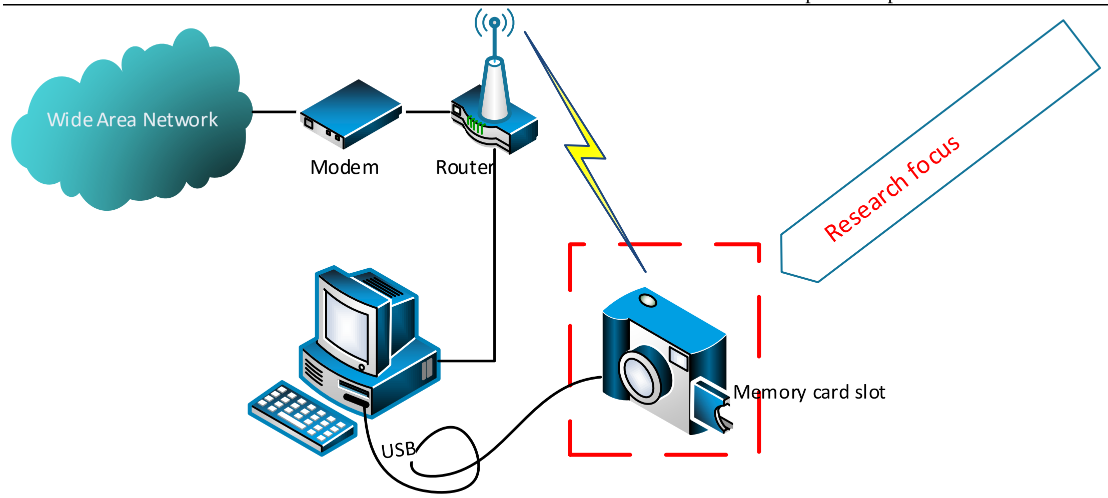
5. Digital Camera

5.1. Context

Variable	Value
Proof of technology (year)	1970
Geography of first proof	USA
Industry	Consumer electronics
Technology stream	Optics and mechatronics engineering
Technological principle	Capture light of the visible spectrum onto a light sensor and digitally store the data received in the device which can then be connected to a network or computer to upload the data to.



5.2. Product essential technologies

Essential technologies	Technology description			
	Technology stream	**Technological principle**	**Function**	**Parts**
Camera	Mechanical engineering	Capture light of the visible spectrum onto a 35 mm film-roll	Create still images	Lens, shutter mechanics, storage medium
Light sensor	Optics engineering	Capture light of the visible spectrum and digitalize (by encoding)	Translate light to digital values	Light sensor, chip
Flash memory storage	Electrical engineering		Store digital data	
Personal computer	Computer science	Electronic calculating, storage, and display device that only uses 1's and 0's as data.	Input, store, process, display data	Operating system, applications, input and output peripherals, processor(CPU&GPU), storage

5.3. Application domain Camera and Digital camera

Case	Application domain			
	Customer need (function)	**Customer group**	**Technology**	**Relevant attributes**
Camera	Capture photos (moving or still)	Photographers	Camera	Size, weight, quality of photo, storage size, battery life
Digital camera (early = analog electric camera)	Capture photos (moving or still)	Digital photographers	Analog electric camera	Size, weight, quality of photo, storage size, battery life
Digital camera (current)	Capture photos (moving or still)	Photographers	Digital camera	Size, weight, quality of photo, storage size, battery life, display

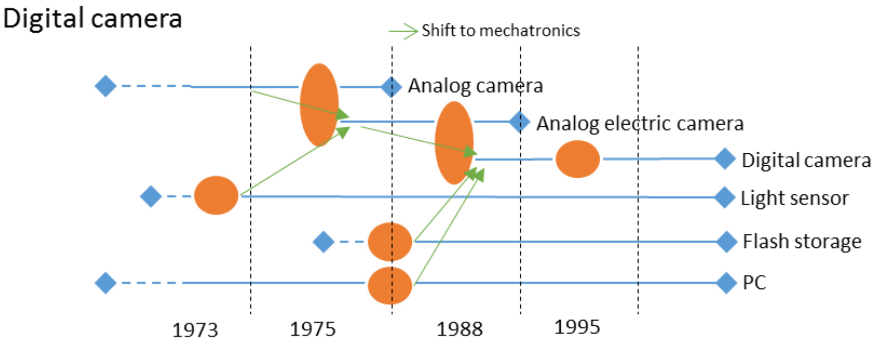
5.4. The product over time

Product name	Year	Interrelatedness of the parts			
		Camera	**Light sensor**	**Flash storage**	**Personal Computer**
CCD chip	1973		Researchers working towards CCD chip in cameras and computer memories.		
Analog electric camera	1975		CCD chip	Storage changed to cassette tape.	
Analog electric camera	1981			Storage changed to floppy disk, to make it a handheld device.	
Analog electric camera	1982	First photocamera with auto-focus.			
Digital camera	1988			Flash memory used.	Store photos in PC similar file format. Connect camera to PC for downloading images (RS232)
Digital camera	1990	First camera with image stabilizer.			
Digital camera	1995				Immediately view result on screen on camera
Digital camera	1996	CMOS caused drop in price of camera → Digital camera on mobile phones.	CMOS chip		
Digital camera	1997			Removable memory “key to the success of the digital camera”	
Digital camera	2005				Wi-Fi connectivity for direct printing or sharing (via e-mail or uploading to computer).
Digital camera	2009				Afterwards change background of a photo (editing)
Digital camera	2010				Editing software on camera (directly edit photo using touchscreen on camera)
Digital camera	2012				Photocamera running Android OS, can do everything a smartphone can except use the cellular network.

5.5. Remarks

Kodak patented the first digital photo camera in 1978 but their first digital camera was postponed until 1995. Perhaps because a digital camera would harm their core business of making film products such as the 35mm film with all its ISO varieties.

The digital camera entered a new application domain in 1995 because by better integrating the essential technologies, a display was added which changed the way the camera was used. The ability to review the photo made an impact in how a photo camera was used which caused the relevant attributes to change.



Digital Camera										
	Camera				Personal computer					
	Lens	Shutter	Storage	Light sens	Operating	APPS	Input peri	Output pe	CPU	Storage
1975	x	x	x	x					x	
1981	x	x		x					x	
1982	x	x		x					x	
1988	x	x		x	x		x		x	x
1990	x	x		x	x		x		x	x
1991	x	x		x	x		x		x	x
1995	x	x		x	x		x	x	x	x
1996	x	x		x	x		x	x	x	x
1997	x	x		x	x		x	x	x	x
2005	x	x		x	x		x	x	x	x
2009	x	x		x	x		x	x	x	x
2010	x	x		x	x		x	x	x	x
2012	x	x		x	x	x	x	x	x	x

Digital Camera										
	PERSONAL COMPUTER									
	OPERATING SYSTEM								STORAGE	
	PEXEC	MEM	MULTI	FILE	IO	NET	SEC	UI	INTSTOR*	EXTSTOR*
1975										
1981										x
1982										x
1988		x		x	x				x	
1990		x		x	x				x	
1991		x		x	x				x	
1995		x		x	x			x	x	
1996		x		x	x			x	x	
1997		x		x	x			x		x
2005		x		x	x	x	x	x		x
2009	x	x		x	x	x	x	x		x
2010	x	x		x	x	x	x	x		x
2012	x	x	x	x	x	x	x	x	x	x

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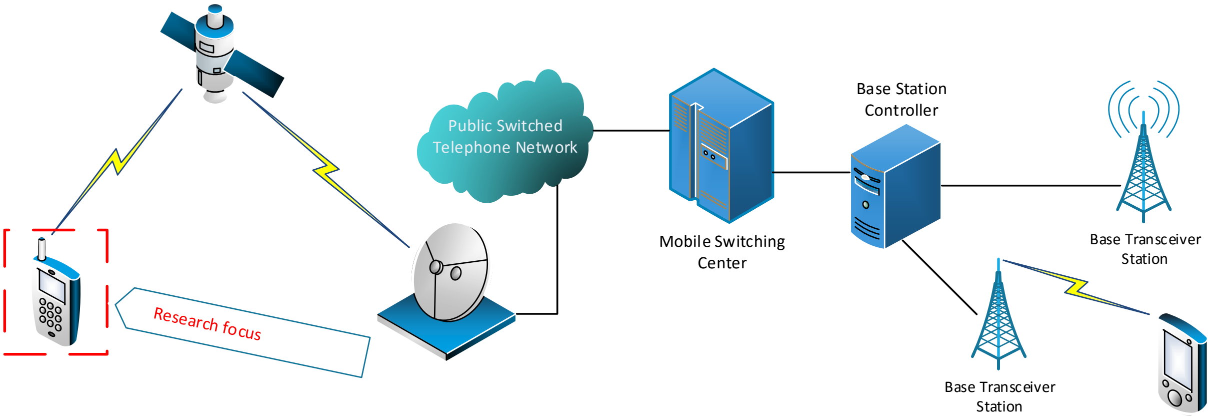
6. Satellite phone

6.1. Context

Variable	Value
Proof of technology (year)	1979
Geography of first proof	USA
Industry	Telecommunication
Technology stream	Telecom engineering, Electronic engineering
Technological principle	Establish multiplex connection with the telephone network to allow voice-, video-, and short text communication. Interaction with the device is enabled by a user interface.



6.2. Product essential technologies

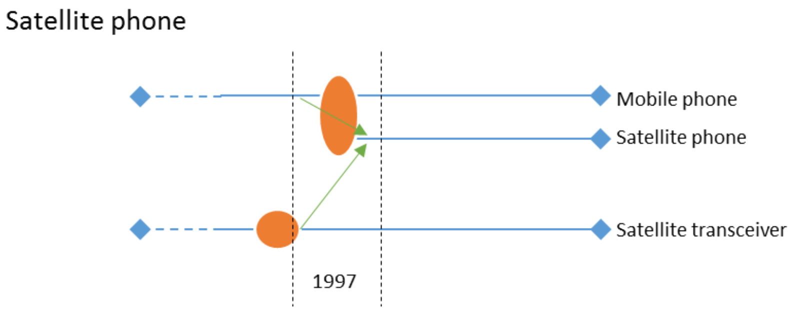
	Technology description			
Essential technologies	**Technology stream**	**Technological principle**	**Function**	**Parts**
Mobile telephone	Telecom engineering, Electronic engineering	Establish multiplex connection with the telephone network to allow voice-, video-, and short text communication. Interaction with the device is enabled by a user interface.	Voice-, and short text communication	Sender (encoder), Receiver (decoder), loudspeaker, input keyboard, display, microphone
Satellite transceiver	Telecom engineering	Decode encrypted radio signals to electric signals and encrypt electric signals to radio signals	Send and receive data to and from satellites	Sender (encoder), Receiver (decoder)

6.3. Application domain Mobile telephone and Satellite telephone

	Application domain			
Case	**Customer need (function)**	**Customer group**	**Technology**	**Relevant attributes**
Mobile telephone	Voice- and short text communication	Communication in areas with cellular services	Telephony	Size, weight, battery life, connection
Satellite phone	Voice- and short text communication	Communication in remote areas without cellular services	Satellite telephony	Size, weight, battery life, connection

6.4. The product over time

		Interrelatedness of the parts	
Product name	**Year**	**Mobile telephone**	**Satellite transceiver**
Satellite phone	1990	Further development focused on the size and weight of the device, extreme weather proofing, ease of use (software).	
Satellite phone	1999	Satellite phone can access the cellular (GSM) network directly (dual mode).	
Satellite phone	2000	Globalstar demonstrates internet connectivity over satellite connection.	



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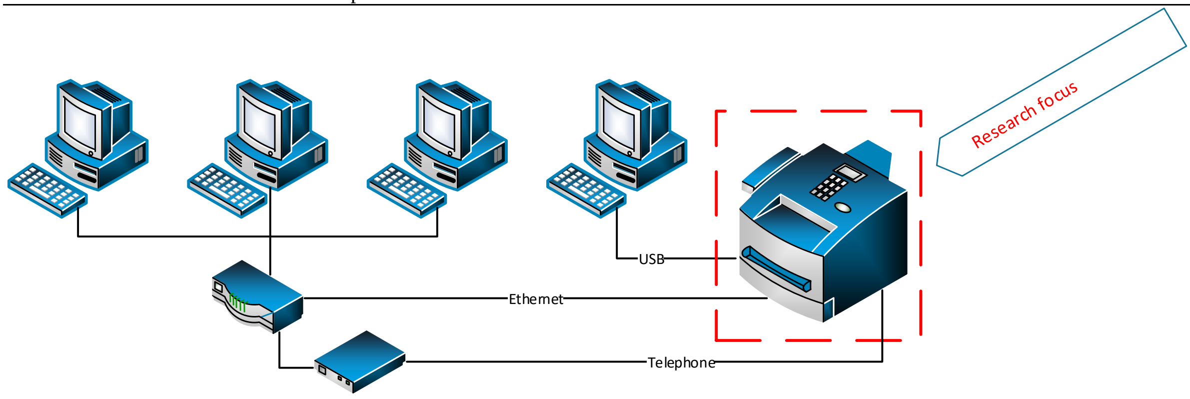
7. Multifunction printer

7.1. Context

Variable	Value
Proof of technology (year)	1990
Geography of first proof	USA
Industry	Computer / Computer peripherals
Technology stream	
Technological principle	Enable a user to communicate with the software interface to control the printer, copier, scanner, or fax function via a user interface on the device, or a remote device over the intra-, or internet, or the telephone network.



7.2. Product essential technologies

	Technology description			
Essential technologies	**Technology stream**	**Technological principle**	**Function**	**Parts**
Printer	Electronic engineering Computer peripherals	Decode electric signal received from an external device and produce an exact copy of the digital text and graphics on physical media.	Create a representation of digital graphics or text on paper (or similar physical media).	Input signal decoder, CPU, motor driver, motor, ink / toner, paper tray
Copier	Electronic engineering Computer peripherals	Use bright lamp to determine black or white, positively charge to light exposed areas and transfer these electrodes to paper	Copy paper	Photoconductor, lamp, ink/toner, motor + driver, paper tray (in&out)
Scanner	Electronic engineering Computer peripherals	Use an optic lens to capture light of the visible spectrum and digitalize this.	Digitalize physical media	Optic scanner, lamp, digitalizer, output (e.g. USB), CPU.
Fax	Telecom engineering Electronic engineering	Process content of paper and create a bitmap, transmit this over the telephone network in the form of audio-frequencies.	Send and receive documents	printer, encoder/decoder to /from audio frequencies
Personal computer	Computer science	Electronic calculating, storage, and display device that only uses 1's and 0's as data.	Input, store, process, display data	Operating system, applications, input and output peripherals, processor(CPU&GPU), storage

7.3. Application domain Multifunction printer and Printer

	Application domain			
Case	**Customer need (function)**	**Customer group**	**Technology**	**Relevant attributes**
Printers	Create a representation of digital graphics or text on paper (or similar physical media).	Big and SM business	Printer	Network connectivity, speed, quality,
Multifunction device (early)	Easy to use all in one device for high speed paper processing.	Big business	MFD	Network connectivity, speed, quality, parallel operations
Multifunction device (halfway)	Easy to use all in one device for high speed paper processing.	Big and Small Office/Home Office business	MFD	Network connectivity, speed, quality, parallel operations
Multifunction device (current)	Easy to use all in one device for high speed paper processing.	Consumers and all business customers	MFD	Network connectivity, speed, quality, parallel operations

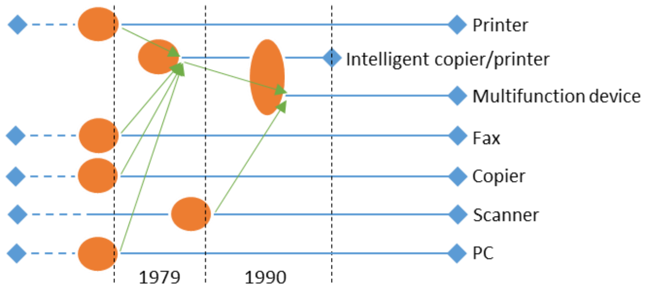
7.4. The product over times

		Interrelatedness of the parts				
Product name	**Year**	**Printer**	**Copier**	**Fax**	**Scanner**	**Personal computer**
Intelligent copier/printer (IC/P)	1979	Printer, copier, and fax machine in one. Examples: IBM 6670, Wang Image Printer, Xerox 5700.				MFD could be connected to 1 PC. Control of the entire device by one CPU (automatic queuing). Software is problematic.
Multifunction printer	1989	Color laser printing Kodak Ektaplus 7016 (+-$4,500)				
Multifunction printer	1990	Ricoh Corp. and Canon Inc introduced digital machines capable of all four functions, but for lack of software offer only two: fax and copying.				Networking ability. Software remains an issue.
Multifunction printer	1991		HP offered a fax/copier add-on module for its laserjet printers.	HP offered a fax/copier add-on module for its laserjet printers.		
Multifunction printer	1992	Okita introduces combined laser printer, scanner, copier, and fax machine. (+- $4,000).				
Multifunction printer	1995	Duplex printing	Copier and printer is combined for the low-end color device market	PC-based faxing	PC-based scanning	Windows-based software lets users access the machine's scanner to scan, view, print, and fax images. Networking option as a module.
Multifunction printer	1996	Development from here onwards for the printer, copier, scanner and fax focused on speed, quality and the penetration into other markets (from big business to medium, SOHO, and consumer markets) by smaller devices and lower prices for MFD's.				Full network printers.
Multifunction printer	1999					First printer with USB connectivity

7.5. Remarks

Long time referred to as 'Hydra', short for Hybrid Document Reproduction Apparatus. Also it has several 'heads' and remained mythical for the public until about 1990.

Multifunction device



Multifunction Device															
	Printer								Copier			Scanner			
	Input sign	CPU	Motor dri	Motor	Ink/toner	Paper tray	Photocon	Lamp	Ink/toner	Motor+dri	paper tray	Optic read	lamp	Digitalizer	CPU
1979			x	x	x	x	x	x							
1989			x	x	x	x	x	x							
1990			x	x	x	x	?	?				x	x	x	
1991			x	x	x	x	?	?				x	x	x	
1995			x	x	x	x	?	?				x	x	x	
1996			x	x	x	x	?	?				x	x	x	
1999			x	x	x	x	?	?				x	x	x	

Fax			Personal computer					
Printer	Encoder	Decoder	Operating	APPS	Input peri	Output pe	CPU	Storage
	x	x	x		x	x	x	
	x	x	x		x	x	x	
	x	x	x		x	x	x	
	x	x	x		x	x	x	
	x	x	x		x	x	x	
	x	x	x		x	x	x	
	x	x	x		x	x	x	

Multifunction Device										
	PERSONAL COMPUTER									
	OPERATING SYSTEM								STORAGE	
	PEXEC	MEM	MULTI	FILE	IO	NET	SEC	UI	INTSTOR*	EXTSTOR*
1979	x	x			x					
1989	x	x			x					
1990	x	x			x	x				
1991	x	x			x	x				
1995	x	x			x	x	x	x		
1996	x	x			x	x	x	x		
1999	x	x			x	x	x	x		

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8. Laser Lithography

8.1. Context

Variable	Value
Proof of technology (year)	1982
Geography of first proof	United States of America
Industry	Semiconductor
Technology stream	Semiconductor physics
Technological principle	Use ultraviolet light to transfer a pattern from a photomask to a lightsensitive chemical photoresist on the wafer.

8.2. Product essential technologies

	Technology description			
Essential technologies	**Technology stream**	**Technological principle**	**Function**	**Parts**
Photolithography	Semiconductor physics	Use ultraviolet light to transfer a pattern from a photomask to a light-sensitive chemical photoresist on the wafer.	Create semiconductors	Wafer, light source, power source, driver unit
Excimer laser	Electronic engineering, Optics engineering	Typically combine a noble gas (argon, krypton, xenon) and a reactive gas (fluorine, chlorine). Electric current stimulates emission of photons.	Emit a beam of ultraviolet light	

8.3. Application domain Photolithography and Laser lithography

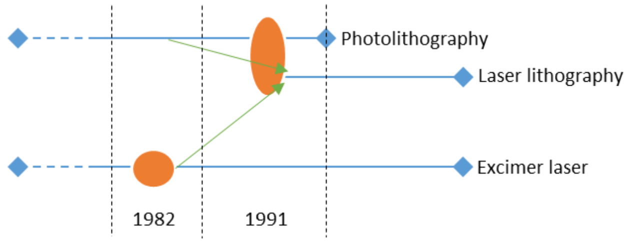
	Application domain			
Case	**Customer need (function)**	**Customer group**	**Technology**	**Relevant attributes**
Photolithography	High resolution semiconductors	Chip manufacturers	Photolithography	Speed, resolution, accuracy
Photolithography with laser	High resolution semiconductors	Chip manufacturers	Laser photolithography	Speed, resolution, accuracy

8.4. The product over time

		Interrelatedness of the parts	
Product name	**Year**	**Photolithography**	**Laser**
Excimer laser	1982	Excimer laser first proof of usability for lithography solutions at IBM.	
Nikon NSR1505EX	1988	First lithography product with KrF laser.	
PAS 5000/70	1991	Original light source for UV (mercury gas-discharge lamp) could no longer reach the desired resolution.	KrF excimer laser used with 248 nm. Resolutions of 400 to 90 nm.

Twinscan XT-NXT	2001	TWINSCAN system, one wafer is exposed while the next is already being measured to maximize productivity and accuracy.	ArF excimer laser used with 193 nm. Resolutions of 100 to 38 nm.
Twinscan XT	2005	Immersion technology to focus light using water	
Twinscan NXE	2010	Previous systems used lenses to focus the light, for EUV mirrors are used to reduce the loss of photons.	Excimer laser excites a droplet of tin or xenon plasma which emits ultraviolet light at a wavelength of 13,5 nm.

Laser lithography



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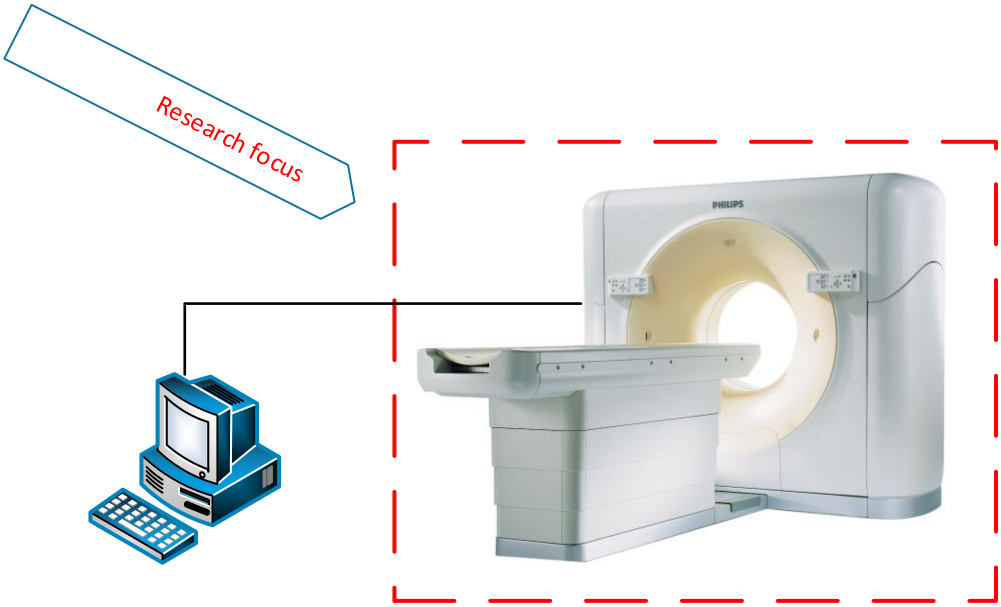
9. Computed Tomography Scanner

9.1. Context

Variable	Value
Proof of technology (year)	1967
Geography of first proof	Great-Brittain
Industry	Medical instruments / Human health
Technology stream	Radiology
Technological principle	Expose an object to X-ray radiation in a multitude of angles around the object, measure the photons using a detector that digitalizes the data, and send this to a computer to render a 3D model from.



9.2. Product essential technologies

	Technology description			
Essential technologies	**Technology stream**	**Technological principle**	**Function**	**Parts**
X-ray	Radiology	Expose object to X-ray radiation and capture the remainder photons on photographic plate	Produce an image of a specific part of an object to see inside the object without cutting	X-ray emitter, photographic plate (storage medium)
Detector		Measures photons that hit the sensor surface and digitalizes the data	Measures the amount of photons.	Detector, encoder, storage medium
Personal computer	Computer science	Electronic calculating, storage, and display device that only uses 1's and 0's as data.	Input, store, process, display data	Operating system, applications, input and output peripherals, processor(CPU&GPU), storage

9.3. Application domain X-Ray and CT scanner

	Application domain			
Case	**Customer need (function)**	**Customer group**	**Technology**	**Relevant attributes**
X-ray	View the internal structure of a non-transparent object of varying density and composition	Radiologists	X-ray	Quality of imagery

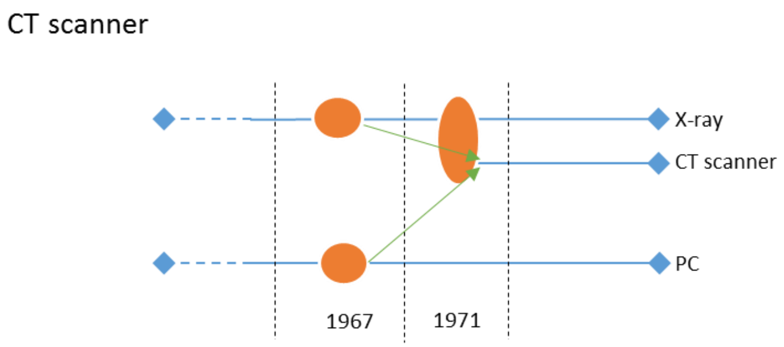
CT scanner	View the internal structure of a non-transparent object of varying density and composition	Radiologists	Computed tomography	Quality of imagery

9.4. The product over time

		Interrelatedness of the parts		
Product name	**Year**	**X-ray tomography**	**Detector**	**Personal computer**
CT scanner	1967	The scan measured the amount of photons under different angles and stored these on punched tape. The 3D image was then constructed by a modular PC using the data on the tape.		
CT scanner	1968-1973	Development focused on decreasing the scan and data processing time (initially +-9 days and +-3 minutes in 1973). This was done by integrating PC technology in the X-ray scanner, and by adding more photon detectors.		
CT scanner	1971	First patients tested.		
CT scanner	1972	EMI Medical introduces the first approved CT scanner and starts selling.		

9.5. Remarks

The PC in the CT scanner gathers the data and sends it to a remote PC that is directly connected to the CT scanner, and runs specifically designed software which can also operate as a remote controller.



CT Scanner										
	X-ray				**Personal computer**					
	X-ray emi	**Detector**	**Encoder**	**Storage me**	**Operating**	**APPS**	**Input peri**	**Output pe**	**CPU**	**Storage**
1967	x	x	x	x						
1971	x	x			x		x		x	x
1972	x	x			x		x		x	x

CT Scanner										
	PERSONAL COMPUTER									
	OPERATING SYSTEM								**STORAGE**	
	PEXEC	**MEM**	**MULTI**	**FILE**	**IO**	**NET**	**SEC**	**UI**	**INTSTOR***	**EXTSTOR***
1967										
1971		x			x				x	
1972		x			x				x	

9.6. Literature list

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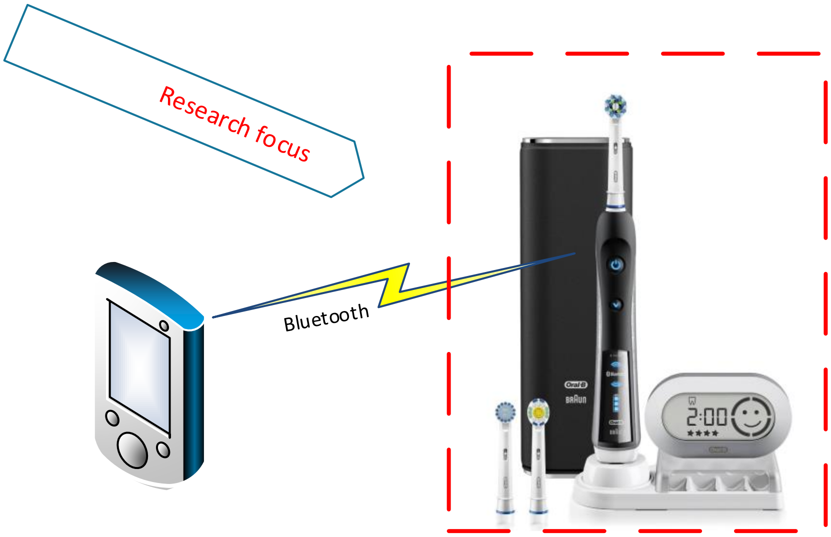
10. Electric toothbrush

10.1. Context

Variable	Value
Proof of technology (year)	1954
Geography of first proof	Switzerland
Industry	Consumer electronics
Technology stream	Health science → Dentistry
Technological principle	Brush teeth by rotating the brush head using an electric motor



10.2. Product essential technologies

Essential technologies	Technology description			
	Technology stream	**Technological principle**	**Function**	**Parts**
Toothbrush	Dentistry	Densely clustered bristles facilitate the cleaning of hard-to-reach areas	Clean teeth	Bristles, handle
Electric motor	Energy technology	Use electric energy to create a magnetic field to power a rotor	Produce kinetic energy	Rotor, stator, pulse-width modulator
Personal computer	Computer science	Electronic calculating, storage, and display device that only uses 1's and 0's as data.	Input, store, process, display data	Operating system, applications, input and output peripherals, processor(CPU&GPU), storage

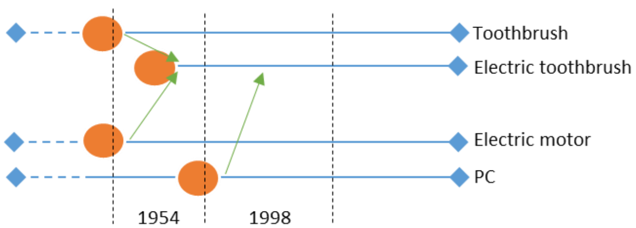
10.3. Application domain Toothbrush and Electric toothbrush

Case	Application domain			
	Customer need (function)	**Customer group**	**Technology**	**Relevant attributes**
Toothbrush	Oral hygiene	Consumers	Toothbrush	Bristles setup
Electric toothbrush (early)	Oral hygiene	Patients with limited motor skills and orthodontic patients	Electric toothbrush	Bristle type, movements per second, battery life
Electric toothbrush (current)	Oral hygiene	Electric toothbrush	Eletric toothbrush	Bristle type, movements per second, battery life

10.4. The product over time

Product name	Year	Interrelatedness of the parts: Toothbrush	Electric motor	Personal Computer
Broxodent	1954		Electric energy via power cord.	
Broxodent	1959	FDA approval, toothbrush launched in USA.		
GE tootbrush	1962		Electric energy from internal batteries	
Electric toothbrush	1963-1997	Development focused on design and bristle motion (including rotation, oscilation, and sonic vibration). In early 1990s inductive charging was introduced by Braun in its Oral-B rechargeable toothbrushes.		
Electric toothbrush	1998			Microprocessor for timer and LCD display. Also added pressure sensor.
Electric toothbrush	2010			Wireless connection to docking station for timer display.
Electric toothbrush	2014			Bluetooth connectivity; discover how you brush using an app on your smartphone.

Electric toothbrush



Electric toothbrush	Toothbrush			Personal computer					
	Bristles	Handle	Electric mot	Operating	APPS	Input peri	Output pe	CPU	Storage
1954	x	x	x						
1959	x	x	x						
1962	x	x	x						
1963-1997	x	x	x						
1998	x	x	x	x			x	x	
2010	x	x	x	x			x	x	
2014	x	x	x	x			x	x	

Electric toothbrush	PERSONAL COMPUTER									
	OPERATING SYSTEM								STORAGE	
	PEXEC	MEM	MULTI	FILE	IO	NET	SEC	UI	INTSTOR*	EXTSTOR*
1954										
1959										
1962										
1963-1997										
1998								x		
2010								x		
2014						x		x		

10.5. Literature list

It's electric jordan electronic toothbrush; braun D9 ultra timer plaque remover electronic toothbrush; cleanodent dental care system; hy-G lonic toothbrush. (1998). *Chemist & Druggist,* 24. Retrieved from http://search.proquest.com/docview/274953299?accountid=27026

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Appendix 2

“Model Types of Technological Confluence”

TU Delft

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						Technological principle			
						Same		New	
						Essential technologies		Essential technologies	
						Technology replaced	Technology added	Technology replaced	Technology added
Technology stream of the new technology	Same	Main functionality	Same	Relevant attributes	Same				
					New				
			New	Relevant attributes	Same				
					New				
	New	Main functionality	Same	Relevant attributes	Same				
					New				
			New	Relevant attributes	Same				
					New				

Positioning a technology in the model starts with identifying the differences between the base technology, and the new, confluence technology in terms of the variables in the model. In the following sections, the definitions of the variables are elaborated upon.

Technological principle

The technological principle is derived from the process that a technology embeds to carry out its main function. For a mobile phone, for example, the technological principle can be described as: a technology that establishes a wireless multiplex connection with the telephone network to allow voice-, and short text communication to be transmitted and received, the user can control the technology via a keypad, and the outcome of any form of input is shown on a display or turned into sound waves.

Essential technologies

We define the essential technologies by looking at what technologies the technological principle requires to fulfill the technology’s main function. From the technological principle described above, for example, we derive the following components: signal transceiver, input keypad, audio receiver, audio emitter, and a display. Using this method of defining essential technologies, the indirect components of a system are left out, such as the battery, FM receiver, and photo camera. Often, indirect components are found to be features, and therefore not essential to fulfilling a technology’s main function.

Technology stream

This is the field of applied science that a technology is part of. When the field of applied science of the new technology is different from the base technology, we speak of a new technology stream. A company that launches a technology in the *same* technology stream requires less new knowledge compared to launching it in a different stream. The CNC machine for example, where technology B is the PC, is launched in a new technology stream because technology B automated many of the functions earlier performed manually, and it also added new ones such as remote control via network connectivity. The entire translation from the drawing to a code understandable for the controller unit via manually creating punched cards, was now automated and much less time consuming than ever before. The CNC machine now belonged to the mechatronics technology stream, because the PC had a significant influence on the system as a whole. This means that effort is put into the embedding of PC technology in the NC machinery, because its developers wanted to automate many functions. Other examples of streams are: mechatronics, automotive, semiconductor physics, computer engineering, and aerospace engineering. An outline of the different fields of applied science can be found here: http://en.wikipedia.org/wiki/Outline_of_applied_science.

Main functionality
The main function that a technology fulfils, such as: transport over land, voice communication, capture photos, and oral hygiene. The main functionality that a technology fulfils is equivalent to the customer need that it fulfils.

Relevant attributes
A technology has certain functional attributes of which some are valued more in a specific context by a certain group of customers. In the disk drive industry a shift in the importance of size, weight and power requirements was necessary to enter the domain of portable computers, while a threshold in the functionality of the disk drive is still being met. Different needs in the domain required an emphasis on different attributes of the technology that were found largely irrelevant in the prior domain.

To further elaborate upon the relevant attributes, another example follows. The personal computer has been given certain shapes, being, among others: desktop computer, laptop, and tablet. Each of the three mentioned have the same *set* of attributes because they are built from the same technology (i.e. same technological group), being: PC technology. What makes each different is the specific *emphasis* that is laid on a *subset* of attributes of personal computer technology. With a desktop computer, for example, weight and size are much less relevant than with a laptop or tablet. And with a laptop, the built-in hardware input devices (e.g. keyboard and mouse) are considered relevant functional attributes above the touchscreen input from a tablet. Of course, within the market for desktop, laptop or tablet computers there is much variety available, but this remains a play of the same subset of relevant attributes. In this example, we also see that the attributes of a technological group can evolve. Touchscreen technology is, for example, later added to personal computer technology, resulting in the tablet computer. As a consequence of the addition of this attribute to the technological group, there are currently laptops on the market that, as well, incorporate touchscreen technology, the so-called "convertible" laptop. The addition of a new attribute can therefore open up new possibilities for other technologies part of the same group.