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REUSING OLD INFRASTRUCTURE TO HOST DATACENTERS:

ECO-INNOVATION AS AN EXAPTATION PROCESS

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Abstract

We describe the reuse of old industrial infrastructure for creating new sustainable technologies as eco-innovations. Reusing old structures is often described as an adaptive process. We suggest that to understanding these processes it is helpful to conceptualize them as exaptations to elaborate how new sustainable innovations emerge. Exaptation is defined as the current use of a structure or feature that is co-opted for a different use than it was originally intended or designed for whereas adaptation is the development a certain feature to better fit its niche. In an exploratory case study we compare how old structures in two historical Finnish paper mill sites were transformed to serving cloud computing datacenters for Google, IBM and CSC. In particular, we observe how equipment for pumping process water was reused for computer cooling function in Google but not in IBM or CSC. Our result suggest that that the scope of exaptation at the sites differed remarkably because the scope of exaptation is sensitive to initial conditions and perceived social gain. Our findings contribute to the conceptualization of sustainable eco-innovations as exaptation processes.

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ABSTRACT

We describe the reuse of old industrial infrastructure for creating new sustainable technologies as eco-innovations. Reusing old structures is often described as an adaptive process. We suggest that to understanding these processes it is helpful to conceptualize them as exaptations to elaborate how new sustainable innovations emerge. Exaptation is defined as the current use of a structure or feature that is co-opted for a different use than it was originally intended or designed for whereas adaptation is the development a certain feature to better fit its niche. In an exploratory case study we compare how old structures in two historical Finnish paper mill sites were transformed to serving cloud computing datacenters for Google, IBM and CSC. In particular, we observe how equipment for pumping process water was reused for computer cooling function in Google but not in IBM or CSC. Our result suggest that that the scope of exaptation at the sites differed remarkably because the scope of exaptation is sensitive to initial conditions and perceived social gain. Our findings contribute to the conceptualization of sustainable eco-innovations as exaptation processes.

Keywords: Eco-innovation, exaptation, datacenter, sustainability

OUTSOURCING INFORMATION TECHNOLOGY SERVICES TO CLOUD COMPUTING DATACENTERS

In this paper we explore how two aged Finnish paper mill sites, facing run down due to low profitability, evolved to datacenters for Google, IBM and CSC, all providers of a new outsourcing mode of production of information technology (IT) functions for firms and consumers, usually called cloud computing services. According to Marston et al (2011), cloud computing services are delivered on-demand to customers over a network in self-service fashion. The resources to provide these services are shared, dynamically scalable and virtual in the sense that users pay the operating expenses but not the initial capital expenditure to set up the services. The nascent industry of cloud computing uses increasing amounts of energy for running its datacenters and makes continuous heavy investment to expand its capacity due to enormously increasing demand for their services. In December 2004, Facebook had 1 million users but served 845 million users by November 2011 (newsroom.fb.com/Timeline).

When first datacenters were built nearly two decades ago, the solutions used in those times were not very ecological by today's standards. Cloud computing service providers face a constant demand from the government officials as well as from customers to find more environment friendly solutions for building new sites. The important features in achieving an environmental friendly data center are related to cooling and minimizing the electricity needed and reusing old infrastructure. The cooling process and energy supply produce carbon dioxide emissions; moreover energy efficiency in operating datacenters is poor. All the problems in greening datacenters cannot be solved by just switching to renewable electric energy sources, the energy wasted in the process due to overlapping heating and cooling problems needs to contained in order to achieve more efficient sites. IT consumes 2 % of global electricity demand and a standard datacenter produces 59 kilotons of carbon dioxide emissions (Masanet, Shehabi and Koomey, 2013). Reuse of old infrastructure in building a new industry has important practical implications to the environment. Construction industry consumes 50 % of all the global resources (Sev, 2009); redeploying old infrastructure would help a lot to stabilize the material balance sheet of the economy.

The premises of paper mills, with access to energy and water, share many elements also crucial for datacenters, which makes them an interesting option for new datacenter sites. Analyzing the two case sites we noted that the paper mills at Summa and Kajaani, of comparable size, output and age, both located in cold Nordic climate, were simultaneously renovated for datacenter use from 2008 to 2012. However, the outcomes of these deployments at the two sites differed widely, which presents a puzzle. For example, in Summa, a datacenter was built up by Google in the old machine hall premises which used the old water pumping infrastructure for cooling the processors. In Kajaani, two services were set up by IBM and CSC using only part of the storage premises, yet, the available waterworks infrastructure was not deployed. Moreover, the additional energy works for backup power at Kajaani remained intact whereas new backup power sources were built at Summa. Why were the assets at these sites utilized so very differently? To what extent could differences in the ways the new cloud computing service providers operate help to understand the process and scope of reuse in general? Our research question is as follows:

What factors influence the scope of reusing old industry infrastructure when founding cloud computing datacenters?

Traditionally, scholars observe how a new industry displaces the old one in the same or related field of applications. To understand industrial change, concepts and theories on design (e.g. Simon, 1962; Abernathy and Clark, 1985), modularity (e.g. Sanchez and Mahoney, 1996; Pil and Cohen, 2006), disruptive changes (e.g. Christensen and Bower, 1996), dissipative structures (e.g. MacIntosh and

MacLean, 1999), cognition (e.g. Tripsas and Gavetti, 2000), and firm specific dynamic capabilities (e.g. Teece, 2007) have been used. To understand site reuse, concepts and theories from industrial symbiosis (e.g. Pakarinen et al, 2010), brownfield (e.g. Dorsey, 2003), and reshoring (e.g. Ellram et al, 2013) have been applied. However, the reuse of old structures for wholly new businesses ventures seizing opportunities to creatively destruct and replace old industries in a Schumpeterian manner presents a largely unrecognized challenge for theorizing on industrial evolution.

Building on the theory of exaptation, recently introduced to management literature (e.g. Dew, Sarasvathy and Venkataraman, 2004; Sarasvathy and Dew, 2005) we conceptualize the transformations of old infrastructures as instances of exaptation process. To our knowledge, this is the first comparative case study to better uncover the mechanisms of how or why similar old structures are sometimes redeployed for new functional uses and sometimes not, in other words, when eco-innovations occur. In current literature, reusing old infrastructure is described as an adaptive process (e.g. Bullen and Love, 2011), although the definitions of adaptive reuse reviewed in Bullen (2007) actually are better characterized as instances of exaptation, as shown below. We seek to conceptually clarify the process of transforming infrastructure to eco-innovation. Our paper, addressing these gaps, is organized as follows. Section two reviews the literature on exaptation and sustainability and describes our theoretical approach. Section three illuminates study methodology, industry background and case firms. Section four presents our empirical findings on the differences and similarities in the two cases and section five our conclusions on what the results contribute to the theory of exaptation.

REUSE OF OLD INDUSTRY STRUCTURES AS AN EXAPTATION PROCESS

The notion of exaptation arose from the critique of Gould and Lewontin (1979) on the widely used traditional terminology describing biological adaptation, which was unable to distinguish between the current utility of a feature in the structure of an organism and the reasons for its origins, i.e.

historical emergence. In fact, their criticism on confusing genealogy with current function was antedated by men of letters long ago. Both Vico (1744) and Nietzsche (1887) painstakingly distinguished between the current beliefs or habits of men from how they came about, previously serving some other purpose arising from different origins. According to Gould and Vrba (1982), exaptation refers to the process where a structural feature that was originally used for some different function was later co-opted for a new function. Adaptation on the other hand means the intentional or unanticipated development of a feature to better fit its purpose. Their definition is open to how the feature originated, by adaptation or not. Exaptation offers one explanation to serendipity, i.e. why certain features started to develop in the first place (e.g. Campbell and Reece, 2005, p.483). Exaptation also explains why new functions need not instantly appear fully effective. For example, the feathers of birds were originally well functioning insulators, but, incidentally, they were of fine use for gliding too. The ability to maneuver in air was then improved by consequent better adaptation of bones and muscles for flying (Gould and Vrba, 1982). This is how exaptation solves the problem of "pre-adapted" structures. The trouble with preadaptation is that the word implicitly suggests teleology, that the unknown future use was somehow planned or predetermined in advance. It ignores the possibility of unforeseen change over time. However, there is neither foreknowledge nor a pre-existing finite list of new functions - when or for what reason exaptations may occur - for old structures. This line of reasoning makes the illogical idea of preadaptation obsolete.

In economics, exaptation processes have been increasingly studied in the past decade in the context of innovation and entrepreneurship. Dew, Sarasvathy and Venkataraman (2004) suggest that exaptation is a central concept to better understand the creation of new markets and opportunities in an unpredictable environment. We suggest that exaptation is the key element to understand much of innovative development, since the history of many inventions, if traced back, reveals that the technology for them was originally designed or tried for different purposes than it was later co-opted for. For example, CD-ROM was designed to replace the vinyl records for better sound quality and durability. After the technology was patented, researchers expanded it to support any form of data storage and it became the basic ingredient of computers. There are different reasons why exaptations might occur in the economic world. First, exaptations might be “active” adaptations. In other words, structures are taken to a different use than designed due to a task at hand, as a certain type of creativity in a crisis situation. Second, they can be features that are available due to a certain technology but aren’t in use for that specific technology. Third, they can also be byproducts of a certain technology as well.

In the current construction literature the re-use of old infrastructures is commonly described as an adaptive process. The review of Bullen (2007) defines how adaptive reuse occurs when building performance is upgraded (Latham, 2000), a change of use required by new owners is introduced (Douglas, 2002), existing buildings or structures are renovated for other than present use (Dolnick and Davidson, 1999), or a process that changes a disused or ineffective item for use in different purpose, according to Australian Department of Environment and Heritage (2004). Comparing these four definitions with that of Gould and Vrba (1982) who define exaptation as the use of old structure in another new function we observe full analogy, even literal identity with the definitions in Bullen (2007).

Reviewing the limited literature on drivers and barriers for reusing old infrastructure, Bullen and Love (2011) suggest that drivers decrease environmental loading whereas barriers increase it. Without challenging this proposal, we maintain that more detailed studies in the mechanisms of barriers and drivers of adaptive reuse, i.e. eco-innovation as new technology creation, i.e. exaptation, are warranted.

The definition of an eco-innovation is not agreed upon in the literature (e.g. Carrillo-Hermosilla, del Rio and Könnölä, 2010). In this paper we follow the broad conceptualization of Rennings (2000) and understand eco-innovations as innovation process towards sustainable development. The literature on determinants on eco-innovation is numerous (e.g. del Rio González, 2009). Andersen (2008) distinguishes between five different types of eco-innovations; exaptation qualifies for her category three, alternative product innovations or new technology paths. The usage of these technologies then later may qualify as types one and two, maybe even four and five, but in this paper we describe them as adaptive processes following the initial exaptation stage. We therefore suggest that adaptive reuse akin to at least Andersons' typology type three of eco-innovations, in line with the conceptualization of Rennings (2000) should be designated as exaptation.

Exaptation is not identical with typologies of architectural (Henderson and Clark, 1990) or disruptive (Christensen and Bower, 1996) innovation, technology speciation (e.g. Levinthal, 1998) or evolvability via first order incremental and second order structural adaptation (Ethiraj and Levinthal, 2004). Whether some of these constructs should be considered in classifying eco-innovations is beyond this paper Exaptation differs from bricolage (Baker and Nelson, 2005) which denotes a creative combination of materials at hand regardless of their isolated purpose, whereas exaptation is not about combining two already existing ideas: the new use of an old material does not exist beforehand.

Instances of exaptation have been detected in documenting the emergence of innovations (e.g. Mokyr, 2000; Bonifati, 2010) and entrepreneurial opportunities (Venkataraman, Sarasvathy, Dew and Forster, 2012). For example, mechanized printing press was invented in Europe by exapting wine pressing machinery for imprinting text on paper at German wine area where Gutenberg lived (Johnson, 2010). In a detailed case study on technology speciation, Cattani (2006) reconstructs how an existing technology evolves to a substantially different one. He concludes that Corning's technological knowledge on specialty glass was accumulated in R&D without anticipation of subsequent use for conducting light rays, but later turned out to be functional for the alternative, as yet unknown application for fiber optics.

Marquis and Huang (2010) suggest that the underlying reasons and conditions why some organizations ex-aptate techniques in an environmental change and turn the change into a success, whereas others do not, dwell in the organizations and their legacy. Studying investment banking acquisitions, they noted that the imprinting effects on the acquiring firms – based on conditions occurring at the time of their founding - manifested differently after they acquired other firms. In particular, banks better used to managing a vast number of branch offices were using these capabilities to better manage acquisitions and integrate activities after bank deregulation made merges possible.

Analyzing the current literature on exaptation, two gaps appear. First, the sustainability orientation in entrepreneurship and innovation - sustainability transition - is not addressed. Although scholars hail sustainability as the key driver of innovation when advising practitioners (e.g. Nidumolu, Prahalad and Rangaswami, 2009), supporting sustainability transitions is a still an open theoretical (e.g. Smith et al, 2010) and unresolved policy issue (e.g. Nill and Kemp, 2009). Institutional and normative factors need to be incorporated in studying innovations (Jennings and Zandbergen, 1995).

Although a recent review on innovation processes in Academy of Management Annals does not yet recognize innovating for sustainability (Garud et al, 2013), sustainability transition is receiving increasing attention as a new research field (e.g. Markard et al, 2012). Scholars conceptualize socio-technical sustainability transitions by including institutional and cultural factors in addition to the technological dimension. This implies a broadening view of innovation taking the social context into account (e.g. Geels, 2004). Studying exaptation for sustainable economics would fit this broader approach. To pursue a sustainable economy, Patzelt and Shepherd (2010) suggest that current ideas on entrepreneurship and innovation are not capable for modelling sustainable innovation, since the focus their search for innovative opportunities differently, including also natural environment. Building on their idea of social gain, we observe both economic and sustainability factors which also are socially approvable as an added benefit. Sustainability factors include social recognition, altruism, and perceived threat.

The second gap relates to the conditions under which exaptation opportunities are seized and their scope. Although previous scholars address some antecedents of exaptation, such as technology and research (Dew et al., 2004; Cattani, 2006), or organizational characteristics (Eckhardt and Ciuchta, 2008), the literature does not clearly address the problem why differences in scope arise in different exaptation processes. Marquis and Huang (2010) refer to the past imprinting process of capability building in acquiring firms as an antecedent for exaptation of these skills after acquisitions. Cattani (2006) considers prior experience to be decisive in redeploying old technology in new field. Exaptation can be a conscious entrepreneurial choice when old structures are conserved for sustainability goals. Addressing the differences of scope in exaptation, we pursue to study the mechanism for more or less extensive exaptation of old infrastructure. These include both business and technology driven as well as societally driven items. To our knowledge, our study is the first to increase understanding on the use of ex-aptive process to enhance sustainability in innovation. As of yet, we do not attempt to build an extensive theory on exaptation for sustainability; through our case comparison, we try to better frame some of the issues in terms of exaptation for sustainability to benefit subsequent study and theorizing.

STUDY DESIGN, INDUSTRY BACKGROUND, AND CASE DESCRIPTIONS

We conducted an exploratory comparative case study (Yin, 2003) in two sites in Finland. The case study approach was chosen to capture rich empirical details of the process of redeploying the sites and to develop theory in increasing understanding of the micro-mechanisms involved. We used publicly available sources and data from the archives of the paper mills, online material of the organizations in question and literature sources. From primary data, we collected a list of items which were demolished, structures which were retained for new datacenter function and what equipment was brought in by the new businesses. We summarized the data in tables and compared across cases what actions were similar and different at the two sites. We also collected background data from firms leaving and entering the sites. Both case histories, unique in kind, described the first two large scale transformations of old industry sites for cloud computing, so it was appropriate to select them for comparative observation. The data sources provide a dynamic view of the processes in question to create a valid outlook of the different underlying causes and outcomes of the specific cases. Archive material with its facts and figures helps to understand why the actions chosen took place and the differences between the two sites and the new entrants.

To some extent, our approach resembles that of Siggelkow's (2002) analysis of the evolution of conducting business in Vanguard Group, where he identifies four core elements, either permanent or new creations. However, his analysis was within-firm and industry while our study narrates a change in both firm and industry. Moreover, he focuses on intangible organizational elements, where their genealogy does not reveal another use in the past whereas our focus is on concrete artifacts where some of our core components are created when old structures enter new functions i.e. by exaptation.

Due to the exploratory nature, we admit numerous limitations in our study affecting validity. Such limitations include small number of cases, publicly available of empirical material, and lack of input from informants. We shall expand our research in another paper.

Paper mills

For paper production, wood based raw material, water, energy, and transportation infrastructure are needed. Paper machine plants need huge upfront investment, currently in the range of one billion euros, but they have long lifecycles. Paper demand is very sensitive to economic cycles, which causes to costly storage times for the products and the need of large cold storage facilities near the factory (Diesen, 2007; Koskinen, 2009).

The first key feature of paper mill sites is the huge size of the premises. The scale of output necessitates big machinery. The machine halls, 250 meters long and over ten meters high, typically have 10 000 square meters floor area, and many mills have 3 to 4 machines running (e.g. Stora Enso archives).

The second key feature is the need of water. Paper making uses 8 to 15 cubic meters water per ton of paper which often requires special arrangements to ensure the flow from nearby water resources. To ensure water supply, paper mills in Finland are located in the immediate vicinity of a lake, river or the sea.

Energy is the third key element. The electricity grid for Finnish paper mills was built when the sites became operational, in some cases, a century ago, and is being continuously updated. In particular, to forcefully abrade logs to mechanical pulp consumes lots of energy. Electricity used at a site amounts to 900 - 2000 GWh annually (Stora Enso and UPM-Kymmene archives). Being near water, many sites have the possibility to use renewable hydropower as energy source although due to continuous growth in production capacity, only a tenth of current total energy comes from a renewable source (Diesen, 2007). Paper mills use energy sources that generate carbon dioxide emissions, such as oil, coal, or natural gas although in Finland using nuclear power is typical. To be profitable, paper machines must run at almost full capacity day and night.

Datacenters

Public cloud computing services providers, which process data globally, offer selected simple standard solutions operating very large datacenters for very many clients. Private cloud service firms, which process data locally or even in isolation offer complex tailored solutions but usually operate smaller datacenters for fewer clients. Whereas it is easy to gain new clients from consumers and small enterprises and provide them with new services, it may take years for cloud service providers to make full use of the potential of large client organizations.

Datacenters need sizable premises, lots of electric energy to run the computers, large cooling system to cope with the waste heat emerging from processors, and optic fiber cable networks for reliable and speedy signal transmission (for general references on cloud computing technologies, see e.g. Kant, 2009; Malkamäki and Ovaska, 2012). About a hundred servers can be accommodated to one square meter of space and service providers may have server rack queues occupying thousands of square meters.

Electrical energy is supplied by national electricity grid. To ensure constant power supply, a variety of back-up power systems to help protect the client may require extra investments, so that lack of power does not cause service slowdown or failure. Cooling is accomplished by letting cold air or liquid flow between the racks of servers. The key terms which are important to understand the energy balance in datacenters are Power Usage Effectiveness (PUE) value, free air cooling and forced air cooling. PUE value is a measure of a data center’s efficiency of energy use and the calculating power achieved. In the ideal case PUE = 1, so all incoming energy feeds the processor only to produce calculating power, which would ecologically also be the most sustainable outcome. Traditionally, PUE values in datacenters depending on the age of the facility vary from 1.2 to 3.0, whereas the newest data centers can achieve values as low as 1.1.

Depending on outside temperatures, different ways of piping the coolant and using forced or free flow cooling are used. Forced air cooling is the traditional way to cool down the primary cooling system of the service racks, which can be liquid-based. Large fans usually run by diesel power generators wind the incoming circulating air with excess pressure. These systems are mainly responsible for carbon dioxide emissions at datacenters. For example, Microsoft's datacenter in the Bay Area is considered a high environmental risk due to its 26 generators (Bay Area Quality Management District, Annual Air Toxification Report, 2013). Free air cooling can be used when outside temperatures are low enough to cause the air in the data centers to cool when let in. Depending on the geographic location of the site and average temperature, one can estimate how many hours per year free air cooling can be used. This system is usually supplemented with generators to cool the air when outside temperatures rise. Cooling becomes more effective with water than with air since water has a larger capacity to store heat per unit weight than air. A further option is to cool the primary liquid system with a secondary liquid system instead of air to make it more effective, if water is available (Norothy, 2010). .

Case Summa Google

Enso Gutzeit has a long history as one of the biggest players in the Finnish forest industry. It built the factory in Summa in 1955. After expansion in the 1970's the site had three paper machines delivering over 400 000 tons of paper per year, consuming close to 900 GWh electricity to that end (Stora Enso archives). Due to constant development in technology and changes in demand, old paper machines turn low in productivity or become too rigid for readjustment and must finally be substituted with new ones, or the whole mill has to be closed. Finnish firms now readjust their business from production to consultation, delivering technical expertise and developing machinery in still rapidly growing geographic areas such as China (Diesen, 2007). Their increased global presence also pushes them to invest in new paper machines abroad close to the customer rather than in Finland or just sell proprietary technology (e.g. www.metso.com/news). In a fusion with the Swedish paper company Stora in the 1990's, the new company Stora Enso became one of the largest firms of this particular industry worldwide. This shifted its investment policy to support global presence more actively. As a consequence, some old sites in Finland turned obsolete and became unprofitable.

Google bought the old paper mill site in Summa in early 2009 and transformed it to an ecofriendly data center using already existing structures of the mill instead of building a totally new site, which is usually more cost-efficient. A few key elements, such as cooling pipelines and ducts, are often part of the hall structure itself. Therefore, in order to achieve highly esteemed low PUE values, it is usually required to build an entirely new premise. After visiting the site for the first time Google noticed that inside the walls, the machine hall had few other existing structures after the paper machine was taken out. Since also the water pipelines were still in operating condition, Google decided to use the existing structures instead. Secondary water-based cooling is more effective in cooling down the primary liquid-based cooling system close to the server racks than traditionally used air (Novothy, 2010). Google benefits from water cooling due to its proprietary patented knowledge of water cooling (Google Water and Cooling 2013). The premises in Summa were the first in the world to use sea water for cooling. While the factory was still operational, the pipelines were also connected to ground water and surface water besides the sea for water intake, and they shared a common release pipeline to the sea. This pipeline was the one Google decided to use for releasing the cooling water back, 3-15 degrees warmer after the cooling process, but they had to build in new pipelines for water intake in the Gulf of Summa. Initially, Google used in the first stage only part (estimated as 30 %) of the capacity of the premises. The carbon dioxide emissions of this stage are 0.4 kilotons per year (2011). When more computing capacity was needed, the news of a second stage to increase the use of the premises was released (ESAVI/230/04.08.2012). However, the Summa site did not have the option to use hydropower for electricity since no power plant was built for lack of nearby waterfalls.

Categorizing different business models of cloud service providers based on history and the nature of their services, one can distinguish between the "old" and big players, actors whose activities are based on a variety of innovations, and others that have a more supporting role (Marston et al, 2011). According to this classification, Google is a long line player in the industry. Google targets all possible clients for its web search engines and Gmail services but it has proven most successful in attracting consumers and small to medium sized organizations for its other public datacenter services.

Case Kajaani IBM and CSC

After a number of fusions, UPM-Kymmene became another world class Finnish forest industry company by the early 2000’s. Its paper mill in Kajaani was functional since the late 1800’s. While running, the site was the fourth largest energy consumer in Finland requiring estimated 2000 GWh electricity and delivering 640 000 tons of paper annually (UPM-Kymmene archives). In addition to three paper machines and cold storage facility, it had pulp and saw mills and it delivered district heating to the town Kajaani. The oldest of these paper machines – the first of total four - had been closed down in the 1980’s but, by legal action the machine hall was conserved for its historically significant design and structure (PSAVI/235/04.08/2010). When the paper mill was shut down in December 2008 for reasons similar to Summa, UPM-Kymmene did not sell the site but pursued to create new workplaces and make use of the already existing structures left behind by one of the biggest paper mills ever built in Finland.

IBM and CSC are the two cloud service providers who, among other tenants, rent facilities and services from Renforsin Ranta, an organization owned by UPM-Kymmene, set up to govern the premises of the old paper factory in Kajaani. IBM can also be described as a long line player, for it has been in the datacenter business for a long time, and, due to its past success as mainframe supplier, it has a strong foothold in corporate clients. IBM expands to private cloud computing services and offers tailored solutions for its business clients. IBM co-operates with the local telecom operator in a joint venture to run its datacenter in Kajaani. In the past few months, it has launched a new private cloud service concept called IBM Spektri, targeted directly for Finnish public sector, taking advantage of the newly built data center in Kajaani. Due to legislation, it is mandatory that certain public databases are physically located within the borders of Finland. IBM recently contracted the maintenance of the ICT services for The Social Insurance Institution of Finland.

CSC – IT Center for Science - is a non-profit organization owned by the Finnish Ministry of Education, providing tailored solutions to universities, schools and hospitals across the nation to support research and education. For example, from May 2013 on, CSC provides all ICT services for Aalto University. Its clientele and offering partly resemble those of IBM. Hewlett Packard is the main equipment supplier to the datacenter (www.csc.fi). In Kajaani CSC also hosts one of the world’s fastest Cray XC30 supercomputers that represent the cutting edge of high performance computing technology. CSC is operating FUNET, a cable network started by the Finnish Ministry of Education in 1983, and the first provider of internet in Finland (Ahonen, 2008).

RESULTS

In early 2009, Google announced the opening of their data center in Summa using already existing structures as well as adapted techniques to achieve one of the lowest PUE-values in the industry. It served as an eye-opener for other cloud computing providers like CSC and IBM to look into the possibility to use closed paper mill sites in Finland for datacenter function, and to achieve low PUE with the structures already available. The findings are summarized in Tables 1 and 2.

Insert Tables 1 and 2 about here

The first intention of the companies in question in this case was to follow Google's footsteps and reuse the still operational pipelines for secondary cooling with water. In addition, they intended to use the operating hydropower plant for ecologically sustainable energy and the machine halls for the service rack building, since it was already connected to water, electric and optic fiber networks, and sanitation. It soon became clear that the entrants needed far less power (about 2 MW) than the hydropower plant could offer (10 MW), so that the power plant would not operate smoothly and it was not feasible to use it. Also the water temperature – which doesn't play such a big role in paper manufacturing – would reach too high a temperature in the summer, which would require specially designed equipment if used as a secondary coolant. At this point it was also noted that the cold warehouse in the premises, not previously intended to be used and not connected to the existing infrastructure networks was an option to be considered. The outside temperature in the area was cold enough for a year-round free-air cooling without the need of any back-up generators and the premises could be easily connected to other networks essential for datacenter use. These were the extremely reliable electricity grid build around the factory area and the fiber cable connection that was already operated by CSC. In the end the result was not what was originally planned and the low PUE was achieved in very different ways from those intended, deviating from how Google achieved it. Next, we will take a closer look at the features that might explain the differences in these two processes.

Premises

In Summa, the paper mill site and some connected land areas were purchased by Google for the price of 40 million euros in 2009 (www.storaenso.com). In the first stage much of the old factory hall was transformed into a data center at an estimated investment of 150 million euros. According to public sources, an additional second stage transformation is now taking place increasing the total costs of the process to estimated 500 million, where the major part of the expenses is caused by new technological equipment (Google about Datacenters, 2013). Stora Enso sold the paper machines for further use or demolished them, filled up the holes in the floor of the factory left behind from the paper machines and made minor surface renovations. Sanitation plumbing of the basement was renewed and the site was connected to the local sanitation network by Google, for sanitation was previously taken care of by the waste refinery plant of the former owner Stora Enso (ESAVI/283/04.08/2010).

Google installed the server racks and cooling systems. All the equipment was designed and specified to fit Google's needs. Although design details are not disclosed, the available information suggests that many solutions were one of a kind innovations in comparison with the standard solutions used in this industry. The site is connected to the old national 110 kV power grid. For lack of nearby waterfalls, using hydropower as an alternative energy source was not an option at Summa.

UPM-Kymmene's paper mill in Kajaani was in many ways operationally similar to Stora Enso's in Summa. After the factory was closed down in 2008, the premises were offered for long-term leasing. UPM-Kymmene disassembled and sold the paper machines, filled the holes in the floor with concrete and did some superficial renovations. The machine halls have access to the existing old structures, such as 110kV and 10kV electricity grids and water pipelines. According to the original plan, a datacenters was meant to be installed in the paper machine halls, Rata and Kone, like Google did in Summa. It turned out that the massive machine halls were too big for the modest demand of tenants, the two datacenter service providers, until their need for more computing capacity would emerge or other tenants would appear. Unfortunately, no large datacenter tenant closed a deal with Kajaani. Therefore, the cold storage hall Varasto rather than any of the machine halls is in use by IBM and CSC for operating their datacenters. The storage hall was then later connected to the existing sanitation network and electricity grid that Rata and Kone had been connected already. Currently, CSC is using 4000 and IBM 1000 square meters from the 10 000 square meters of the cold storage hall. In comparison, CSC invested 10 million euros in Cray Cascade supercomputer and used additionally about 6 million euros. IBM investments are estimated to be some million euros (www.renforsinranta.fi; www.csc.fi).

Cooling

The infrastructure of water pipelines and pumps was mostly exapted for reuse in new cooling function by Google in Summa. Stora Enso had built upstream dams at Lake Saaramaa and Turpaankoski rapid to ensure high enough water level in the estuary of Summa River at Gulf of Summa where the water pipes for intake and release of the excess water were located. Two new pipelines were built deeper in the sea for cooling water intake. Old water pipes for water outflow are still in use. The water areas are still owned by Stora Enso and since the dams are no longer needed Stora Enso shall take them down in the future (ISAVI/21/04.09/2010).

Google's custom made equipment is specially designed to use sea water as a coolant for servers. The system includes a primary closed circuit with liquid-filled racks so that the water is as close to the warm servers as possible. The primary system is cooled down with a secondary system that pumps water from the sea through the two newly built pipelines into the data hall and is then released through the old pipeline back to the Gulf of Summa. The temperature in outflowing water is 3 to15 degrees higher than in incoming water (ESAVI/283/04.08/2010). In Kajaani the water pipelines used by the paper factory are still in place and water can be delivered at the speed of 0.6 cubic meters per second at temperatures between 1 to 22 degrees in the summer. The usage of the water even as a secondary coolant sets demands on the design of equipment, for if the water temperature arises close to 22 degrees the standard equipment available in the market ceases to function properly. When using seawater as in Summa this is not a problem since at the intake depth of 5 meters the temperatures don't climb that high even in the summer. This is one of the reasons why water is not used as a cooling system in Kajaani at CSC, for the investment for making tailored equipment in small scale is not reasonable. Therefore, CSC uses standard free-air cooling system well suited for most of Northern Europe for practically all year long (European Free Air Cooling Map, 2012). However, IBM investigates the possibility to construct a dual air-water cooling system.

Energy

When paper mills at Stora Enso in Summa UPM-Kymmene in Kajaani were built, in 1955 and 1919 respectively, the electricity they needed for operating purposes was provided from the national 110kV grid, which had multiple parallel lines by design to ensure the power supply even if a line or two were dysfunctional. This updated network is still operational in both Kajaani and Summa premises and is used by both Google, and by CSC and IBM. The estimated annual energy use by Google is 280 GWh in electricity, 2.1 million cubic meters natural gas, and the waste heat produced by the servers. There are also 21 diesel powered generators with the total capacity of 110MW of power yielding 42 MW electricity to keep the essential systems running 100 % in case of grid failure (ESAVI/283/04.08/2010).

The datacenter at Summa still uses less energy than the paper mill, for Stora Enso used 857 GWh in 2003, of which Google currently requires one third (Stora Enso archives). Two Finnish datacenters, Google being one of them, arose to top nine of the most efficient energy users in terms of PUE value (Wired Online Magazine, December 2011). However, the decision to install diesel backup power source can be criticized as unnecessary. The national electric grid in Finland has extremely high reliability amounting to only 1 – 7 minutes disconnect per year since 1998 (Finnish Energy Market Authority's Annual Report, 2012), vanishingly small compared with 90 to 200 minutes disconnect per year since 2002 in USA according to Washington Post (March 8th 2013). For example, Amazon promises with 99.95 % certainty that their stored data is reached at any given time (Amazon Service Level Agreement 2008). In other words, the service is available but for about 260 minutes in a year, compatible with the US power grid disconnect time.

The demand for energy at Kajaani is one tenth of what UPM-Kymmene can offer to its tenants. The hydropower plants in Kajaani was designed to provide massive power load and since CSC and IBM need only a few MW each, it turned out not to be beneficial for the parties to use local hydropower before the premises are filled with multiple computing service providers using the existing supply together.

DISCUSSION

Our results suggest that the micro-level technological innovations can be described as exaptations. We also reveal remarkable differences between the two processes in our case study. First, Google had much of the old water pipeline infrastructure exapted for cooling its equipment, whereas this was not the case at CSC and IBM. Due to technology leadership in applying water cooling for datacenters, Google was able to effectively use old pipeline structures and water supply for cooling. Google used own datacenter design specifications for water cooling and exapted old pipelines when it suited their blueprint. However, water cooling for small datacenters, although technologically possible, was not economically feasible, since it would mean additional effort in R&D. In Kajaani, the infrastructure for water cooling was also too large for IBM and CSC for exaptation, when not supported by investment from UPM-Kymmene or required by other tenants simultaneously arriving at the premises. Therefore, air cooling was the first solution, although plans to use water are ongoing.

Second, Google had the main factory halls exapted for datacenter premises, whereas the exaptation by CSC and IBM was small and focused on the storage building. As to ownership, Google purchased Summa mill and some nearby land areas from Stora Enso all to itself in a one-time transaction. Because of Google's ownership, all renovations and new structures, but for filling the holes in paper machine hall floors, were completely on its responsibility. Google built some connecting cable to the national network (ESAVI/473/04.09/2010). The fiber cable connection came from TeliaSonera Oy (Submarine Cable Map, 2013). Planning for further investment, they followed "stand alone" mode and did not see the need to offer the premises to other tenants. In Kajaani, all the buildings, land areas and new structures remained in the ownership of UPM-Kymmene. The company intended to lease the premises for long term to cloud computing service providers and other business clients. All renovations to benefit tenants were done by UPM-Kymmene. Only fiber cable connections came from FUNET, owned by Finnish Ministry of Education.

Google, one of the largest public cloud service providers was able and willing to make upfront investment for increase in service volume and it expected rapid return. The UPM-Kymmene premises have a capacity to host up to ten times more active tenants than they currently do. As of now, some 20 smaller firms mainly occupy the storage building at the site. UPM-Kymmene may keep trying to get major datacenter players to fill the still empty factory halls. After all, Facebook, finally deciding for Sweden, was also interested in settling down in Kajaani, yet, huge clients are not available all of the time. To sum up, the scale of operations in organizations taking old structures into new use varied.

Third, CSC and IBM did not redeploy any old available hydropower plants for primary or fallback energy source, whereas Google built new diesel powered generators for backup electricity source. The only major technological difference between the two sites related to energy production. Kajaani had an operational hydropower plant whilst Summa had not. Hence, Google decided to invest in backup energy production required by its internal design specifications, but, following planning norms applied in USA, overinvested to secure the supply of energy with own diesel generators. The scale of this investment was probably way too high for conditions at Summa and Finland in general.

In Kajaani, taken together, IBM, CSC and other tenants had too small power demand to benefit from the available hydropower, which cannot function properly without large enough demand. Both sites use the national 110 kV power grid as their primary source of energy.

Differences in business goals and processes

Why were there such major differences in the extent of reuse between these two fairly similar cases? We suggest that the business goals and processes of the entering organizations largely determined to what extent old structures could be reused – defining the possibilities for exaptation processes to take place. Google serves individual clients and organizations with their standardized product in public cloud. This business model seeks extreme efficiency and scalability in meeting the demand for selected services with own design for equipment. Google invested for new capacity to fill the premises in two stages with their special equipment, since their business model of targeting consumers with standard solutions allowed almost instant scaling to use the new capacity for global demand.

The business models of IBM and CSC were designed for private cloud services for larger organizations, which clientele was expanding in a discontinuous stepwise manner. While IBM is a giant player in providing cloud services, its business model and clientele, differ from those of Google. IBM wants to serve medium to large organizations providing them with tailored private cloud access and services. Although IBM utilizes economies of scale and is capable for upfront investment at will, the preferences of its large clients seeking private cloud services tend to favor stepwise investment in local datacenters. Huge upfront investment was prohibitively expensive to meet the uncertain nature of the increasing demand. Clients of CSC are large public institutions who can allow for short delays of some minutes in case of power failures. This contrasts with the intolerance of Google for any breaks in delivering services to its hundreds of millions of clients.

Differences in social gains

The goals that forest industry firms had in transferring their assets to datacenter firms varied. Stora Enso, with many of its mills outside Finland competing with domestic investment, pursued a fast exit approach in Summa and was successful. By selling the site to Google in a single deal Stora Enso looked for quick benefits from closing down the production site, whereas the setting in Kajaani was a bit different. UPM-Kymmene pursued a stepped approach to help to maintain employment in the more isolated Kajaani area after huge layoffs, and it took the transient role of a lessor to divest its assets more slowly. Old structures were transformed to fit new purposes, but the ownership remained at UPM-Kymmene.

Some aspects of that project were also stakeholder driven. Whereas there are many other paper mills near Summa, Kajaani is relatively isolated, which makes it more difficult to redeploy the regional forest resources partly owned by private farmers, who can put pressure on the industry, and re-employ the workforce, who has political power. The purpose in Kajaani was to draw attention and new businesses to that specific area to re-employ local inhabitants. In the end, the premises at

Summa now employ few people, although Google maintains a research organization elsewhere in Finland (Google about Datacenters, 2013). The premises of UPM-Kymmene in Kajaani now employ as many people as was the case before closing the paper mill (www.renforsinranta.fi). Finally, the timing of cloud service providers entering the two sites coincided but Stora Enso and UPM-Kymmene, due to their different commitments, faced different stakeholder expectations. The fact that datacenter business is sensitive to stakeholders' and clients' ecological values is reflected not only in the measuring of PUE but also in the news that Google has announced it shall build a windmill park to deliver 72 MW power amounting to 600 GWh green electricity in the 110 kV grid for its Summa site (Google Policy Europe 2013).

Our findings are in line with aggregated data received from United Kingdom (Kesidou and Demirel, 2012) and Germany (Horbach, Rammer and Rennings, 2012). Both studies emphasize the significance of consumer, customer or societal requirements and anticipating regulatory restrictions in addition to short term or long term financial gains.

Conclusion

We conclude that the initiation possibilities and outcomes of exaptation are highly sensitive to initial conditions. These include differences in technological factors, differences in business goals and logic of earning of the exapting or the exapted firm, which influence their ability to invest, and differences in organizational and procedural legacies and capabilities of new entrants. These findings are in line with previous literature (e.g. Dew et al, 2004; Marquis and Huang, 2010) concerning exaptation. We also suggest that the difference between adaptive development and novel technology creation, following the definitions of adaptation and exaptation, should be noted.

We also conclude that past or current owner's stakeholder issues influenced the decisions of forest organizations so that when divestment was not successful, local sustainability issues become quite relevant. As to the symbiotic development of the two sites (e.g. Pakarinen et al, 2010), Kajaani had a history of hundred years and Summa over fifty. The entry of datacenters disrupted the local social sustainability more in Summa than in Kajaani. The site at Summa was transformed to ecology with Google as dominator whereas Kajaani resembles ecology with more diversity, Renforsin Ranta as keystone player, to use the terminology of Iansiti and Levien (2004). Cognitive recognition of opportunities for sustainability (e.g. Patzelt and Shepherd, 2010) is not enough to overcome economic investment considerations. We conclude that studying institutional or normative components of sustainable innovation in a multi-level approach (e.g. Rennings, 2000; Geels, 2004; Smith et al, 2012) in the process of old infrastructure exaptation would be beneficial.

Finally, we conclude that differences in and temporality of triggers in the environment for seizing entrepreneurial opportunities in the right moment as suggested by Teece (2007) are important for the scope of exaptation. The multi-level approach might provide means for enabling sustainability transformations in a shorter time span.

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Table 1 Case Summa: Google

Stora Enso’s paper mill	Items demolished	Items sustained	New items introduced
Land and water areas, control reservoir dams to ensure water supply	The dams are no longer needed for control, to be demolished	Stora Enso still owns the water areas	NA
The machine hall building	3 paper machines were dismantled and sold out	The machine hall building	Google owns the facilities. Cavities in the machine hall floor were filled. The components for the servers, cooling and back-up systems are designed for Google’s specifications
Water pipelines to the Gulf of Summa for pumping the incoming water and releasing water	Old water intake pipeline not used, demolished?	A water pipeline to release warm cooling water to the northern side of the remaining breakwater in the Gulf of Summa	Two new pipes 1.6 meters in diameter and 130 meters in length were built in the depth of 5 meters for water intake and released 3-15 degrees warmer. The water flow is 0.83 m^3/s for maximally 40 Mm^3/a
Stora Enso’s safety structures, own fire brigade	No fire brigade	NA	New power generators are equipped with an automatic closing down system, smoke detectors and fire plugs, the temperature of the transformers is monitored and air ventilation has emergency stops
National 110 kV grid built to ensure power supply even when some lines fail. The paper mill used 857 GWh/a. Local 10 kV power lines	none	The grid is functional, Google’s estimated usage from the network is 280 GWh/a, the waste heat of servers is used too	Full 100% back-up power for essential operating systems is ensured by a total of 21 diesel generators totaling 110 MW output to provide 42 MW electricity
Own waste treatment plant	none	Partial renewing of sanitation pipes	The facility has been attached to the local sanitation network
National wireless connection (Wi-Fi) for office needs	none	Wi-Fi connection operating, too slow for datacenters	TeliaSonera underwater fiber cable to Helsinki, via Estonia to Europe, and to Russia, now used by Google
Gasum's natural gas trunk pipeline with pressure station, Haminan Energia's local pipeline, 3 MW district heating boiler	none	Gas pipeline, estimated to deliver 2.1 Mm^3/a, and district heating are used by Google	NA

Table 2 Case Kajaani: CSC and IBM

UPM-Kymmene’s paper mill	Items demolished	Items sustained	New items introduced
Old paper mill with one machine hall	The paper machine was disassembled	The old paper machine hall is a historical protectorate not to be demolished	UPM-Kymmene still owns all the land and water areas and premises leased to long term tenants
New paper mill with two machine halls totaling 8 000 m^2, and cold storage hall 10 000 m^2	Paper machines were disassembled	The two empty machine halls now named Rata and Kone, and the cold storage hall named Varasto	CSC rents 4000 m^2 and IBM 1000 m^2 in the Varasto building. In Rata and Kone buildings, cavities in the floors were filled. CSC installed Cray Cascade supercomputer and IBM its own service equipment
Structures for water use include a pipe from the river, equipment for chemical water purification	none	The pipe is functional delivering water at a rate of 0.6 m^3/s in temperatures between 1-22 degrees	The water is not used by CSC or IBM for cooling. Plans to use water cooling in the future pending
UPM-Kymmene’s safety structures, own fire brigade	No fire brigade	Rata and Kone buildings connected to UPM-Kymmene’s safety structures	Fire and other datacenter safety equipment built in Varasto by Sweco, subcontractor to UPM-Kymmene
National 110 kV grid built to ensure power supply even when some lines fail. Local 10 kV power lines	none	Rata and Kone buildings connected to UPM-Kymmene electricity network	Varasto was connected to the electricity network by Sweco, subcontractor to UPM-Kymmene
Water sanitation systems, waste management operated by Kuusakoski	none	Rata and Kone buildings connected to the Kuusakoski operated sanitation systems	Varasto was connected to the sanitation system by Sweco, subcontractor to UPM-Kymmene
National wireless connection (Wi-Fi) for office needs, FUNET fiber cable	none	National wireless connection (Wi-Fi) for office needs, FUNET fiber cable	Public FUNET fiber cable managed by CSC is connected to Varasto, Rata and Kone are within close reach of connection
Three hydropower plants with 35 MW and a pellet power plant with 88 MW output. The paper mill used 2200 GWh annually	none	The pellet power plant is in use for district heating. The hydropower plants are operational but too massive for current energy demand	Power source is the 110 kV electric grid