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Of Corals and Web Portals

Towards a Digital Representation of Risk for the Cold-water Corals in the Oil and Gas Sector

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Abstract. Integrated Operations in the oil and gas industry depend on highly co-operative yet computer-mediated and distributed workflows across complex information infrastructures. In particular, offshore operations rely heavily on digital technologies to gain remote access to subsea oil or natural gas fields, and are at the same time subject to strict requirements by authorities to prevent pollution in the marine environment. Operators are consequently dependent on models and representations to assess and predict environmental risk. However, the heterogeneous disciplines operating a field cannot count on a shared perspective on environmental risk as their activities span across organizational and political boundaries. We present a case study from a Norwegian oil and gas company that is developing a set of tools and methodologies for providing heterogeneous users with awareness of the risk for the cold-water coral reefs off the coasts of Norway. In particular, we focus on the articulation work carried on to let representations and models compensate for the inevitable lack of shared awareness of environmental risk while at the same time fit the existing sociotechnical infrastructure. We discuss actors' strategies to foreground the infrastructure by: (1) *bootstrapping* the environmental data; (2) *mediating* with the existing corporate infrastructure; and (3) *enacting* the subsea context for operators.

Keywords: Environmental risk; Awareness; Articulation work; Information infrastructure; Integrated Operations

1 Introduction

The Norwegian continental shelf (NCS) is the Norwegian territory encompassing portions of the North Sea, the Norwegian Sea, the Barents Sea, and the Arctic Sea. Since oil was found in the late 1960s, as a result of technological innovation, the oil and natural gas industry has populated the NCS with a complex network of wells, subsea installations, pipelines, transportation vessels, fiber-optic cables for data transfer, and remotely operated vehicles. The NCS is also home for the

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world's largest population of a species of cold-water coral called *Lophelia pertusa*. Even though the intense activity of the fishery industry reportedly accounts for the damage of 30-50% of Lophelia reefs (Fosså et al., 2002), since the 1980s concern has been raised in connection with the distribution and the sociopolitical impact of offshore oil and gas operations. Despite the proliferation of laws and regulations to assess and prevent subsea environmental risk, no comprehensive regulatory framework is available today. As a consequence, companies are compelled to develop not only the technical devices but also the methodologies to establish and maintain an *awareness* of present and future risk and meet the legal requirements.

The Norwegian oil and gas industry association has labeled as *Integrated Operations* a new reality characterized by collaboration across organizational boundaries, the integration of people and technical tools, and the centralization of data repositories (Norsk olje og gass, 2005). In particular, offshore operations are a highly cooperative effort that relies entirely on the collection of data from remote subsea locations by one company and its vendors and contractors thanks to hybrid networks of sensors and devices. All together they constitute large-scale sociotechnical systems – or *information infrastructures* – involving digital and non-digital artifacts and social practices that encompass heterogeneous professions. For example, drilling a new well requires, among others, drilling engineers in charge of monitoring the process, data engineers assessing the quality of the incoming data, geologists with knowledge of the reservoir, and the new emergent figure of the environmental coordinator monitoring the impact of operations on the subsea biological resources. The lack of shared awareness has deep reasons, mainly rooted in (1) the tendency towards a traditional organization structure; (2) the focus on educating domain specialists; (3) the specialized and silo-like nature of IT systems (Hepsø, 2009). Cooperation therefore rests on a continuous balance that cannot provide for a shared awareness about the risk of the cold-water corals: each discipline looks at different kinds of object – the geologists at the reservoir, the drillers at the well and pipes, and so forth – and has different time constraints – drilling is a strictly real-time decision-making task, while the pollution on cold-water corals often becomes evident over the long term. However, the objects everyone is looking at have a common feature: they are not directly accessible by humans. The quest for risk awareness is therefore entirely dependent on digital artifacts like models, maps, and diagrams. In a word: representations. Reaching some level of awareness of subsea environmental risk in Integrated Operations must therefore on the one hand rely on technology-filtered information and, on the other hand, scaffold cooperation by providing a perspective that is meaningful for users that belong to heterogeneous professions.

CSCW has often focused on articulation work (Schmidt and Bannon, 1992), intended as a collaborative set of interdependent yet distributed work activities that often exhibit sophisticated coordinative practices, even though strikingly few studies are set in the oil and gas industry, see e.g. (Heyer, 2009; Rolland et al., 2006). Moreover, the analysis of articulation practices has often been centered on the artifact (Monteiro et al., 2013). We instead adopt an *infrastructural inversion* (Bowker, 1994) to disclose a specific type of articulation work made of the coordinated practices that scaffold and adapt the information infrastructure as a whole.

In this paper, we want to investigate how tools and methodologies for cold-water coral risk prediction are developed to build and sustain risk awareness. We pose the following research question: *How is environmental risk awareness supported in the oil and gas information infrastructure?* In particular, we look at the articulation strategies to construct representations of risk for the inaccessible subsea reality in a research and development project (EnviroTime) in an international oil and gas company (NorthOil) in collaboration with industrial partners. EnviroTime is a highly cooperative project involving researchers with background in marine biology, environmental chemistry, anthropology, and computer science. We identify three articulation strategies used by NorthOil to compensate for the lack of shared environmental awareness: *bootstrapping* (to understand which environmental data should be available); *mediating* (to tie the new data to the existing infrastructure); and *enacting* (to let the subsea reality "live" for the diverse target users).

Thanks to a rich and multi-faceted case study, we contribute to CSCW by explicitly elaborating the notion of articulation work as a design strategy emerging in practice with reference to the large-scale settings of an information infrastructure. In so doing, we discuss the connection between articulation work and risk awareness through practices grounded on digital representations.

The remaining of this paper is organized as follows. In section 2 we provide an overview of the theoretical framework guiding our analysis. In section 3 we describe the empirical background and in section 4 we outline the methodology adopted in our research. In section 5 we present our findings that are further discusses in light of our theoretical lens in section 6. Finally, in section 7 we summarize our contribution and point at some future directions.

2 Theoretical background

Awareness has been recognized to be a problematic concept in CSCW (Cabitza and Simone, 2013; Gross, 2013; Heath et al., 2002; Schmidt, 2002). Schmidt (2002) provocatively remarks that the very first question we should ask is: "*awareness of what?*" (p.288). Here we discuss awareness in the sense of the coordinative articulation practices (Gross, 2013) developed by actors to become aware of the environmental risk associated with their and others' activities in an offshore operational field. We take this as a point of departure by trying to understand how actors ask themselves the same question and what happens "behind the scenes" to leverage the relationship between computer-based representations and the reality they have to fit. The highly distributed yet interactive nature of oil and gas operations nevertheless requires us to look for explanatory concepts capable of taking aspects of distribution and technological mediation into account. The concept of information infrastructure is useful to delve into the large-scale and long-term nature of collaborative environments not only in the oil and gas business. Literature has also focused on how infrastructures support the temporal and spatial scale of environmental data curation and sharing, see e.g. (Karasti et al., 2006). The relevance of taking an information infrastructure perspective within CSCW is by now established (Monteiro et al., 2013; Ribes and Lee, 2010). Inspired by research in the Information Systems (IS) and Science and Technology Studies, Ribes and Lee (2010) point out that CSCW is well positioned to study infrastructures, but there is a need for a more detailed and systematic attention to this specific kind of computer-mediated collaborative work. The authors also argue how the themes unfolding from this perspective all account for the broader issue of technological delegation, as infrastructures cause a redistribution of labor between humans and technologies.

Both CSCW and IS have provided a vocabulary to analyze cooperative work in distributed settings, for instance with the notion of articulation work (Schmidt and Bannon, 1992), as the invisible and often unrewarded work that is not formalized yet vital to keep an information infrastructure alive. Schmidt and Bannon (1992) argue that CSCW should in particular treat articulation work as a design strategy, i.e. as an important input to requirement specifications for cooperative technologies. In general CSCW has studied articulation work as limited to particular settings and timeframes of technology design and implementation (Monteiro et al., 2013). Our case represents in fact an effort to address the information infrastructure that unfolds “behind the scenes” of a situated reality. As a working definition, Monteiro et al. (ibid.) characterize information infrastructures as interconnected workplace information technologies that are open to number and types of users, embrace dynamically evolving portfolios of systems, and are constrained by an installed base of existing systems and practices. Infrastructures are also shaped and used across many different locales and endure over long periods (years or decades). Methodologically we adopt an *infrastructural inversion* (Bowker, 1994) to shift the attention from the articulation work around one end artifact to the broader type of work required to let the infrastructure sustain the local implementations of technological artifacts. What we investigate in this paper is exactly the articulation, background work done as part of the EnviroTime project as a design strategy, aimed at both supporting and extending NorthOil’s infrastructure. Articulation can for instance happen in practice by means of coordination mechanisms (CM), as described by Cabitza and Simone (2013). Among awareness-promotion CM, ordering systems (classification schemes, metadata structures) are used to articulate not actions directly, but rather the maintenance of specific structures that support the interconnection of actions (ibid.). Bringing to the fore this type of work is indeed core to analyze the political and social background an information infrastructure rests upon (Bowker et al., 2010). Common Information Spaces (CIS) have also been proposed as tools shared by cooperating actors to interpret and align their mutual work by building awareness of activities that are spatially and temporally asynchronous (Bannon and Bødker, 1997). However, the concept of CIS has been criticized in literature, especially to understand what “information” really is and what should really be "common" (Hepsø, 2009; Rolland et al., 2006). In our case study, the dilemmas the actors are facing are of the same nature: *What is environmental information in the oil and gas infrastructure? Should it be shared? How?*

3 Background Context and The EnviroTime project

Today 78 oil or natural gas fields are in production on the NCS from the North Sea to the Barents Sea (source: www.npd.no). At the same time, a wide population of cold-water corals inhabits the NCS (Fosså et al., 2002). Coral reefs are in turn shelter to a fascinating range of marine fauna. While no harmful discharge was allowed in the 1980s by the Norwegian government in connection with human activities in the North Sea and the Norwegian Sea, today a much stricter constraint prevents any type of physical discharge outside northern Norway and on the Barents Sea (NME, 2010). In spite of this, as also acknowledged by our informants, authorities do not provide a detailed environmental regulatory framework (Knol, 2013). Oil and gas companies carry on with an intense offshore activity on the NCS to search for, extract, and produce subsurface resources. One of the most delicate moments is represented by the drilling of a new well. Causes of pollution are for example the spreading of so-called drill cuttings (rock material removed from a borehole while drilling), drilling mud (material and fluids used to drill a borehole), or the occasional leakage of oil or natural gas from wells or pipelines. In order to be granted a license to operate in an area, companies must set up subsea monitoring programs to assess the present and future impact of oil and gas activities on the marine environment.

In this context, NorthOil (a pseudonym) is an oil and gas company headquartered in Norway with activities in more than 30 countries, but particularly concentrated on the NCS. The technological innovation in connection with the Integrated Operations regime enabled NorthOil to move its operations further offshore. Today numerous subsea installations are operated remotely, thanks for instance to intelligent sensors and devices and fiber-optics for real-time data transfer. Offshore activities therefore rely on highly computer-mediated work, where little contact point between humans and subsea life is possible. As part of the move towards Integrated Operations and to complement the lack of detailed environmental guidelines, NorthOil started the EnviroTime research and development project in 2011 to realize a new infrastructure for online environmental monitoring in collaboration with a number of industrial partners. Among them, Quality Certification Body (QCB, a pseudonym) was enrolled for its well-established methodology for predicting the environmental risk on cold-water corals based on offline data. Its target was now to merge it with NorthOil's technology and turn it into a thorough real-time framework. In particular, EnviroTime should provide NorthOil users with a web portal divided into two parts. The first part is based on a geographical information system (GIS) with updated predictions of risk for the coral reefs and mainly targeted at assisting the environmental coordinator, an emerging figure responsible for monitoring the impact of oil and gas activities on the natural resources. The displayed information would be the combination of data gathered from a number of sources (e.g. drilling and logging activities; reports from environmental surveyors and authorities). In turn, the environmental coordinator's decisions would impact on others' activities, e.g. if drilling has to be stopped or delayed in case of possible harm for the coral reefs. This GIS-based part of the portal thus provides an interface to a second part dedicated to the drilling engineers. Here, graphs and diagrams describe and log the tendency of key operational and environmental parameters (e.g., the drilling speed and how they relate to the particle sedimentation rate).

4 Research method

Our research is grounded on the EnviroTime project as the main case study. We have conducted an extensive, ethnographically-informed fieldwork to follow actors in their daily articulation effort. The author has been granted access and a fixed desk in NorthOil research center. She has spent on average three days a week there from April 2012 until April 2014, conducting both participatory and unobtrusive observations in meetings, workshops, and teleconferences regarding EnviroTime. Several pages of field notes have been taken. In addition, she has conducted 24 semi-structured interviews (each lasting on average one hour) with participants in EnviroTime from NorthOil and QCB. The collection of internal documentation has been a further tool to acquire an overview of the company's policies and strategies.

The researcher applied a mix of an inductive and a deductive approach to data analysis. First, the data set (interview transcripts, field notes, documentation) was open coded. Keywords have then been iteratively clustered into broader categories of articulation strategies. The choice of the three final categories (*bootstrapping*; *mediating*; *enacting)* was inspired by the literature as discussed in section 6. To increase validity, the categories were refined in collaboration with other members of the research group the researcher belongs to. The analysis process has been inspired by the interpretive tradition in Information Systems (Walsham, 1995), grounded on the seven principles presented by Klein and Myers (1999). The principle of dialogical reasoning in particular accounts for how the case is presented to the reader. As data emerged, we decided to inject snapshots from the fieldwork into narratives (e.g. by quoting statements or short dialogues during meetings). The adoption of narratives for data analysis helps to reproduce an observed situation characterized by variable temporal embeddedness, eclectic data, and no clear boundaries (Langley, 1999).

Finally, we underline that NorthOil's research center did not equal our field site. Indeed, as indicated by Blomberg and Karasti (2013), the site of a research inquiry is ultimately a construction by the researcher. The hermeneutic foundations of the interpretive approach provided a lens to understand EnviroTime as a process deeply entangled both with the sociotechnical context inside NorthOil, and with the sociopolitical context that NorthOil is part of. It is often physically impossible for the researcher to account for long-term phenomena spanning across vast communities. As described above, the EnviroTime project has all the features of a large-scale attempt in terms of organizations involved, end users, time span, and geographical distribution. Nonetheless, as underlined by Ribes (2014), "*anytime there is a "large" endeavor you will find actors tasked with managing the problems associated with its scale*" (emphasis in original). Accordingly, we focused our attention on those actors in the field site that must develop articulation tools and techniques to discover and manage the scale of their infrastructure as part of their daily routine work.

5 Articulation strategies for environmental risk awareness

EnviroTime soon turned out to be much more than an issue of software development. In fact, two problems came to the surface related to environmental data management. First, the sensors that are traditionally used in oil and gas are not well suited to track slowly changing biological parameters. Second, marine biology is a highly fragmented discipline, so no standardized data management practices or metadata structures are available to guide oil and gas operators in a field that is not their domain of expertise. As a consequence, NorthOil decided to dedicate full-time resources to increase the knowledge about corals and other biological resources' reaction to the exposure to human activities. This element of novelty had then to be counter-balanced with the integration of new data management practices in the existing workflows. Environmental data have to be modeled and visualized in a format the end users are traditionally accustomed to. We identified three strategies that NorthOil and its project partners adopted in EnviroTime to overcome these issues. These strategies represent our formulation and thus not an explicit formalization by NorthOil. Moreover, they do not consist of three clear-cut moments in the history of the project; rather, they have been running in parallel and informed each other since the project's inception.

5.1 Bootstrapping: the importance of the real-time laboratory

Echoing Schmidt (2002), the very first problem that EnviroTime had to face was: *When we talk about environmental risk, what should we be aware of in practice?* To collect data from an unmanned subsea environment, devices equipped with sensors have to be deployed. But which ones? And how? In this sense, the subsea environment needs to be "bootstrapped": meaningful parameters have to be obtained from a situated reality to be made part of the broader discourse of oil and gas. Before the official beginning of the EnviroTime project it was not really clear which type of environmental data have to be collected, how often, in what quantity, and from which locations. Also pressed by the need to apply for research funding, NorthOil opened two test settings, one (field A) in the Norwegian Sea, and the second (location Y) offshore north Norway where oil and gas operations are prohibited today.

Field A: time is business. In 2009 NorthOil elaborated a business case to demonstrate to authorities that the drill cuttings discharged during the drilling activity need not be taken onshore but could be left to sediment on the sea bed away from biological resources and the coral reefs in particular. Therefore the company developed a temporary real-time monitoring solution to track a number of parameters (e.g. water currents, pressure and temperature, particle sedimentation rate) to predict the possible dispersion of rock materials and sediments when drilling a new well. The chosen test location was an existing oil field (dubbed field A), where the company was seeking permission from authorities to open another well. As no fixed data transfer cables were available at field A, a surface buoy had been connected to the sensor rack on the seabed to send real-time data onshore through to a satellite link. Unfortunately, either due to the collision with a vessel or the bad weather, the buoy suddenly went lost after a few days. NorthOil had to plug in third-party software to model oceanic currents to infer the missing data and provide the authorities with a sufficient report. Time means money in the oil and gas industry. Despite the technical problem, the temporary real-time platform demonstrated that the discharged materials did not need to be taken onshore and could be deposited on the sea bed, away from the corals: "*If the drilling campaign is postponed of one month it can be much higher costs, so the time is very important to have a solution in the right time. Time is an important issue*." (Environmental advisor, interview, December 2012)

Location Y: an open laboratory. A second test location was chosen at Y, an area rich of coral reefs where no technical infrastructure has ever been installed. Y is also a geographically strategic area. Here the NCS is at his narrowest, therefore constituting a relevant site to study biomass, fish migration and spawning, and water currents. It was therefore deemed a suitable laboratory, where NorthOil could monitor the baseline behavior of biological resources away from possible sources of stress due to human operations. As two NorthOil employees told us, attempts to deploy sensor racks and fiber-optic cables for real-time data transfer had begun in the early 2000s. However, technical failures and harsh weather conditions led to delays and unforeseen costs. At one point, data could be collected offline and stored in hard disks placed in the same support as the sensors and powered with a battery. Yet, as pointed above, time proved to be an important factor, so this approach did not demonstrate robust enough. In 2013 a fiber-optic cable was finally put in place, sending the sensor data straight from the sea floor to an onshore data center. As no legacy information was involved, NorthOil decided to implement an open web platform that the public could freely access. Historical and real-time data about water currents, presence of particles, salinity, and videos and images of the coral reefs became easy to visualize and download. The web platform proved a useful tool to attract the attention of research institutions in order to develop analytical tools and better sensors to investigate what is actually at stake "down there".

5.2 Mediating: Integrating across routines, space, and time

A system with the scope of EnviroTime could not, of course, be thought as disentangled from the existing and well-established infrastructure of oil and gas operations (its so-called installed base). Therefore, a second question the actors had to face was: *How to tie the process of awareness to the existing infrastructure?* NorthOil started to "cement" the foundation of the lessons learned from the A and Y test setting. A new stream in project was thus initiated, to extend and integrate the existing work processes with the new data governance practices learned in the A and Y test settings. We were directly involved in the regular meetings to discuss the data governance processes. Participants were enrolled among the project managers, the environmental advisors, and the IT leaders. This task soon proved a non-trivial one, as NorthOil has more than 30000 formal work processes approved by the corporate management. One project manager explains the problem: *"Work processes for leveraging existing operational data like surveys, maps, production are already available. We must see where they integrate. We have to identify if there are gaps or non-gaps [in the list of] work processes to know if they need to be integrated or not. There is a whole group of side activities they do for every field every year for which there is no clear work process description today. Each department works in a slightly different way."* (Internal meeting, October 2013)

It stood clear how the problem of integrating the work processes was actually unfolding as a problem of integration at several levels. First of all, at that of the disciplines and their daily routines. One IT leader explains: "*When describing work processes we must focus on the interactions between environmental coordinators, GIS experts, etc. Today data are spread all over, in different formats, with no standard maintenance... the goal is to get control. Today we don't know what to do with the data we have, so we must describe routines."* (Internal meeting, August 2013) Unfortunately the co-existence of environmental and technical information is not an obvious marriage. Two environmental advisors point out: "*Operational people do not understand the real-time relevance of tracking the fish status*"… "*But it could be something important to look at when drilling!*" (Internal meeting, August 2013)

Moreover, the problem of integration emerged at the level of handling incoming data across space, where spatiality can be that of the different data sources (e.g. databases, spreadsheets) but also that of the different vendors (e.g. for data analysis) or contractors (e.g. an external company logging drilling data in its proprietary format). The same IT advisor quoted above adds: "*It is important to have a description in the work processes about what to do with every different source and data. Every datum can come in different formats and timing and vendors. In this latter case there is a need for quality check. For example: what to do when a survey map comes from a vendor via mail?"* (Internal meeting, August 2013) Indeed, as new types of sensors and data analysis tools were adopted, new types of both raw and complex datasets became available, e.g. surveys, maps, which are often realized by vendors.

Nonetheless, data integration could also be read as a problem of integration across time: "*We must consider predictive simulations as historical data that lay in the future. For instance coral analysis provides a coral risk that is not observed (...). When data become historical then it is really important to have a data governance that handles these data contra predictions. It is not the real-time part that is difficult, but how to assemble and work with the static map layers. The real-time is much simpler to get to.*" (IT advisor, internal meeting, August 2013)

The discussions in the meetings were thus soon directed towards what new information would constitute the master data in NorthOil infrastructure, i.e. the persistent and non-transactional data to be shared across multiple systems and processes in an organization. For example, maps resulting from the process of analyzing the risk factors for the coral reefs could be made available to drilling engineers. On the other hand, the EnviroTime project could benefit from the existing master data, e.g. about production activities, to understand the possible level of pollution on the biological resource (amount of discharges, possible chemicals adopted); or about the organization's employees to track the person responsible for a survey or for indicating a coral structure as safe.

5.3 Enacting: representing the subsea on the desktop

Oil and gas operators are well-trained professionals with knowledge about their own subject matter. However, this knowledge is deeply intertwined with the technologies and information systems they commonly use to discover phenomena. As outlined above, cross-disciplinarity can face boundaries in terms of routines and spatial and timely constraints. As the EnviroTime portal had to speak to a rather heterogeneous group of end users, a further dilemma EnviroTime participants faced was: *How to represent subsea environmental risk in meaningful terms for the users?*

Before being enrolled in EnviroTime, Quality Certification Body (QCB) had developed an offline methodology to assess the risk for coral reefs in connection with human marine operations. This methodology had now to be incorporated in the machinery of EnviroTime. In practice, this means that it had to fit both the new real-time data flow and NorthOil infrastructure. A wide range of maps (or geographical objects) is available in NorthOil's installed base. Once a survey for biological resources has been completed, the responsible environmental coordinator for the area identifies the locations of the coral structures. Corals are thus positioned onto the existing maps and approximated as geometrical shapes, together with wells, pipelines, and other fixed technical infrastructure. The responsible environmental coordinator assigns a color to each coral based on the assessed health. Secondarily, GIS-based information is combined with the drilling plan and weather and ocean current forecasts into software modeling systems, to understand how the drilling discharges will spread and if they will sediment onto the coral structures. However, no software available to NorthOil puts together GIS and current models. QCB researchers therefore developed a script to resolve this lack of communication. As a result of this step, coral structures are mapped inside a "risk matrix". The matrix is used twice in EnviroTime. Once, to *portray* the conditions of corals before any drilling activities. In addition, EnviroTime participants initiated a discussion with NorthOil's GIS department to integrate the corporate maps with the new incoming real-time data. As a consequence, the risk matrix can be used a second time to *predict* the future impact during and after drilling. In general, the risk matrix is a well-known tool in risk assessment. The one realized by QCB researchers consists of an apparently simple 4x4 table, with the expected probability of pollution on the y-axis and its consequence on the x-axis. Each cell is filled with intuitive colors (red, green, yellow, orange) to signal the level of danger connected to each situation. Then the consequence for a given coral structure is mapped as a black dot for the calculated probable pollution. Such matrix is then included in the metadata structure with a set of attributes: corals are assigned an identity, a time, a space, a responsible person, and a condition (or health state).

6 Discussion: Articulation work, revisited

Monteiro et al. (2013) state that researchers in CSCW should focus more on how order is produced and maintained for the large-scale and integrated working settings, or information infrastructures. The design and development of a cross-organizational system for real-time environmental risk prevention in Integrated Operations (as is the case for the EnviroTime project) requires that a level of order is indeed achieved across a distributed oil and gas organization (NorthOil). Order in EnviroTime rests upon an extensive digitalization, as the subsea reality can only be accessed through digital devices turning the natural environment into series of discrete data. These data have to be re-ordered as Lego blocks to re-construct a meaningful and relevant reality for the end users. We must thus delve into the design strategies to entangle a complex matter like environmental risk with the installed base of NorthOil.

This paper is not focused on providing specific design recommendations. The aim is to empirically investigate the evolving relationship between articulation work and awareness. We started with the story of a coral, Lophelia. But how do we build a digital representation of Lophelia in practice, so that it carries weight inside NorthOil? We adopted an information infrastructure perspective because we argue that, to be convincing, Lophelia has to be seen relationally, that is to say as an infrastructure. This is the motivation for the methodological choice of taking an infrastructural inversion (Bowker, 1994) that allows us to look at the articulation strategies as moments of emergence of the infrastructure: "Understanding the nature of infrastructural work involves unfolding the political, ethical, and social choices that have been made throughout the development. Analytically (…) this is *shifting the emphasis from changes in infrastructural components to changes in infrastructural relations*" (Bowker et al., 2010, p. 99, emphasis added) In this sense articulation work is the lens to investigate the sense making process that goes about along the trajectory from subsea nature to maps displayed on a web browser. Thanks to an extensive ethnographically informed fieldwork, we identified three interdependent articulation strategies to support awareness for subsea environmental risk and that the actors put in practice to define: (1) When are data *good enough*? (Bootstrapping); (2) When are data *compliant enough*? (Mediating); (3) When are data *relevant enough*? (Enacting)

As a first articulation strategy, we depicted the process of **bootstrapping** environmental data, in an attempt to get to know the unknown. We indeed borrow the term "bootstrapping" from Science and Technology Studies, in particular from (Bowker, 1994) who describes the infrastructural work put in practice to conjure "global" parameters in highly contextualized and imperfect realities. As indicated by Schmidt and Bannon (1992), in articulation work actors must often engage in activities that are extraneous to their daily tasks. Indeed we showed how EnviroTime participants had to open the boxes of marine biology or corporate work processes that were previously alien to most of them. In the case of laboratory location Y, bootstrapping strategies emerge in practice as an ongoing effort of enforcing the trustworthiness of the early results. It is indeed important in an ethnographic study to attend the ongoing work to make systems trustworthy (Jirotka et al., 2005). Location Y was chosen intentionally by NorthOil away from any existing human activity, to make sure that the environmental baseline obtained from the sensor-based measurements would not be believed as biased by human factors. In addition, data were made freely accessible online. Therefore trustworthiness was also enforced by enrolling politically independent research institutions in the process. In the case of the tests run at field A, NorthOil realized how awareness should also be tied to the industrial production parameters that NorthOil must inevitably respond to. The tests were tailored in terms of a predefined business case that not only showed authorities that discharges can be handled in a safe way, but also showed the oil and gas sector that this approach led to saving time and money. We can read this effort as an instance of infrastructural inversion to discover the hidden referential structure that comes about in the politics of building and maintaining awareness.

Second, we labeled as **mediating** the phase where the EnviroTime project participants initiated a separate work package to understand how to adapt environmental data management to the installed base of NorthOil. Workflows in an oil and gas company must follow the approved work processes, which represent an institutional artifact all new information systems and practices should comply to. A well-calibrated integration of environmental data governance inside the legacy processes compensates for the fundamental lack of cross-discipline shared awareness. The infrastructure can include the invisible environmental work thanks to its reification into explicit representations (Blomberg and Karasti, 2013). We portrayed how this effort of mediating environmental information emerges as a problem of integrating data across *work processes* (the routines of each discipline);

time (accumulated vs. future data); and *space* (different data sources, including different providers). On the one hand, the adaptation of work processes unfolds as a standardization cycle, where environmental data management practices are rendered compliant to the corporate-approved infrastructure. In latourian terms (Latour, 2004), a due process is granted to the unknown (nature) to gradually become a legitimate member of the known (the oil and gas business). On the other hand, space and time are tricky categories. Pollock and Williams (2010) call for the need within CSCW to be more systematic in accounting for the multi-sited and longitudinal nature of corporate information infrastructure. Since the spatial and temporal scope of an infrastructure like EnviroTime might prove overwhelming for a single researcher, she operationalized Pollock and Williams's invitation by adopting the strategy of scaling ethnography (Ribes, 2014) presented in section 4. In so doing, the research could disclose how actors themselves deal with spatial (e.g. by defining work processes to handle third-party environmental surveys) and temporal (e.g. by defining routines to store new data to easily compare them with historical data) integration. However, mediation can prove difficult to achieve, due to the heterogeneous backgrounds of the professional communities involved and issues affecting the technologies adopted (Parmiggiani and Hepsø, 2013).The solution might require pragmatic decisions to give a voice to those elements that should be the motivation for innovation (the corals, the environment) but that are often forgotten.

We finally identified a third articulation strategy as **enacting**. The term "enact" is inspired by Mol (2002), who prefers it to "perform" to describe how objects become real when they are framed and played with when made part of a practice. In his review of the concept of awareness, Schmidt (2002) argues that in order to understand the phenomenon of awareness in cooperative work, researchers should look at how the world in which cooperating actors act and interact is given to them as a meaningful world. Tradition in CSCW drawing for instance on actor-network theory has long acknowledged the relational co-evolution of work practices and technologies (Aanestad, 2003), in line with a conceptualization of information infrastructures as a sustained relation: "infrastructure… is part of the balance of action, tools, and the built environment, inseparable from them" (Star, 1999, p. 377). The maps and the graphs on the EnviroTime portal are necessarily imperfect technology-mediated representations aimed at portraying the far subsea reality for each professional group in their own terms inside their daily routines. For instance, integrating real-time environmental information with the known corporate map layers is a strategy to "construct" a meaningful picture of environmental risk. From a different angle, the strategies of enacting can be read as a matter of context awareness. EnviroTime embodies the process of reduction and objectification undergone by the environmental data that is due to the formal representational schemas of corporate technologies. It is not a question whether to reduce the environmental context, but how (Chalmers, 2004). Tools to facilitate the rendering of contextual elements could be coordination mechanisms (CM) (Cabitza and Simone, 2013). In our story, this might be the case of the integration script developed by QCB (see paragraph 5.3). Interestingly, the same code that QCB developers wrote embeds the phenomenon that EnviroTime is trying to portray, i.e. how human activities meet and overlap with the subsea natural environment. Also the risk matrix (paragraph 5.3) as a form of categorization for the coral structures is a CM, as an ordering system to govern the flow of work in assessing environmental risk. It is actually interesting to underline the convergence of these categorization tools towards the street categories (usage of green, red, and yellow colors from the semantics of the traffic light) to convey a straightforward message. The risk matrix is a commonly used tool in risk assessment in general. Here, we wanted to foreground how it is made to fit with the machinery of subsea environmental risk prediction.

7 Conclusions and future directions

Awarding the cold-water corals a primary role in the oil and gas offshore business is one of the keys towards the goal of Integrated Operations. Due to the distributed nature of traditional oil and gas disciplines, the development of cooperative systems cannot rely on the existence of a shared awareness of environmental risk, which must be based on representations of the unreachable reality of the seabed. In this paper, we portrayed the articulation work done as part of a large-scale research and development project in an oil and gas company to implement a system for real-time subsea environmental monitoring. By taking an information infrastructure perspective, we asked how articulation work can sustain the quest for risk awareness. We thus contributed by shifting the focus from the final digital artifacts that should enhance cooperation among actors, towards the infrastructure that supports them. We took an infrastructural inversion (Bowker, 1994) to investigate the design strategies to adapt and extend the corporate infrastructure in a punctuated manner. For the sake of analysis we identified three of these strategies: bootstrapping, to become acquainted with the subsea reality; mediating, to adapt the biological data to the oil and gas corporate reality; and enacting, to let their representations become meaningful for operators. In so doing, we drew a connection between articulation work and the notion of awareness as a coordinative practice based on digital representations.

To conclude, we point at some future directions. EnviroTime is an ongoing project that has not reached a closure yet. Nevertheless, we invite future research to discover if EnviroTime could constitute a Common Information Space (CIS). Interestingly, the oil and gas associations promote a shift towards collaboration arenas to integrate personnel, a notion which was compared to that of CIS (Hepsø, 2009). The notion of CIS was originally proposed by Bannon and Bødker (1997) to describe a space actively constructed by the users who cooperate to shape and resolve meanings, at least temporarily. However, as pointed out by Rolland et al. (2006) by grounding on Mol (2002), the essential characteristic of CIS is the fact that they allow for a temporary resolution of meanings through representations by being *malleable* and *mutable*. It is too early to state whether the EnviroTime portal constitutes a CIS or if it will rather end up reproducing the same fragmentation it is meant to avoid. What we can say is that by foregrounding the infrastructure as it is being modified and extended by the actors, we can study how (digital) artifacts are made malleable offstage to reach for the necessary compatibility between the new requirement of risk awareness and the existing installed base.

A further aspect that future work should look at deals with the reconfiguration between human work and technological delegation in infrastructures entailed by initiatives like EnviroTime (Ribes and Lee, 2010; Ribes et al., 2013). The form of automation produced by artifacts like the integration script described above is only one example of the way technology can lead to a redistribution of work. This aspect has consequences also for the way ethnographically-informed studies in CSCW should account not just for how technical interventions are able to avoid human work, but also for *how* they substitute human work in *practice*. Thanks to EnviroTime, we saw how environmental experts became traceable, and thus accountable, for assessing the health status of coral structures. As pointed by Ribes et al. (2013), technological delegation implies a redistribution of responsibilities for decision-making in organizations and reconfigures what becomes visible or invisible in the actors' work.

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