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Knowledge Infrastructures: Part III

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This issue of Science and Technology Studies constitutes the third instalment of the special issue on Knowledge Infrastructures. Our initial call to take stock of existing research in this topic area across STS produced a high level of response and so the "special issue" will ultimately extend over the entire four issues of volume 29 of the *Science & Technology Studies* journal for the year 2016.

In the previous two issues of *Science & Technology Studies*, we have presented seven substantively very different studies. The first instalment presented an initial batch of three studies: Wyatt et al. (2016) explored the treatment of controversy within the production of the Wikipedia entry relating to schizophrenia genetics; Parmiggiani and Monteiro (2016) examined the production of infrastructures relating to the monitoring of environmental risk in off shore oil and gas operations; and Boyce (2016) analysed the work of connecting infrastructures for public health surveillance. The second part of the special issue put forward an further set of three articles and a discussion paper: Fukushima (2016) discussed value oscillation in knowledge infrastructures through two case studies in Japan's drug discovery; Jalbert (2016) analysed the issues of power and empowerment in environmental monitoring infrastructures for citizen science in the context of hydraulic fracturing; Dagiral & Peerbaye (2016) investigated the ways infrastructural issues come to matter in the social worlds of rare diseases; and Shankar et al.'s discussion paper (2016) shed new light on the role social science data archives have played as infrastructures in the development of social science disciplines.

The four articles presented in this third instalment of the special issue continue to present very different studies. The four book reviews also appearing in this instalment further expand the substantive diversity and demonstrate the disciplinary breadth of interest in knowledge infrastructure studies.

Articles in This Third Part of the Special Issue

The special issue opens with an article by Yu-Wei Lin, Jo Bates and Paula Goodale on crowdsourcing weather data. The "Co-observing the Weather, Co-predicting the Climate: Human Factors in Building Infrastructures for Crowdsourced Data" paper addresses a core issue for a number of sciences moving forward: how to build citizen science into their knowledge infrastructure. For the observational sciences (for example, Galaxy Zoo) and the digital humanities (the Bentham project, for example), there are huge benefits to building citizens into both the data infrastructures (highlighted in this paper) and through this process into the knowledge infrastructures being constructed. The authors of this article produced an ethnographic analysis of three central projects: the Weather Observation Website and the (presumably doubly ironically named) Weather Underground, which are about collecting data from local weather stations; and the Old Weather project, which like the Bentham project is seeking to crowdsource transcriptions of old weather logs from naval vessels and other sources. The authors produce a nuanced description of the work of socialization, embodiment, engagement with professionals (how often to calibrate instruments, for example), development of tacit knowledge and trust-building needed to make the emergent infrastructure work.

This is a valuable contribution to our understanding of the issue of the division of cognitive labor within the crowdsourced science: the citizen scientists are never just unskilled labor paving the way for the real scientific work. They need to learn about professional standards and how to engage with them; they need to develop new skills (e.g. transcribing US naval logs, with a new vocabulary to decipher) and so forth. Further, they need to develop modalities for offering and eliciting skills and tips to their respective websites. Finally, there is a degree of bodily and emotional engagement, which accompanies their work.

While many of the articles included under the umbrella of knowledge infrastructures have involved information technologies, our focus also extends to other forms of technology used to collate and aggregate knowledge. The theoretical interests of STS, in any case, do not see an infrastructure as the upshot of a particular technology in itself, but recognise that infrastructures are built out of configurations of technologies, people and institutions. In the second article "Taxonomic Government: Ecuador's National Herbarium and the Institution of Biodiversity, 1986 – 1996" we turn to a very different incarnation of the knowledge infrastructure, in the herbarium, and yet find that many of our existing theoretical concepts for understanding IT-enabled infrastructures still apply. This article explores the idea that a knowledge infrastructure can amount to a form of government, drawing on the Foucauldian notion of governmentality and highlighting the performativity of infrastructure work. Peter Taber describes the emergence of the National Herbarium in Ecuador as the upshot of a specific conjunction of biological expertise, the state and foreign finance, spanning public and private institutions and involving some unexpected alignments of interests between taxonomists and the oil industry.

The herbarium at the time Taber describes was built upon a conceptualisation of the value of knowing what species existed where and consequently acted as an infrastructure that rendered biodiversity in a particular form as a governable object. The knowledge infrastructure of the herbarium offers a basis for decisions to be taken on prioritisation of conservation interventions. In the time period that Taber describes a shift occurred in the notions of value surrounding the plants of Ecuador, from a substantive approach based on the economic valuation of plants towards a spatial approach that mapped species by locations and enacted biodiversity as an object of prioritisation in its own right. The logic of spatial prioritisation was built into the National Herbarium at this time though the collection of identified specimens mapped to a finer scale of location than had previously been considered. The fieldwork that produced this data entailed specimen collection in very challenging terrain, and biologists working in the field consequently moved from an opportunistic association with tree felling for oil drilling into a much closer collaborative relationship that tied knowledge of biodiversity tightly to the activities of the oil industry.

This paper therefore offers a distinctive perspective on the performativity of knowledge infrastructures by coupling detailed investigation of the expertise and alliances that enable the infrastructure with a focus on the specific forms of knowledge that the infrastructure embeds (including an understanding of how they could have been otherwise) and a focus on what it is that the infrastructure achieves in terms of the actions that it makes available. The focus on governmentality gives us an insight into the highly consequential nature of knowledge infrastructures as political tools and offers resources for unpacking some of the complex loops of feedback between the forms of knowledge that an infrastructure embeds and the various forms of action that feed into and stem from the set of values that the infrastructure enacts.

The paper "Promises that Matter: Reconfiguring Ecology in the Ecotrons" documents a reconfiguration of ecology's scientific and social missions through an analysis of large-scale research infrastructures called 'ecotrons'. Ecotrons are the latest incarnation of infrastructures in a genealogy of artificial biospheres; they are large instruments designed to produce experimentally valid knowledge through the controlled manipulation of closed, artificial ecosystems. They enable the live simulation of the environmental conditions anticipated in, for instance, global warming scenarios. Céline Granjou and Jeremy Walker conducted a study of two ecotrons recently-built in France that are the first ecological facilities sponsored by the Très Grandes Infrastructures de Recherche (TGIR) unit of the National Centre for Scientific Research (CNRS). The authors drew from interviews and exchanges with key researchers engaged in the conception and construction of the ecotrons as well as analysis of institutional documents and scientific literature presenting results of ecotron-based research.

Granjou and Walker consider ecotrons as sites for the elaboration and re-alignment of narratives of justification that embody important promises regarding the scientific status and social role of ecology. They propose thinking of ecotrons as "promissory and anticipatory infrastructures" with the potential to federate a wide community of ecologists around political narratives and shared research agendas. While ecologists have long struggled to get the scientific status of their discipline recognized, the anthropogenic changes that societies face today open new opportunities for ecology to reaffirm its promise both in terms of scientific contribution and practical relevance, and the ecotrons are seen to play a key role in this context. As the detailed account provided by the authors shows, ecotrons are an infrastructure of promise that materialize a profound reconfiguration of ecology's practices and wider civilizational narratives. What ecotrons materialize in particular is the promissory vocation of ecology to secure the resilience of the vital ecosystem of the planet. The paper ably demonstrates that ecology's infrastructures and futures are coproduced in the same movement. Ecotrons are integral to the rise of functional ecology, they encapsulate an ambition to make ecology a 'hard' science and present themselves as an emblematic 'Big Ecology' infrastructure.

One important contribution of the paper is the attention given to the role played by objects, infrastructures and materialities in stabilizing scientific promises, while studies of scientific promises have often focused on the role of speeches or the importance of politico-scientific leaders. Granjou and Walker show that it is a mistake to think of narratives and promises on one side, and passive materialities waiting for meanings on the other side. Instead, infrastructures like ecotrons materialize, combine and align promises that, in this case reconfigure ecology into a hard, anticipatory and engineering science. Their study invites us to pay more attention to the role of material objects and infrastructures in the elaboration of scientific promises and visions.

The final article "Of Blooming Flowers and Multiple Sockets: The Role of Metaphors in the Politics of Infrastructural Work" published in this third issue was initially submitted to Science & Technology Studies as an open call manuscript. It is, however, published as part of the Knowledge Infrastructures special issue, as its focus on the development and maintenance of information infrastructure complements the kinds of infrastructural work and topic areas covered by the other articles. More specifically, Marcello Aspria, Marleen de Mul, Samantha Adams, and Roland Bal explore the role of two metaphors for innovation and infrastructure integration in the development of a regional patient portal in the Netherlands. In the development project the 'blooming flowers' refers to third party e-Health initiatives and the 'multiple sockets' to the portal.

The authors' premise is that metaphors have real consequences for agenda setting and decision-making; metaphors are viewed as operationalizations of sociotechnical imaginaries. The authors explore empirically how metaphors were enacted during the early stages of the project, and how this affected the development of the portal. The authors analyze the role of metaphors in defining the organizational, technical and economic boundaries of the e-Heath platform, and in endorsing the portal as an independent, non-partisan attribute in a newly envisioned technical, economic and social infrastructure for the region. The authors focus on the generative character of metaphors and argue that they are constitutive elements of information infrastructures. Metaphors become part and parcel of a recursive process of ontological constitution: elements that help to construe their ontological status and their imagined social order, and that are perpetuated and shaped by that order at the same time. While the two metaphors in the study helped to make imaginaries of 'integrated' and 'personalized' health care more definite, cognizable, and classifiable, they also concealed the politics of infrastructural work. Rather than acting simply as heuristic devices, these metaphors "act as forceful 'actors'" that become deeply engrained in the project's imaginary. While they contributed to the prescription of futures and agendas for the platform, they at the same time drew attention away from the human work required in developing and maintaining infrastructures, and from questions about the relation between infrastructures and their users.

Aspiria et al. also argue that 'engaged participatory research', as they call their research approach, can contribute to redirecting the gaze onto socio-technical and political complexities, and to raising timely questions about the implications of imaginaries that bypass the materiality and politics of infrastructure. They point out that the act of 'spelling out' metaphors can open up a space for new imaginaries and alternative strategies. With this study they contribute to existing knowledge about infrastructural work, and specifically to a renewal of the interest among STS scholars in the role of discursive attributes in information infrastructures.

Reflections and Emerging Themes

In the previous two editorials we started to discuss themes that we have identified in the presented articles. In addition to the concerns with scale, invisibility, tension, uncertainty and accountability identified within the first batch of articles (Karasti et al., 2016a), the second issue briefly discussed a methodological issue of infrastructural inversion, and considered knowledge infrastructures as performative of the knowledge produced and as core sites of political action bringing forth concerns with power, marginalization and values (Karasti et al., 2016b). These themes continue to echo also across the four pieces presented in this third instalment of the special issue on knowledge infrastructures. In the following we briefly draw together two additional themes that emerge at this stage, temporality and labor.

Temporality emerges as a significant theme across this issue, both methodologically speaking, in terms of the varying orientations of STS researchers to the work of infrastructuring across differing time frames, and also substantively in terms of temporal issues that participants attend to and reconcile within their infrastructuring work. As Bowker (2015) points out, infrastructures have a complex temporality that often entails a messy developmental story with no defined end point. Unpicking this temporality can be a considerable challenge to the analyst, but also an illuminating and fruitful exercise. In terms of methodology the papers in this issue divide between retrospective accounts that offer a long view of infrastructuring over time and accounts based on real-time engagement with infrastructure projects in the making. Taber takes a historical perspective built upon archival work and retrospective interviews to explore the development of Ecuador's National Herbarium and its role in a changing approach to the valuing of biological resources. The retrospective nature of the study allows Taber to build a picture of change through time and by doing so to construct an argument about the contingent nature of the infrastructural arrangements that prevail across the time period. He demonstrates, ultimately, that the taken-for-granted status of biodiversity measured via particular forms of species inventory was arrived at through a series of practical steps and conceptual shifts that could have been otherwise. In this paper, as in the paper by Shankar et al. (2016) in the previous issue, the virtues of a historical perspective on infrastructuring are made clear, when the long view offered by a historical approach to research is coupled with a set of STS sensitivities to the heterogeneous, contingent and consequential nature of infrastructuring work. In similar style, albeit across a somewhat shorter time frame, Lin et al. adopt a framework of "following" to capture "value-making and value-changing processes, and dynamics of components, actors, rules, and relations in the infrastructure". The temporal framing of the study permits certain kinds of claim about emergence, contingency and consequences in knowledge infrastructures.

By contrast, other papers in the issue (and indeed many STS studies of knowledge infrastructure) tend to focus on real-time engagement of the researcher with the everyday work of infrastructuring. Here temporality emerges as an analytic theme when researchers recognise the significance of the different temporal frames that participants in knowledge infrastructure projects work orient to in their everyday work, uncovering themes that resonate with Steinhardt and Jackson's (2015) focus on the "anticipation work" that infrastructuring involves. Granjou and Walker explore ecotrons as a promissory infrastructure that attempts to materialise an envisioned future science and thus to secure the status of ecology as a respected science and basis for policy formation. Aspria et al. describe participants in the development of an online health portal as they engage in agenda-setting and making of decisions –activities that define current actions but also, as agendas always do, involve planning, anticipating and predicting the future. The paper unravels the complex sets of present and future concerns that animate the production of plans through a specific focus on metaphors that participants use to depict their goals and that, as the authors suggest, shape the expectations placed upon the project. These papers demonstrate the purchase offered by a detailed engagement with the present work of infrastructuring as it builds in attention to other time scales, rendering past and future present in the here and now. Such work builds on and enriches the existing STS perspectives on the significance of temporality in infrastructuring (Edwards et al., 2009) including notions of "infrastructure time" (Karasti et al., 2010) and the "long now" of infrastructure work (Ribes & Finholt, 2009). Historical and real-time approaches yield distinctive analytic purchase and, taken together, attest to the importance of methodological diversity, in temporal terms, across the array of STS engagements with knowledge infrastructures.

A second theme which emerges across these articles is that of labor. Just as in the wider economy, labor is being configured differently in the new knowledge infrastructures. Indeed the parallels are strong. Increasingly, academic labor is becoming that strange mix of a largely rhetorical entrepreneurialism wrapped around a reality of unprotected bit work. These articles explore the issue of labor in rich ways. Lin et al. point to some of the emerging possibilities for reconfiguring the academic labor environment. There is no need to cleave to the ivory tower model of knowledge as that which is performed within universities – a creaky model (under challenge since the late nineteenth century with the rise of research laboratories in the chemical and then the electrical industries). Rather, citizen scientists can make genuine contributions to scientific work. Some citizen science projects – for example the early Galaxy Zoo – had the citizens doing piece work rather on the Amazon Mechanical Turk model: making the work as simple and automatic as possible (a recollection of the women 'computers' in Hubbles' laboratory who mapped the skies in the early twentieth century – itself an echo of Prony's intellectual division of labor for producing logarithms, hailed by Charles Babbage as a major breakthrough for humanity). Lin et al. rightly claim that the work their citizen scientists are doing is highly skilled. The struggle for the soul of an academic enterprise now is partly about how to recognize and compensate fairly that work.

Granjou and Walker's paper looks at the labor involved into bringing 'nature' into the laboratory in ecosystem science. They analyze the emergent anticipatory infrastructure in terms of a fusion of research scientific agendas and geoengineering solutions to climate change and related issues through the reification of the concept of ecosystem services in the infrastructure. We are reminded – as with Antonia Walford's (2012) work – of the often invisible labor it takes to bring the world into the computer. It takes vast physical installations such as the ecotrons in France or the BioSphere projects in the States to make all things be equal enough to be countable and actionable. They describe the scientists working on these projects as being moved into a modality of pre-emptive security. This is a second kind of reconfiguration of academic labor from Lin et al.'s; the latter looked to democratizing science (with concerns about equity), the former to operationalizing science (with concerns about a new division of intellectual labor tying science to the invasive security state). Taber observes a similar move: in his case the integration of systematics research into the operations of the oil companies seeking to garner Ecuador's oil reserves. The botanists gain access to samples through use of the equipment of the companies: the price to be paid, as with Granjou and Walker, is to integrate their work into commercial and state interests. While it is true that scientific work has been closely tied to the interests of the State (despite the misleading image of the nineteenth century 'gentleman amateur' funding their own research), these new kinds of tighter integration both change the labor of doing scientific research by integrating it into the infrastructure of the neoliberal state: the very same specter that haunts Lin et al.'s work. Whilst the theme of labor is lighter in Aspria et al.'s paper, the two metaphors they discuss are integrally about working imaginaries and labor ecologies. Again, the question arises of the modalities through which new forms of knowledge work are adopted: as they point out, the metaphors used (the blooming flowers and the multiple sockets) are performative of different kinds of work organization.

Issues of labor are coming to the fore in discussions of the new kind of workforces we are creating (Uber, Airbnb) and the role of new modes of 'artificial intelligence' (supplanting jobs through automation, Amazon Mechanical Turk). It is natural that these same issues are expressed in the new forms of knowledge infrastructure we are building, which endeavor to integrate scientific labor into this more general movement.

Book Reviews in This Third Part of the Special Issue

In this issue the book reviews have been commissioned by the editors of the special issue on knowledge infrastructures in order to enable us to broaden our scope beyond journal articles and to indicate the broader intellectual context within which STS approaches to knowledge infrastructures have arisen in recent years. The four books (Kleiner et al., 2013; Wouters et al., 2013; Mongili & Pellegrino, 2014; Meyer & Schroeder, 2015) reviewed for this issue were selected from a torrent of publications on new forms of knowledge infrastructure. Taken together, the reviews surface the commonalities across this emergent domain. Yrjö Engeström (1990) argues that 'when is a tool?' is a better question than 'what is a tool?' – the latter is essentializing, the former situated. A theoretical concept such as knowledge infrastructures (KIs) is only useful to the extent that and at the moment when it can be used to characterise an emergent phenomenon it terms of a received body of literature. Each of these books – while not necessarily using the term "knowledge infrastructure", demonstrates the value of this approach. Each text, as the reviewers identify, adds something to our understanding of the concept. Across the four volumes we encounter a rich array of new case studies of infrastructures that arise within and enable knowledge work across and beyond academic disciplines. These texts also broaden the scope of the voices involved in commentary upon the aspirations and experiences of knowledge infrastructures. They include an array of authors both from STS and from participants within some of the projects under evaluation and target a variety of audiences from various disciplines and policy-making communities.

The Fourth and Last Part of the Special Issue

In the fourth and last instalment of the knowledge infrastructures special issue, in addition to presenting the remaining successful submissions, we will step back to review the identified themes across the full collection of papers. We will aim at that point to draw together some themes concerning the current state of understanding of knowledge infrastructures from the viewpoint of STS, to provide a basis from which to evaluate the distinctive contribution that the theoretical resources of STS are making within this territory, and to chart new directions for the study of infrastructures for research and knowledge production. This kind of assessment of the state of the field was anticipated in the announcement of the special issue and is facilitated by the rich and diverse set of contributions represented across the four instalments.

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Co-Observing the Weather, Co-Predicting the Climate: Human Factors in Building Infrastructures for Crowdsourced Data

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Abstract

This paper investigates the embodied performance of 'doing citizen science'. It examines how 'citizen scientists' produce scientific data using the resources available to them, and how their socio-technical practices and emotions impact the construction of a crowdsourced data infrastructure. We found that conducting citizen science is highly emotional and experiential, but these individual experiences and feelings tend to get lost or become invisible when user-contributed data are aggregated and integrated into a big data infrastructure. While new meanings can be extracted from big data sets, the loss of individual emotional and practical elements denotes the loss of data provenance and the marginalisation of individual efforts, motivations, and local politics, which might lead to disengaged participants, and unsustainable communities of citizen scientists. The challenges of constructing a data infrastructure for crowdsourced data therefore lie in the management of both technical and social issues which are local as well as global.

Keywords: crowdsourcing, big data infrastructure, citizen science

Introduction – All Weather is Local

In June 2011, the Met Office in the UK launched a crowdsourcing weather observation website[1] (WOW), in partnership with the Royal Meteorological Society and supported by the Department of Education. Branded as a weather website "for everyone", the WOW project aims to crowdsource weather data from private observers in order to build up a record of weather observations for sites across the UK. The intention of the Met Office, as expressed in a press release, was to "encourage further growth in the UK's amateur weather observing community… help educate children about the weather and…become the UK's largest source of weather observations." (Met Office, 2011)

Parallel to this investment in engaging the public in weather observation, the Met Office Hadley Centre for Climate Prediction and Research has also worked with the Zooniverse platform, branded as a collection of "the Internet's largest, most popular and most successful citizen science projects"[2], to initiate the Old Weather (OW) project, which aims to engage the public in the generation of data for climatological science. 'Citizen scientists' are recruited to help recover weather observations made by the crews of historic ships by transcribing digitised versions of ships' log books. These transcriptions contribute to climate model projections and will improve scientific knowledge of past environmental conditions.

These two flagship platforms for crowdsourcing data for atmospheric sciences have attracted much attention, particularly in relation to their technically excellent web-based platforms which enable data collection, and their close connection with the Met Office and other scientific institutions. Undoubtedly, the functionality and interface of the technical systems affects the engagement of potential contributors and/or citizens scientists. However, such a technologically deterministic perspective overlooks how citizen scientists operate and why they participate. Without empirical evidence of how the public, who are the target users of these platforms, perceive the call for their involvement in 'citizen science', and how they engage in these projects and interact with one another and with other stakeholders, it is difficult to develop robust strategies for building an infrastructure for crowdsourced weather data. In turn, this has implications for innovation, knowledge production, and public engagement in science.

This paper addresses these questions from a practice-based perspective by exploring the *glocalised* practices of citizen scientists and the relationship between amateurs and professional scientific experts. Through investigating the experiences and socio-technical practices of amateurs and citizen scientists, we aim to understand the dynamics in the process of building a *glocalised* big weather data infrastructure through connecting various individuals, communities, and organisations through a mixture of bottom-up, organic, modular methods and (semi-) formal institutional management practices. Designed to engage 'everyone', tensions and asymmetries are argued to be found in the construction of these infrastructures for crowdsourcing data. Through investigating the involvement of citizens in scientific research, we also explore the emotional aspect of *doing* citizen science. Challenging the common binary dualisms of the rational and emotional, body and mind, our examination of the experiences of citizen scientists will show that emotions play a major role in motivations. This also advances research on the relationship between amateurs and experts in knowledge production, and on the construction of identities of citizen scientists.

Knowledge Infrastructures

Various parties (institutions, individuals, communities, organizations), etiquettes, rituals and practices, laws and regulations, facilities and tools are involved in crowdsourcing data. The concept of an 'infrastructure' that contains people, regulations and norms, and artefacts (Star, 1999) helps to frame the subject under study as something beyond a technical entity. Several conceptual frameworks proposed in existing STS literature can be adopted to understand the socio-technical dynamics of an infrastructure. For example, it can be epitomised as a unique epistemic culture (Knorr-Cetina, 1999), a community of practices (Lave & Wenger, 1991), a social world where heterogeneous actors and artefacts reside and which has its own hierarchies (flat or tiered), codes, norms, traditions, shared interests, and common practices (Strauss, 1978; Clarke, 1991).

Edwards (2010) provides an infrastructural perspective to understand the development of a global weather and climate knowledge infrastructure. A knowledge infrastructure to Edwards (2010) is a Large Technical System (LTS) where a network of individuals, organizations, artefacts, and institutions are brought together to generate, share, and maintain specific knowledge about the human and natural worlds. This definition of knowledge infrastructures, taking a collection of individuals, organizations, routines, shared norms, and practices into account, echoes Star and Ruhleder (1996), Bowker and Star (1998, 1999), and Star and Bowker's (2010) theories that emphasise the socially constructed aspect of information and communication technologies (ICTs). According to them, infrastructures usually have three components: the artefacts or devices used to communicate or convey information; the activities or practices in which people engage to communicate or share information; and the social arrangements or organizational forms that develop around those devices and practices. These conceptualisations are based on classical STS methodologies and analytical frameworks that call for de-construction and contextualisation of the development and adoption of ICT infrastructures (MacKenzie and Wajcman 1999; Rip and Kemp 1998). They deliver the same message that has been summarised in Edwards et al. (2013: 13), "Transformative infrastructures cannot be merely technical; they must engage fundamental changes in our social institutions, practices, norms and beliefs as well".

This paper follows this line of argument by looking into the practices, organisation and manipulation of technical artefacts, and social arrangements within the citizen scientist communities of atmospheric science. These socio-material practices, digital artefacts, and associated norms and rules will be placed in cultural and social-technical contexts where infrastructures like WOW and OW are being developed, organized and governed. But, more importantly, looking at volunteer contributors' practices allows us to uncover those invisible, forgotten, taken-for-granted or hidden figures and issues involved in the construction of an infrastructure for crowdsourced data. This line of investigation is guided by the framework that Star and Strauss (1999) propose in relation to analysing the 'invisible work' of an infrastructure, especially when the infrastructure comprises many sub-systems, each of which is equally complex and within which many practices are made visible and/or invisible. Understanding these visible and invisible practices and processes therefore politicises the development of an infrastructure, and will inform future development of not only the infrastructures themselves (e.g., to improve the engagement with contributor communities, to facilitate easier contributions via better human-computer interfaces), but also of related social theory.

Methodology

The WOW and OW projects are used to frame and scope our study, informing both the collection of empirical data and the sampling of interviewees. Both projects offer a space that enables amateurs (loosely defined communities and/or individuals) to contribute data for atmospheric sciences. The selection of these two citizen science infrastructures is not random. Whilst WOW is similar to other infrastructures for amateur weather observers such as Weather Underground or the Climatological Observers Link (COL), focusing on the UK-based WOW project and the OW project allows us to examine the local practices and experiences of UK-based amateurs and citizen scientists.

It is also timely to study the WOW and OW projects as the technical systems and the contributor communities engaged in them are still at an infant development stage. As Bowker and Star (1999: 34) note, "Good, usable systems disappear almost by definition. The easier they are to use, the harder they are to see. As well, most of the time, the bigger they are, the harder they are to see.... Infrastructures are never transparent for everyone, and their workability as they scale up becomes increasingly complex". Before the projects get too massive and too difficult to grasp, we aim to get in early to capture and document as many layers of socio-technical arrangements as possible.

A variety of data have been collected for the purposes of this research, including four in-depth interviews carried out during April-August 2014. Two interviews were conducted with private weather station owners who were potential contributors to WOW, and two were conducted with OW contributors. In the interviews, informants were asked their motivations for collecting or transcribing weather data, the challenges faced, and the enjoyment and frustrations they felt during the processes of, for example, setting up instruments and transcribing data. These interviews were conducted as a part of the *Secret Life of a Weather Datum* project funded by the Arts and Humanities Research Council (UK) during 2014-15. As part of this project, professionals who led on the WOW and OW projects were also interviewed, and these interviews were used to provide context for the research presented in this article. This wider project aimed to explore the values and practices associated with different projects, organisations and communities on the journey of weather data from initial data production, through quality control and data processing, on into re-use in climate science and financial markets (Bates et al., 2015). The methodology employed, following the spaces, the actors and the evolution of data as a journey, has enabled us to identify and explore the value-making and value-changing processes, and dynamics of components, actors, rules, and relations in the infrastructure. These data were enriched by further data collection including online ethnographic observations on the OW project forum and the WOW mailing list, participatory observations of Maker events, short informal interviews with participants involved in Maker communities, and desk research of documentary evidence relevant to these cases (for example, relevant blogs and press releases). As demonstrated below, these conversations and observations revealed the emotions and bodily performance embedded in the data collection practices, and allowed us to picture the assemblages of a range of actors and objects. The rich narratives collected through the interviews and observations have illustrated different socio-cultural values and practices that shape data production, processing, distribution and re-use on its journey through the infrastructure. The organic yet systematic method of "following a weather datum" (Bates et al., 2015) exploits the materiality of data, a property Bowker (1994) and Edwards (2010) suggest we should focus on when investigating "infrastructural inversion".

Amateur Weather Observation and the Weather Observation Website (WOW)

The goal of the WOW project is to engage weather enthusiasts, school students studying weather and climate, and other actors to create an active global online weather community. The kind of data WOW accepts covers a wide range of forms and formats, including ad-hoc information such as notes like 'it is snowing here', or an uploaded photograph of the weather one has observed, or the readings routinely collected from manned or automatic weather stations. It also displays other social media content such as Twitter snow reports tweeted using #uksnow. Website visitors can explore the British weather, looking at how it varies from place to place and moves across the country. A forum has also been established to enable WOW users to communicate with one another, share hints and tips, and to enable the Met Office to provide help and assistance as required[4].

As of 4th April 2013, the MetOffice announced that since launching in June 2011, the website had "received more than 100 million weather observations from weather enthusiasts all over the world" (Met Office, 2013). These observations are currently used by the Met Office to provide hyper-local information to meteorologists and UK citizens during extreme weather events, and research is currently being undertaken to explore how the amateur WOW observations might be used for weather forecasting purposes (Bell et al., 2014).

WOW is constantly being improved. For example, it has been updated to make it easier to input observations and photos. The Met Office also has plans to better correlate reporting of weather impacts with associated photos, integrate the Met Office's 5000 weather station site observations into WOW, investigate options for collection and visualization of energy and temperature output data from solar panel systems globally, and improve photo display and search functionality. Users will also be able to submit their observations and photos by mobile phone.

It has been claimed that there was "zero up front infrastructure costs involved, and the platform scales automatically to meet the variable demand from the UK and internationally" (Bell et al., 2014). This statement on the one hand highlights the easiness and low cost of initiating a crowdsourcing platform, yet on the other hand downplays other factors involved in the development, implementation and maintenance of a socio-technical infrastructure. As will be shown in the two cases below, the invisible labour and emotions involved in carrying out the volunteering work are often overlooked.

Amateur Weather Observation Practices

Many people have weather stations these days (Eden, 2009; Burt, 2012). Commercially available weather stations such as the Davis Vantage are easily acquirable in outdoor or electronics shops on the high street. The Davis consists of fairly standard instruments. It has an electrical resistance thermometer and other standard sensors, a rain gauge on the outside of the station, and some observers also have anemometer to measure wind speed on the roof of their house. The Davis is connected to the Internet, and uploads observation data from the weather station every five minutes (or a different interval configured by the user) to an online data storage platform, which can be downloaded every week or so by the user. Users resultantly have five minute records of a range of variables such as temperature, wind, rainfall, air pressure, humidity, solar radiation etc.

Private weather station owners often have a deep interest in weather observation. As one informant told us,

> "Lots of people have weather stations. It's just a natural thing that if you're interested in something you want to get practically involved, and it's a practical way of getting involved in meteorology and actually measuring the temperature, or measuring how much rain fall. So it makes you understand, it forces you to observe what's happening outside a bit more. And that in turn makes you wonder about the processes and makes you want to read more. So one thing leads to another really. But I like to do things as well as just read about them. So it's really from the practical thing, inclination to really want to immerse yourself in the subject and try and understand more about how things work." [AWS01-1]

In this quote, we can gather that the informant is a self-motivator who enjoys observing and recording weather data.

Bodily performance is highlighted in the following quote from the informant, when asked if there are any particular challenges in collecting the data and what can go wrong with it:

> "Obviously, you need to have some familiarity with the equipment to set it up in the first place. It helps obviously, that I had the equipment set up in my previous home. It's always easier setting up something the second time because you're more familiar with it. There is a certain amount of cabling involved because although it's a wireless weather station, I didn't go wireless for all the sensors because it would have been even more expensive. So I had to route some cables from the wind vane and anemometer, and the solar and UV sensors down the chimney, down to the ground, and bury them in the back garden, along a wall and so on. But I've done that sort of thing before. Of course the main challenge is actually mounting the equipment, part of it at a high enough height to record the wind." [AWS01-2]

Here, we can see the importance of developing one's familiarity with and experience of the instruments and the local environment in order to gather better data. The joy of observing weather goes side by side with the slightly laborious bodily performance of installation and calibration of the equipment.

What does a weather station owner do on a regular basis? It is important to keep a regular and consistent "routine":

> "I don't do as much as I would like to, but I have done. I check the barometer every now and then, at least once a month. And the thermometer I haven't checked for a while, but I actually need to really get hold of a calibration thermometer. The one I've got is pre-calibrated, but that's when I bought it in 2009 and that should really be done once a year. There's a national standard thermometer. I can borrow one, or get hold of one, and then actually just recalibrate really. But in an ideal situation you are meant to recalibrate these instruments every so often, every couple of years I'd say." [AWS01-3]

The opening of this statement is interesting. The informant seems to know what he *should* do to keep a continuous record or to meet professional standards (e.g., calibrating the instruments), but due to other limitations, he was not able to do so. This on the one hand suggests amateurs' understanding of professional codes of conduct, and on the other hand highlights differences between amateurs and professionals. Whilst the Met Office has to commit to providing accurate and timely weather information, amateurs may have more flexibility, be recording the weather conditions 'just for fun', and feel less obligation to meet professional standards.

The informant did, however, try to conform to best practices to produce good quality data:

> "You're meant to really calibrate your sensors every now and then because even though it's automatic it's all very easy to leave it just running and assume that the data you're getting are entirely accurate. But of course the data you're collecting are only as good as the instruments that are recording them, which can sort of malfunction or they can show some slow drift in time that might not easily be detectable. In other words they might not be recording entirely accurate data, or they could stop recording if there's some glitch or something. So you need to keep an eye on the data, I'd say on a weekly basis. So that's why the website's useful to keep checking. Occasionally the Internet connection gets lost and then you find it's not archiving the data. But what happens is there's a back up on the weather station, so actually, usually it still is and then you just have to unplug and plug it in a certain way, and take the batteries out and put it all back in. It's a bit of a pain, but it's something that you just have to do occasionally. But it's a pretty good system." [AWS01-5]

In this quote, one learns some ad-hoc local arrangements the private weather station owner developed in order to accommodate local problems or factors. These socio-technical arrangements symbolise "bricolage" (Johri, 2011); one has to make do and adjust to the local conditions faced at that particular moment. They also demonstrate the importance of vernacular and tacit knowledge which is not written in scientific textbooks.

Some of these weather station owners keep the data for their own records, and others share them by uploading onto websites such as WOW, Climatological Observers Link[5] and Weather Underground[6]. Data from thousands of privately owned weather stations are integrated in these various platforms.

The informant expressed excitement about the prospect of using crowd-sourced data to co-produce weather forecasts, and the wider implications of sharing data

> "I'm perfectly happy with having these websites which anybody can access and give a forecast (which I believe, I'm not entirely certain, but I think it's) based partly on my data. There's no point in spending a lot of money on equipment for something I'm passionate about and interested in if it's not in some way benefiting other people, well even from an education point of view. Even you know, the data are not of professional standard, but the station is a semi-professional station so the data can still be used in some research and teaching context, from that point of view. So I mean if it helps Weather Underground with their forecast in a small way, then I'm absolutely fine with that. I think it's great because it's a wider use of the data. So rather than just me using it or my students using it then anyone can log onto the site and use it." [AWS01-4]

This response demonstrates that in some cases, whilst data are being collected because of weather station owners' passion for weather observation, altruistic opportunities for data sharing emerge through time as institutional support evolves and communities of practice grow. Altruism is not essential to the identity of citizen scientists and amateurs, but a quality that is cultivated through the social and technical assemblages they are embedded within. The response also highlights some of the ways in which amateur and professional data and equipment may differ, and points to additional educational and cultural values these amateur-generated data possess. Involving the public in weather observation may encourage citizen scientific culture and improve public understanding of atmospheric sciences. The data can be shared, as long as other socio-technical arrangements, such as web platforms and time, are available.

Whilst the above informant generated his own weather observation data using a ready-made Davis weather station, some technology enthusiasts build their own weather stations using microcomputers such as the Raspberry Pi. Some participants of Open Source Maker communities such as Raspberry Pi groups, local hackerspaces and FabLabs, and even Linux User Groups (LUGs) have developed an interest in making home-made weather stations. The already diverse and hybrid Open Source Maker communities (Lin, 2005) are further hybridized by such an interplay between citizen science and Open Source making.

An infrastructure that includes the owners of these home-made weather stations and the data they produce, undoubtedly faces challenges of managing, standardising, and integrating different epistemic cultures, especially when amateurs meet experts. We can sense the challenges from the narratives below when the informant discusses their passion for Raspberry Pi technologies. The questions here are: are these different interests (e.g., in the gadget Raspberry Pi or in weather observation) juxtaposed on an equal ground, or is there a hierarchy in terms of preferences amongst them? Do these practitioners consider themselves as 'citizen scientists' or ' Raspberry Pi hobbyists'? In light of the in-depth interview with one Raspberry Pi weather station maker, and informal conversations with participants at other Raspberry Pi makers' events, learning to configure a Pi usually takes priority over weather observation, which is often a secondary interest.

Many of the Raspberry Pi weather station owners are more interested in the low-cost configurable, programmable open-source technological components. Weather stations are one of the classic projects that Raspberry Pi owners build, and various step-by-step construction guidelines can be found in online instructions, technology magazines and books. Building or owning a Raspberry Pi weather station therefore may not necessarily mean that one is interested in weather observation (because if they are interested in weather observation, they may easily get a Davis Vantage, or similar weather station, from the shops). Often, an interest in open source software and hardware co-exist or perhaps outweigh these observers' interest in weather observation. For example, asked what came first - the interest in the weather or the Pi, a informant who has built not only a AirPi weather station but also done other Pi projects firmly said,

> "I was sent a link to the AirPi project essentially and I thought this is very me because it combines several of my previous interests in the form of the electronics, the Raspberry Pi, the weather, programming, er, things I'd done during my degree course. And I thought this seems like a very nice way to try meshing knowledge in a new way." [AWS02-1]

Members in such Maker and Hacker communities often express that they build or collect things 'just for fun' (e.g., Torvalds & Diamond, 2001). This emotional expression requires a deeper understanding – fun for whom? Why is it fun? Why would or wouldn't a Raspberry Pi weather station owner contribute the data to WOW? Is it because it is less fun? Where does the fun part end – if at all?

These are interesting questions with regard to motivations, but they also relate to the materiality and affordances of the Raspberry Pi. Asked what he enjoyed about having a Raspberry Pi, a weather station, and the resultant data, the informant said,

> "It's kind of my version of art. People paint as creative expression, my creative expression is a bit more logical in terms of programming. I always quite enjoyed Lego as a kid and, specifically what I enjoy is the constrained solutions - if you're trying to do something and you have these resources how can you best do what you're trying to do? And so building the weather station is kind of a subset of that but it's why I get into a lot of programming of electronics. I got this neat idea how can I do it with what I already have or getting the least amount of stuff possible off eBay and things like that. And so the Raspberry Pi weather station is just another version of that." [AWS02-2]

Richard Stallman, the founder of the Free Software Foundation, became a free software advocate and practitioner because he wanted to fix a paper jam, a very personal and local problem (Williams, 2002). Similar to Stallman's paper jam problem, and the findings from numerous free/open source software studies (e.g. Ghosh et al., 2002, Lin, 2005, Freeman, 2007), the motivation for turning a Raspberry Pi into a weather station in this case can be attributed to solving an existing problem at hand:

> "I had the barometer because I was getting quite tired of the let's go check BBC weather. For short term predictions, I can generally get a good idea of what's happening off the barometer." [AWS-2-2]

Our informant had no plan for sharing his data with anyone, uploading them anywhere, or doing any analysis of them. He said that he had managed to have the weather station recording since January 2014, so six or seven months data existed at this point.

> "I don't have any definite plans because for me that weather station is hobby territory not must absolutely do it work territory. And so I'm just sort of enjoying the graphs and the nice little thing in the corner of my screen on my desktop PC which shows the latest readings there as well. I'm just sort of enjoying those things and be able to check if it's been raining and what does the rainfall look like?" [AWS02-3]

This problem-solving mindset and behaviour also leads the informant to disregard himself as a 'citizen scientist'. To him, he was only interested in trying out and adding different sensors onto the Raspberry Pi for "a good learning experience". He recounted:

> "For me I wouldn't class too much of what I do as citizen science. I mean the Raspberry Pi stuff that I write about you could count as 'educational science'. I would class something as potentially citizen science if someone was applying his professional knowledge to doing it. I know I am not." [AWS02-4]

Whilst the informant, who is an open source software developer and advocate, didn't currently share his weather observation data via a platform such as WOW, drawing on his open source experiences he did recognise that he would get some benefit from doing so:

> "The motivation for sharing the data I suppose would just be a cross between… something along the lines of I've got it I might as well share… crossed with, er, trite, but sharing is caring sort of thing… You do get a little bit of a… not jolt, but boost, or you get a little visceral pleasure from sharing and helping other people out and it would come under that." [AWS02-5]

When questioned why he did not share the data he collected, the informant explained that whilst he shared his software code, he was concerned that the quality of his data was not good enough for sharing. Further, whilst he was open to considering sharing data for some weather variables he thought were more accurate, he didn't feel it was a priority for him at the present time:

> "I have been considering doing that for the things which I know wouldn't be affected by the sunlight so that's particularly with the pressure and for the rainfall but also means I do have to write then the software model to do that. And it's not hugely complex I just haven't got into the right frame of mind where I'll sit down and write this bit of software today. So I haven't done it but in the future I suppose I would be interested in doing that because it does seem interesting" [AWS02-5]

The challenge of 'time' again is flagged up here. If the informant doesn't have time, it is difficult to make commitments and provide consistency in data collection or tool improvement. The practitioners may have interests and motivations, but 'time' is a critical factor that affects their engagement.

This view is quite common amongst those who are engaged in this wider hackers' community, loosely structured by members who share a repertoire of open source practices (Lin, 2005). Even if the Pi weather station owners have demonstrated that they can collect data, and they believe in open source philosophy, they don't necessarily prioritise sharing the data they have been collecting. Their motivation for collecting data is not necessarily because of concerns about meteorology or climate change, but something 'tokenized', something linked with practicality, passion, and emotions, rather than altruistic 'gifting' to the wider community. Phrases such as "just in case one day I need it", "just for fun", "just because I want to" and "just because I can" were heard often in informal conversations at Maker events.

Climate Data Rescue and the Old Weather Project

> "It's the weather, it's the history, and it's the forum I think for me are the three key important things that have sort of kept me interested in it really." [OW1-20]

The Old Weather project was initiated to help climate scientists use weather data from historic ship log books to study climate patterns from the past. Before satellites, weather data transmitters, and computer databases, weather conditions at sea were dutifully documented by sailors by hand in the log books of ships. For years, climate scientists have been keen on using these historical records to establish baseline climate data. However, much of these data exist only in hand-written documents stored in archives and are inaccessible to most people.

Dr. Philip Brohan, a climate scientist at the Met Office Hadley Centre since 2002, has been leading the Old Weather project that crowdsources efforts to transcribe scanned copies of log book pages, some more than 150 years old, and make them available to climate scientists worldwide (Brohan et al., 2009). Project scientists integrate the transcribed data produced by Old Weather volunteers into existing large-scale data sets, such as the International Comprehensive Ocean Atmosphere Data Set, which are used by researchers around the world. Begun in 2010, in its first two years the Old Weather project involved more than 16,000 volunteers in transcribing 1.6 million weather observations from British Royal Navy log books.

As well as weather observations, the log books also contain information on maritime history, scientific explorations, military operations, and dramatic rescues and shipwrecks at sea. While the data extracted from these records will be useful to climate scientists, these documents are also a wealth of information for historians, genealogists, people who wish to find out their family histories, or anyone interested in exploring the diplomatic, scientific, technological and military aspects of the voyages, and the experiences and accomplishments of seafaring people.

Because of its intersection with historians and maritime enthusiasts, the Old Weather project engages a diverse group of volunteers (or 'citizen scientists') (Eveleigh et al., 2014), quite different from the amateur weather observers or the Raspberry Pi Makers community. One informant who has been involved in the project for nearly four years told us that she learned about the project on BBC Radio 4. She was rather taken by the idea of contributing to climate science to address climate change. The other informant, an administrator in an Environmental Science department in a UK university who has also been involved in the project for more than three years, said she was moved partly by her curiosity about her colleagues' work, and partly taken by her concern for the planet. It was this "wider picture" that kept her hooked for so long:

> "Feeling that that is a worthwhile thing to do, and it's contributing to a scientific project that I think is important. And then I think I got interested in the wider picture as it were, of life on board the ships, and the whole thing of the naval history mostly of the First World War, about which I knew nothing. So it kind of spread itself out into all the other topics as well." [OW1-1]

A social conscience, some background knowledge in weather observation (some even run their own weather stations), and interest in history are widely shared amongst the participants. Each of these three elements are linked with motivations and are highly emotive. Those emotions are clearly demonstrated in the accounts the informants provided, especially with regard to their interaction with the historical materials and with fellow participants.

The historical data, for example, contain certain narratives that move people. Volunteers experienced emotions by reading the log books, and feel attracted to the historical materials they view online. Reading and transcribing these historical materials also give volunteers a sense of connection to the lives of people that lived many years ago. As one participant vividly described:

> "I don't know how but it does feed into one's imagination, and a broader sense of sympathy. On one of the ships I was on, it was coming back from Africa after the First World War had ended. And the number on the sick list kept going up, and of course it was the influenza epidemic. And I

remember realising that I was really quite anxious about this ship and this crew. I was thinking this is silly, you know, this is all a very long time ago, whatever's happened's happened. But I realised I was really getting quite anxious about my crew, and you know, hoping that they were all going to, you know having come through the war that they were actually going to come through the flu epidemic." [OW1-2]

Transcribing historical data therefore is not a mechanistic act. It is embodied, emotional, personal, and connected with one's interests and existing tacit knowledge of histories and geographies. Telling the interviewer what she chose to transcribe, an informant said:

> "The Royal Navy ones after a bit I got that there were certain parts of the world I quite liked, and other parts of the world I was less keen on. So if I'd finished one ship and was looking for a new one I quite often thought I'd like another one that is for example, in East Africa because I'd done one or two there, and I'd got to know the names of places, and all that kind of stuff." [OW1-3]

The Old Weather project, as also seen in the case of amateur weather observers, confirms again that 'citizen science' involves highly embodied and emotive activities. When volunteers were asked to work on newly digitised North American ship logs introduced in 2012 after the success of transcribing Royal Navy Ships' logbooks from the period around the First World War, there was some initial resistance. Problems occurred during this period because these emotional and embodied dimensions weren't fully recognised. Some volunteers deliberately avoided transcribing these new materials. This is because many of the volunteers had little knowledge about the American ships and histories, and it appeared to be intellectually as well as emotionally difficult for them.

> "It was really quite hard work because the American logs were very different to the Royal Navy ones. The interface was also changing. The initial interface was really quite experimental, and it was just very hard going." [OW1-4]

This change in the source of materials being transcribed – the result of a celebrated collaboration between The National Archives (UK) and the National Oceanic and Atmospheric Administration (USA) – had a dramatic impact on community dynamics and practices:

> "With the American boats being different, the databases working very poorly, the frustration of how bad it was at various things... The poor moderators had to keep everybody happy because at that point [name of former participant] had gone, we'd had some fun, it was all looking like a disaster, we were in the unfamiliar zone, and it would have been very easy then for everybody to go. But somehow we got ourselves through that. Then it was a case of everybody trying to be as jolly as they could, keep the things going, lauding the work that we were doing so far. Picking up interesting things from the American ships to try and make them look as interesting as the Royal Naval ones had been. But I think we were on a knife edge at that particular moment, it was very scary. We did lose a lot of people who decided that actually, the whole thing meant so much to them that to cut and run was probably the only sensible way to deal with it. And there's people like me who actually can't imagine life without it." [OW2-3]

This informant has used a lot of (negative) emotional words in this extract, such as 'frustration', 'un/happy', 'disaster', 'unfamiliar', 'trying', 'scary'. This extract reveals the affect the expanding Old Weather data infrastructure imposed on her and other participants. Another recounted:

> "Because there was a big change when the American ships came in, and a lot went, "Oh it's nothing like the Royal Navy books, I don't really understand what's going on here." And this off switch of comfort just said this is not the familiar anymore, this is not what you chose to do, but what you did like doing was the editing, and there's tons of that left. So a lot of people said, "I think I've done my bit for citizen science climate transcriptions, let somebody else have a go and I'll go off and do my editing," which takes a certain amount of experience to do I think." [OW2-4]

Here, we see how the change of the OW infrastructure (the involvement of new institutions, larger databases and a new interface) shapes the community practices, attitudes, behaviours, and dynamics. A loss of the 'familiarity' experienced with the Royal Navy materials and histories, generated uneasiness and discomfort for the participants. While many technologists would consider "the more data the merrier" in a big data era, the data from the field demonstrates that the OW community members had mixed feelings about the addition. Even if the citizen scientists understood the purpose and usefulness of the American ship logs - "[At the phase when] the American logs were chosen specifically to provide weather records for, particularly for the Arctic, and that sort of part where they didn't have many records. So they looked for where they were lacking, and found ships that would provide that, so it's very targeted" - the participants could not help feeling alienated from the new log books from the American ships. The negative emotional response to certain types of data to be added was due to their attachment to certain historical materials, personal knowledge of specific historic periods and regions, confidence of rendering accurate and credible data, and familiarity with original materials. Not being as familiar with the history of North America and the new materials, made it initially more difficult for them to engage, transcribe, and edit the ships' log books. Nonetheless, over time many of the participants adapted to the change, and pushed ahead with the transcription task.

These subtle and often hidden relationships between data and data users are hinted at by Bowker (2005) when he proposes that "raw data" are an "oxymoron". Following this argument, others such as Gitelman (2013) have rejected the presumed objectivity of data, arguing that data afford certain types of knowledge to be produced, rather than innocently discovered. We subscribe to these arguments, and consider the relationship between data (the original inscriptions recorded in the ship log books as well as the value-added data produced through different processes) and citizen scientists' emotional responses and sentimental feelings towards data. As argued earlier, the narratives and textuality of these historical records have driven the volunteers to engage with and rescue the stories of the ships' crews. The value-added data generated by the volunteers of the Old Weather project therefore are not just fact-based scientific weather records, but also other accounts of everyday life and occasions including death. These narratives are not trivial, but impact different lives in a variety of ways.

Asked to assign values to the voluntary work she has been involved in and compare them, one respondent reflected:

> "I think the scientific value I would put first, but then definitely the historical information, which is also being recovered, in terms of the other comments in the logs. And I think particularly stuff about people. We fairly regularly get people posting on the forum saying, I am researching my family tree and I know that my grandfather, or my great uncle, or whatever was on this ship, you know is there any record of him? And we're able to point them, perhaps to the logs or to say, "they're not up yet, but they should be, so check back", this sort of thing. So I think it's helping to recover some history that isn't going to get known about otherwise. And actually, sometimes correcting information, which has been slightly wrong, for example deaths in particular 'cause we start recording all the deaths of anybody. Now the majority of them were already recorded, but sometimes the information we had from the log was actually a bit different in terms of cause of death, or the date, or whatever. And also we've sometimes had recordings of deaths of people who were part of the crew, but weren't actually naval personnel - boys who were sort of local, in Africa particularly, who were taken on board, and they tended not to get recorded. There were a few where it was actually recorded, a death, and so we've made sure that they get kept. So there's a bit of sort of almost recovery of lost history in some ways. Which also feels important to me, and kind of honouring people in a sense. Particularly in the people sense of it that honouring people who you know, perhaps died of this and maybe haven't been recorded at all. We can add a bit of detail perhaps, particularly if they were buried at sea we might be able to actually have the location for example because they did quite often put in the latitude and longitude when they buried somebody at sea." [OW1-5]

Some of the historical value of the OW data, especially interest from external people such as members of the public who had ancestors on the ships or originating from different continents were unexpected by some of the OW participants. However, these observations demonstrate the ways in which these crowdsourced data are not confined to scientific interpretation, but are also open to a wider, more diverse, use and interpretation. These historical data are collated through an editing process, and are shared via the naval-history.net website for anyone to access and read.

The embodiment in *doing* 'citizen science' can also be seen in the hidden, invisible, and often emotional practice of reading and making sense of hand-written historical documents. For example, flagging up the problem of transcribing digitised 'handwritten' historical documents, where the handwriting varies enormously, one informant shared her frustration saying,

> "[The handwriting] can vary a lot even just on one page; you can get half a dozen different handwritings on one page of a log sometimes. I think definitely one of the main frustrations is just trying to decipher what it is, and trying to make sure, particularly with the weather records that you're as accurate as possible because three people have to transcribe each page. … If everything is different then that weather record basically isn't useable, it gets thrown out because it's not accurate enough. You really are wanting to make a big effort to get it as accurate as you can, and hope that everybody else is too." [OW1-6]

The accuracy of the data was emphasised in the quote above. To ensure the data accuracy, the participants have to familiarise themselves with not only the instructions but also the social norms of asking for help on the forums. For example, how to ask and frame a question:

> "Particularly with editing, I usually go through a reasonable amount of the ship and then I start posting questions, sometimes about odd things I haven't been able to either read, or I think I can read it, but I've no idea what it means. Does anyone know what's going on here as I've been unable to find anything?" [OW1-6-1].

Socialisation is a good way of learning and finding solutions to overcome the problem of discerning handwriting. Our forum observations and the interview data suggest that most of the socialisation took place online rather than offline. Zooniverse organises annual conferences for volunteers to meet up, but it was the forum that played an important part in many volunteers' life and was mentioned again and again in the interviews. An Old Weather participant said,

> "It's quite unusual, it is pretty much all online. There's a facility to send personal messages, so some of it isn't an open forum. It's not just you sitting at your computer in isolation transcribing away. It's also actually relating to other people who are doing it, and assisting them, being able to ask for assistance. ... And quite often other people can come up with something. There are one or two people who are absolutely brilliant at tracking down obscure ships, for example. And others who've got a really good eye for odd handwriting. Or just people who happen to know that part of the world, for example, and therefore you know, are more likely to be able to work out where are we, what is this name, or whatever. So it kind of draws on everybody's skills I think. Sort of a group effort." [OW1-7]

The personal and tacit knowledge has been highlighted in this quote. This echoes what is mentioned earlier about the role of local and tacit knowledge of an amateur weather observer. Asked what kept her motivated overall in what she did with the Old Weather Project, another informant said

> "I think the sense of contributing to something that I care about, but also definitely the forum. The forum is massively important. It's an extremely useful source of information and assistance. But it's also a real community. I was just looking at it before our chat, having a look to see what had happened since yesterday, and in the chat thread someone has just announced the birth of his first child, for example, one of the transcribers [laughs]. And we have that quite a bit. People are telling each other about important things in their lives, or that they're going off on holiday so they won't be around for a bit, but they'll put some photographs up when they come back, and this kind of thing. So it's got a real kind of community sense, as well as being a very useful source of can anybody read this writing, does anybody know what's happening here." [OW1-8]

The online social space was described as "a very friendly place" with "a support element to it [plus] a lot of personal interaction as well as some fun bits" [OW1-12]. One informant who had also tried other citizen science projects on Zooniverse explained why she favoured the 'Old Weather' project:

> "There's the opportunity to be more involved; the opportunity to have both the social life and getting the citizen science out of things is there, and that's the mix that I like. Whereas some of the others like the Mars stuff just seemed empty, barren, devoid of personality really, and that does not suit me." [OW2-2]

Crowdsourcing Data Infrastructure and Connected Communities of Practices

Data can be scaled up, through some form of organization, standardization or institutionalization, to become 'boundary infrastructures' (Bowker & Star, 1999). Extended from the original idea of a "boundary object" (Star & Griesemer, 1989; Clarke & Fujimura, 1992) through which diverse actors are brought together to shape and interact within a large platform or infrastructure, we can conceptualise these crowdsourced data objects as a form of boundary object that connect different individuals and communities as they move through the infrastructure. In this sense, the crowdsourced data infrastructure should be recognised as a "glocalised" socio-technical infrastructure, containing various 'boundary data objects' whose production, processing, distribution and use are embedded in local practices and value systems that resonate with local conditions and limitations.

This modular way of building and connecting communities of practices enacts the 'scalability' and 'extensibility' of a big data infrastructure (boyd & Crawford, 2012; Kitchin, 2014a, Kitchin, 2014b). However, it's important to acknowledge that when a data infrastructure expands, not only data but also a range of socio-technical elements are assembled. These modularized components include communities, tools, pathways, and methods. In the communities we study here, in which the general public are connected with the professional scientific community, additional challenges are also brought into play in relation to the management of scientific knowledge production:

1. **Local, personal, and tacit knowledge**
   The fact that there were far fewer people transcribing the American ship logs (compared to the number of volunteers working on Royal Navy's ship logs), and that many felt "This is not my cup of tea", emphasised that different citizen science projects are attractive for different types of people. The motivations for getting involved vary from individual to individual. It is very personal and very embodied. Deeper engagement with citizen science requires local knowledge, interests and emotional attachment – something participants can associate with and recognise cultural references or interests.

2. **Socialisation**
   Having a shared place for mutual support or knowledge sharing is another crucial feature in citizen science projects. This may take forms of face-to-face real-life meet-ups (e.g., Zooniverse annual meetings or Makers faires) or on-line forums or mailing lists. Raspberry Pi makers' communities self-organise many online forums to support one another and facilitate cross-boundary learning and problem solving. Members of the OW community tend to favour conversations that take place on the project's online forum, perhaps more so than the WOW mailing list members. Our observations of the OW forum found a lot of light-hearted dialogues illustrating community support and social interaction.

3. **Embodiment (the physical, emotional and cognitive activities involved in recording, observing, transcribing and editing)**
   Weather observation involves more than recording scientific facts. Transcribing and editing historical records also requires more than just reading and typing. In the former, configuring and tinkering devices is a common practice found amongst amateur weather observers. In the latter, OW citizen scientists have engaged with recovering data and stories, empathising with and caring for historical shipping crews, imagining seafarers lives, and guessing old-fashioned handwriting. Understanding some of the hand-written documents was the biggest

challenge some OW informants reported. There were times people had to 'improvise': "We're all told that if you really can't read it, guess extravagantly because actually, you probably know better than anybody else what it's likely to be if you've been transcribing for a while" [OW1-9]. We can therefore recognise that crowdsourced data are inscribed with emotions, experiences and bodily performances.

4. **Attitudes towards professional standards and data quality**
   As seen in the narratives provided by the amateur weather observers and the OW participants, the citizen scientists we interviewed were aware that the weather data they produced might not be 100% accurate. However, desires for the quality of data that expert scientists strive for were nonetheless reflected in the volunteers' practices and mind-sets. OW respondents, for example, demonstrated a strong sense of duty to the project – emphasising a desire for completeness and accuracy. Mechanisms (formal and informal) were developed to ensure data quality and standards. For example, to ensure the accuracy of the transcribed data OW volunteers peer-review one another's work, and the amateur observers took time and efforts to calibrate their instruments and data to take local conditions into account. Aware of the importance of good quality data, most of the volunteers had a strong sense of responsibility with regard to the data they were producing.

5. **Trust from the professional scientists**
   The relationship between citizen scientists and the professional expert scientists provides insight into the citizen scientists' attitude towards their roles and responsibilities, and their self-identity as participants on projects such as Old Weather. The volunteers' dedication to completeness and accuracy garnered respect from the climate scientists, who spent time engaging with and building relations with members of the community and answering questions if needed. The interview data suggests a genuine sense of responsibility and delight is generated through interactions with the professional climate scientists.

Given the diversity and heterogeneity within and across these citizen science projects, a crucial question for understanding a big data infrastructure based upon them is how to homogenise and integrate these crowd-sourced data collected and generated in distributed environments into a global big weather and climate data infrastructure. This is not merely a question of 'how to' achieve this technically, but also one of how to tackle the social issue of ensuring that the diverse interests existing in different citizen science projects are harmonized, sustained and maintained within a single infrastructure.

The existing STS literature has addressed the issues regarding homogenizing and standardising boundary objects (see e.g., Star & Griesemer, 1989; Fujimura, 1992; Wenger, 2000; Lee, 2007; Star, 2010; Jensen & Kushniruk, 2014) but the issues haven't been discussed in the context of distributed data collection and generation. Our study begins to bridge this gap by looking into the construction of infrastructures for crowdsourced data, in a similar effort as seen in the two articles published in the earlier parts of this special issue on knowledge infrastructures: the production of Wikipedia (Wyatt et al., 2016), and grassroots infrastructures (Jalbert, 2016). The aforementioned communities of practices (weather enthusiasts, private weather station owners and citizen scientists), though seemingly unrelated, all share one character, which is a loosely defined (and perhaps also ephemeral) boundary and a flexible membership. Members of these communities have varying interests. The data are inscribed with the contributors' memories of places, lifestyles, interests, values, and communities they reside in. In a big data infrastructure where the data crowdsourced from different origins are aggregated and integrated, these data that are produced by different parties dislocate from the places they came from.

Although data are usually considered as scalable and extensible in a big data infrastructure, our findings suggest that, whilst scalability may be relatively achievable on the technical side, it is more difficult to handle aggregated, augmented, and accumulated human factors on the social side of the infrastructure, especially in relation to people's emotions, memories and attachment to histories, norms, traditions, and social spaces.

While the data can be aggregated, the memories and emotions and human factors cannot be accumulated at the same scale, speed, or in the same way. When data are put together, the personal characters of these data are erased. From our investigation into those hidden and invisible practices of citizen scientists involved in the OW project, for example, we found the challenge of dealing with human factors in a scalable big data infrastructure. Participants reported the struggle of maintaining motivations when the materials being transcribed became disconnected from their personal interests and existing knowledge base. Building up a big data infrastructure involves not only aggregating data, but also human factors. These hidden issues can only be identified if we understand the local practices of data generation and collection, how they shape the ecology of the infrastructure, and what the 'matters of concern' are for those invisible workers who take care of infrastructural breakdowns, failures, and repairs (Star, 1999; Star & Strauss, 1999).

Conclusions

While crowdsourcing user-generated and user-contributed content and data has become an accepted method for producing scientific knowledge, it is timely and important to get a better understanding of how infrastructures for crowdsourced data operate. In these kind of large-scale, networked computing infrastructures where data that are generated and collected from different sources are housed, processed, and aggregated, the 'bigness' has been seen in terms of quantity as well as variety (formats, types). Data included in such big data infrastructures come from various sources, and are generated by different users and organizations through different means. All these data collected, collated and generated in different ways for different purposes denote diverse (and sometimes conflicting) agendas and identities, materialised in specific forms that can be converted into different formats that are re-used, re-mixed, aggregated, re-contextualised, and re-purposed. To understand the construction process of a big data infrastructure, we need to understand how these diverse communities, individuals, organisations and institutions function at the local level and the outcomes and consequences when they are connected together.

This paper has looked into the local experiences and practices of amateur and citizen scientists contributing to atmospheric sciences. The respondents in this study include amateur weather observers who create their own digitalised records of the weather, and citizen scientists who contribute to the OW project to restore and recover historical archive materials. We have highlighted the affective and emotional aspects of the practices and bodily performance to tease out the visible and invisible human factors involved. We have also discussed the challenges of dislocating and depersonalising these crowdsourced data in a big data infrastructure, especially in terms of loss of motivations and sense of identities.

Whilst a scientific data infrastructure often denotes something more stable, standardised, structural, and institutionalised, the involvement of citizen scientists creates a more unstable and uncertain space. How to coordinate and sustain the efforts of these diverse communities and integrate them into a big weather data infrastructure remains a challenge to be overcome.

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Notes

1 http://wow.metoffice.gov.uk/
2 https://www.zooniverse.org/about
3 http://www.wunderground.com/weatherstation/overview.asp
4 https://groups.google.com/forum/#!forum/met-office-wow
5 https://www.colweather.org.uk/index.php
6 http://www.wunderground.com/

Taxonomic Government: Ecuador's National Herbarium and the Institution of Biodiversity, 1986–1996

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Abstract

From the late 1980s to the mid-1990s, biodiversity went from being an arcane, technical way of thinking about natural resources, to an important object of political concern and planning in Ecuador. This historically novel relationship to biological resources was catalyzed in large part by Ecuador's National Herbarium. The Herbarium's work modified existing regimes for managing plant resources during a time of economic crisis, and served as infrastructure for the field of biodiversity conservation in the country by helping to prioritize geographic regions for intervention. Biologists' practices were woven across protected area planning, environmental assessment and development projects. Through archival documentation and oral histories, I analyze biodiversity's emergence as a governable object out of an institutional arrangement I term "taxonomic government", organized around taxonomically-based biological systematics.

Keywords: infrastructure, economization of biodiversity, governmentality

Introduction

Beginning in 1988, a field program administered by St. Louis-based Missouri Botanical Garden (MOBOT), under the auspices of the Ecuadorian state, conducted a number of formally contracted botanical inventories for foreign oil companies. The majority of the work took place in or around Yasuní National Park, the country's largest Amazonian protected area. Field technicians for the program that would become Ecuador's National Herbarium worked as fast as they could "behind the chainsaws and ahead of the bulldozers", as reports from the time put it (Neill, 1990). Technicians salvaged plant specimens from what had previously been the canopy level of felled trees before the sites were cleared for construction. Concluding a report to the Calgary-based oil company Petro-Canada on fieldwork along the company's newly constructed road, the MOBOT-affiliated botanist David Neill (1990) wrote:

> Besides petroleum itself, the forest resource is the most important economically in the region; and in the long term the forest is much more valuable even than petroleum. How will this development take place, and how can the forest be managed on a sustainable basis? For rational development to take place, it will be important to know, for example, where stands of high-quality timber occur […] and how to predict where these occur.

Three decades later, Yasuní National Park is once again in the midst of large-scale petroleum development (Acosta, 2010; Rival, 2010). Critics who are unequivocally opposed to it, as well as those who aspire to balance petroleum production with environmental concerns now focus their advocacy on the number and uniqueness of species to be found in the park. Thus, evaluating the "global conservation significance of Ecuador's Yasuní National Park", Bass et al. (2010: 3) write that "Distribution maps of amphibian, bird, mammal and vascular plant species across South America show that Yasuní occupies a unique biogeographic position where species richness of all four taxonomic groups reach diversity maxima".

Neill and his colleagues in the late 1980s framed their work as a first step toward rational forestry, which could commercialize particular tree species in a coordinated, sustainable way. In contrast, the concerns of experts and the public presently center on the impending loss of species in an area now conceived as one of the most biodiverse in the world (Bass et al., 2010; Finer et al., 2009). The syntheses of biological studies prompted by the controversy unequivocally demonstrate the biological importance of Yasuní. They also show the enormous effort made to catalog species and quantify diversity within the park; to propose these as intrinsically valuable in lieu of any direct utility to broader Ecuadorian society; and, more recently, to link them to other environmental problems like climate change. In the intervening decades, then, a novel object – biodiversity – has become a compelling focus of political action.

This article uses the history of Ecuador's National Herbarium to examine how the social, technical and political concern for biodiversity was instituted in the country. The National Herbarium played a catalyzing role in this process by generating a technological apparatus that straddled public and private institutions and assisted with targeting conservation areas by provisioning species-level botanical data. Its work formed the basis for new relationships to Ecuador's biological resources as its methods and scientific products became widely available managerial tools.

The core of my analysis focuses on the period between 1986 and 1996. In 1986, a field program was proposed by MOBOT that would allow international NGOs to design conservation programs in Andean South America on the basis of specimen-level biological data. In 1996, Ecuador's Ministry of the Environment was created with a mandate framed in terms of the governance of protected areas for biodiversity conservation, replacing pre-existing Ecuadorian institutions. In these eleven years, the practices of systematic biology, and botany in particular, formed the foundation for a pervasive new way of linking institutions to the environment. The period coincides with the coining of the term "biodiversity" (Wilson et al., 1988; Takacs, 1996) and its ascendance as a theme of specialized literature, multilateral agreements, bilateral funding and widespread public interest. The present case thus helps us to think about how, and with what consequences, biodiversity emerged as a political problem in Ecuador.

To understand these issues, this article draws together science and technology studies scholarship on "economization" and infrastructure with the "governmentality" approach to the study of modern institutional power associated with Michel Foucault (Burchell et al., 1991). As scholars of economization have argued with regard to calculative rational action generally, the capacity to evaluate biological resources is, in part, a function of the specific technological setting in which actors operate (Callon et al., 2007). In Ecuador in the 1990s, biologists focused their efforts on creating knowledge infrastructure to assist with identifying biodiversity conservation priorities. Their frequently ad hoc "infrastructure work" (Star & Bowker, 2010) resulted in enduring mechanisms for the management of biological resources. Drawing on oral history, historical archives and secondary literature, I show how the uptake of this work produced biodiversity as a "knowable and administrable domain" (Rose et al., 2006: 86), on the foundation of taxonomically-based biological systematics.[1]

In order to better distinguish what kind of program biodiversity conservation was upon its entrance in the 1980s, I begin my examination of empirical materials by distinguishing two distinct paradigms by which plants were configured as resources in 20th century Ecuador. I then turn to the creation of the National Herbarium, examining the infrastructural arrangements that made it possible to presumptively attribute value to territory in terms of biological resources, en masse. Following this, I examine how the National Herbarium applied the logic of biodiversity to petroleum work sites as a novel spatial scale of floristic evaluation, and molded the industry of environmental consulting. Finally, I show how foreign debt and austerity created the conditions for the Ecuadorian state's uptake of this technology, which spanned the fields of conservation and environmental consulting. Biodiversity became an institutionalized relationship to biotic resources as biologists' practices and infrastructures linked a wide range of public and private organizations. I conclude by briefly considering some contemporary implications of what I term "taxonomic government". First, I consider in greater detail how literature on economization, infrastructure and governmentality can inform our understanding of biodiversity.

Instituting Biodiversity: Economization, Infrastructure, Government

Ecuador's National Herbarium, and the organizations that it worked with, sought to reframe the diversity of life as a resource, a project of what Çalişkan and Callon (2009, 2010) refer to as "economization". Biologists conducted basic exploration and research in biological systematics, and used the resulting data for territorial planning. Their work revolved around the construction of new scientific infrastructures to coordinate between different organizations and communities of experts (Star & Bowker 2010; Star 2010), with the eventual goal of reworking the existing Ecuadorian institutions involved in managing biological resources. Biodiversity conservation was thus a project of what Michel Foucault (2007) referred to as "government" or the "conduct of conduct" (Burchell et al., 1991: 2), defining and grappling with the problem of biodiversity loss by reformatting institutional relationships to biological resources.

Biologists working in Ecuador in the latter half of the 20th century were alarmed by the rapid conversion of forest to agricultural purposes that they observed. MOBOT field botanists Calaway Dodson and Alwyn Gentry (1991) documented a severe example of this over three decades of fieldwork in the western, coastal region of the country. At that time, they estimated that only 4% of the forest remained that had existed at the beginning of the 20th century. Their experience suggested that numerous species extinctions had already occurred in the region. They estimated that the total conversion of forest on the coast would result in the loss of over 1200 more endemic vascular plant species. The authors argued that the region was being damaged by state policies encouraging irrational land use, and that conservation programs needed to be enacted on the basis of more thorough biological inventory.[2]

Dodson and Gentry's approach was consistent with how biologists and others increasingly posed the fragility and finitude of life's diversity as a problem in need of intervention under the heading "biodiversity" in the late 1980s (Wilson et al., 1988). Biological explorers and their precursors had always identified local resources and circulated them through entrepreneurial and administrative networks (Müeller-Wille & Scharf, 2009; Raffles, 2002; Sevilla & Sevilla, 2013). What biologists called for with greater frequency in the 1980s was a different function that could presumptively treat the diversity of life en masse as a resource around which social relationships could be reorganized to avoid environmental devastation. Recent literature on economization thus provides a useful vocabulary with which to analyze how conservation "[enacted] particular versions of what it is to be 'economic'" (Callon et al., 2007: 4).

As suggested by Dodson and Gentry (1991), the central focus of conservation planning was on what, following Callon et al. (2002), we could call the "qualification" of plant resources through biological inventory. Callon et al. (2002) use the term "qualification" to characterize how new commercial goods are configured by interactions among various entities and processes such as advertising, testing, focus groups, and patterns of consumption. The salient properties of a product, the aspects that demand refinement by producers and form a value for consumers, emerge out of this distributed activity. "Qualified" objects may be framed as "singular" and incommensurable with other objects; ordinally ranked amidst other goods; or treated as stores of quantifiable value. International and domestic Ecuadorian actors qualified geographic areas of interest for biodiversity conservation in a variety of ways throughout the 1990s. These ranged from assertions about the scientific importance of sites due to the fact that they had never been biologically explored; to simple species lists; to the identification of endangered and endemic species; and eventually to diversity metrics generated through rigorous inventory. Conservation planning involved producing large quantities of "first-order" data (typically, lists of species found in a locale) that could then be summarized into new "second-order" products (such as estimates of local endemism or floristic maps).

Biologists' practices treated the volume of living forms as a "value" distributed across geographic space (Bowker, 2005). While this is an intuitive simplifying formal move, the technical work required to produce descriptions of biodiversity in these terms is still massive (Bowker, 2000a). For example, botanists had long relied on spatially coarse records of plant collecting localities and the circulation of anecdotal information through networks of colleagues. Coordinating efforts to save biodiversity in Andean South America required MOBOT to format and pool large volumes of spatially-referenced botanical data with information from other disciplines. These needed to be available to the various actors working on conservation, which then needed standardized ways to assess the information at hand. Economizing Ecuador's biodiversity was thus, among other things, a problem of knowledge-infrastructural design.

The National Herbarium comprised part of what I term a "technology of spatial prioritization" that grew up around biologists and other experts, spanned public and private organizations, and assisted with the identification of conservation targets. This technology enrolled the traditional tools of plant systematics into new projects of the management of biological resources. As Li (2007) puts it, conserving biodiversity was a matter of "rendering technical", or formulating the problem of conserving life's diversity in terms amenable to botanists' expertise (cf. Rose, 1999; Mitchell, 2003). Biological inventory and the production of knowledge infrastructures embedded experts in a technological setting that allowed them to apply formal decision criteria to biodiversity conservation interventions on the basis of their own disciplinary techniques (Miller & Rose, 1997; Callon & Muniesa, 2005).

As the National Herbarium was forming, Ecuador was undergoing sweeping political and economic changes, due largely to its foreign debt. From the 1980s to the 1990s Ecuador slid from economic stability to currency collapse. Those two decades saw massive inflation, reductions in public spending, the removal of subsidies for domestic industries, and the stripping away of controls on foreign investment (Hey & Klak, 1999; Jácome, 2004). Thus, the emerging technology of spatial prioritization was guided by the needs of international actors, who provided the only funding available during this period of austerity. Moreover, neoliberal reforms had important impacts on how botanical fieldwork interacted with petroleum development, the country's most important economic sector. Botanical collecting not only used petroleum development to conduct fieldwork, but transposed the logic of biodiversity to the oil field to study the impacts of development. Biologists' practices and infrastructures eventually reoriented the Ecuadorian state's governance of biological resources, not by direct coercion, but by provisioning it with a new technology for reckoning with space and resources that cut across the burgeoning fields of conservation and environmental consulting.

Ultimately, I suggest that biodiversity was produced through "taxonomic government", a retrospectively discernable apparatus that crystallized over the time period in question with the National Herbarium at its center. The starting point for Foucault's analysis of "governmentality" was that the conduct of conduct is not the sole purview of a monolithic state, but occurs in countless ways throughout society (Silverstein, 2015; Erazo, 2013; Asdal, 2008a; Rose et al., 2006).[3] The analytical question of interest to studies of governmentality is how particular mechanisms and rationales for the "conduct of conduct" become widespread, conventionalized and institutionalized – sometimes to the extent that they become constitutive features of "the state", though this is not necessary (e.g. Donzelot, 1997; Power, 1999). This analytical move refuses to posit transhistorical functions of the state so that the question can be posed more pointedly of how particular rationales and mechanisms coalesce into intelligible, enduring paradigms of political power.

From this perspective, the botanical norms by which new plant species are described are just as potentially "governmental" as more familiar functions of the modern state: they order social action. The practices on which taxonomic government was based were those of biological systematics, as MOBOT director Peter Raven and the biologist-philosopher E. O. Wilson put it, "hitherto regarded as 'little science'" but "badly in need of growing large" (1992: 1099). In examining "taxonomic government" I focus on the practices of biologists as these cut across numerous different organizations and projects. The term "taxonomic government" distinguishes the political technology that emerged in Ecuador in this period from environmental politics in which ecology or other disciplines played more prominent roles in Ecuador and elsewhere (e.g. Lowe, 2006). It also distinguishes this technology from that which might develop where statistical or molecular methods form the basis for large-scale biological inventory, rather than the physical inspection and description of specimens. I thus intend to highlight a form of governmentality based on a very specific set of practices. Taxonomic government emerged as one way of *doing* biodiversity on the basis of taxonomic biological techniques as these became increasingly available: biologists' infrastructure work defined both what the problem was, and how that problem would be passed along to other communities of experts (Karasti et al., 2010; Bowker & Star, 2000). The approach taken here thus examines the reflexivity or "performativity" of social institutions through the infrastructure work involved in constituting them (Rabinow, 2003; Bowker, 2000b; Mackenzie et al., 2008; Jasanoff, 2013).

Before turning to the details of the technology of spatial prioritization that was founded by the National Herbarium, it is useful to briefly distinguish prior forms of resource management from the spatially-oriented rationality that came to characterize biodiversity conservation.

Substantive and Spatial Logics of Plant Resource-Making

While biodiversity is commonly referred to as a "resource", the program enacted by the National Herbarium deserves to be distinguished from other relationships to plant resources. In this section I contrast two different tendencies in the economization of plants, which I term "substantive" and "spatial" logics of resource-making.[4] The substantive logic focused on particular plant species that posed identifiable utilities to people, especially through economic improvement and commercialization. The treatment of plants as "substantive" resources most closely resembles what someone is likely to have in mind when they think of a resource: a good that meets specific human needs or wants. On the other hand, the spatial logic began with the geographic space to which plants were assigned as a resource category. This is a more abstract and formal way of reckoning with resources, and a precursor to how plant resources were increasingly framed in biodiversity conservation in the 1990s. To exemplify the substantive logic, I turn to the work done by MOBOT's program in the mid-1980s in Ecuador. For the spatial logic, I examine the planning conducted in the mid-1970s, forming the basis for Ecuador's system of protected areas and the National Herbarium's later work. Contrasting these two logics shows how the work of the National Herbarium segued from a more conventional program of exploration and plant resource development, to one that emphasized the spatial distribution of flora as a basis for institutional planning.

The substantive and spatial logics examined here are best conceived as tendencies intrinsic to natural resource governance throughout colonial and postcolonial history (on forestry see Grove, 1996; Tucker, 2011; Mathews, 2011). In Ecuador, a substantive logic of plant resource-making formed the basis for the industrial use of plants for much of the 20th century, either in the context of programs for national economic development with assistance from the U.S. Department of Agriculture (Acosta-Solís, 1944) or in transnational business dominated by firms like United Fruit

(Striffler, 2001). After World War II, Latin American countries frequently relied on U.S. capital and technical expertise to develop natural resources, including plants (McCook, 2002; on Ecuador see Cuvi, 2011). As late as the mid-1980s, the pattern of plant science in the service of U.S. assisted resource development still held sway, in programs like the one that inaugurated MOBOT's field program in Ecuador.

MOBOT's field collectors, such as Dodson and Gentry, had worked sporadically in Ecuador since the 1950s (Dodson & Gentry, 1978). The permanent field program that eventually became the National Herbarium was initiated by a USAID-funded project with the Ministry of Agriculture and Livestock beginning in 1984. The project's stated goal was "to strengthen the capacity of professional foresters and botanists in Ecuador to study and manage the Ecuadorian humid tropical forests by means of a dendrological and economic botany study of selected sites in the forest of the Amazon region of Ecuador".[5] Its primary deliverable to USAID and its Ecuadorian partner institutions was to be an illustrated dendrological guide, "Plant Resources of Amazonian Ecuador". MOBOT's work was part of a larger project designed to help the Ministry of Agriculture and Livestock identify and begin researching commercially viable trees in the Amazon, a region that had not received extensive dendrological study previously (Neill, 1985).

Provisioning useful information on commercializable tree species required the ability to perform plant taxonomy in the country, and thus demanded access to a herbarium. A herbarium can be conceptualized as a reference library of plants, built up through the gradual accumulation of specimens identified by experts in taxonomic families. The fieldwork conducted by MOBOT personnel was intended to produce specimens from Amazonian trees, and generate the scientific infrastructure required for future commercial research. MOBOT personnel began in 1985 by establishing a regular collecting site in the upper Amazon. Specimens were brought back to a herbarium dedicated to forestry outside of Quito, and duplicates of these were circulated internationally to be identified. As taxonomic identifications were sent back to Ecuador, a "local" collection of expertly identified specimens accumulated. The resulting information was fed into the larger USAID-supported research on useful plant species to characterize the properties of their woods, optimal growing conditions, yields and other factors. The substantive logic of economizing plants thus involved the intensive technical development of woody plant species on the basis of biological exploration and research in plant systematics through globally distributed scientific networks. MOBOT's forestry program resembled others in a longer history of collaboration in Ecuadorian forestry reliant on U.S. sources for technical expertise and capital (Cuvi, 2009).[6]

A project conducted jointly by the U.N.'s Development Programme and Food and Agriculture Organization in 1976 exhibits a contrastive, spatially-oriented logic of resource-making in Ecuador (UNDP-FAO 1976). Occurring just a few years prior to MOBOT's collaboration with USAID described above, projects such as this set the stage for a major burst in protected area planning during the late 1980s. The project's goal was to support the creation of national parks in order "to maintain outstanding wild areas of the country for the sustained production of a flow of products and services that will contribute to the benefit of the population and national development, without diminishing the natural capital of these areas". Rubrics for designing the system were borrowed from the Food and Agriculture Organization (UNDP-FAO 1974) and U.S. National Park Service (USNPS 1974). The report's criteria were intended to be comparable within and across national contexts, and match up with the categories of U.N. funding mechanisms (such as its recently minted Man and the Biosphere Programme) in a manner that presaged the conservation boom of the 1990s (Fairhead & Leach, 2003). The project's final report presents geographic regions ranked according to coarse descriptions of resources, amenities or judgments of their uniqueness.

Biologists consulting for the World Wildlife Federation (WWF) produced a follow-up report in 1978 focused specifically on the Yasuní River watershed, which ranked fifth on the original report's overall list and first among its recommended protected areas in the Amazon (Pearson et al., 1978). The WWF report did not present information on the economic uses of plants in the watershed, but argued for its value on the basis of the density of plants found there and the distinctiveness of the flora. The authors identified 405 species, suggesting the area might have 12 times that in reality (Pearson et al., 1978: 15). The 1978 report advocated "complete protection", and suggested boundaries for a reserve.

The 1976 U.N. report framed Ecuador's prospective national parks as repositories of "natural capital" in need of rationalization: they required protection in order to maintain viable stocks of resources. The authors presumed that plants in these regions constituted some form of resource requiring further qualification. As opposed to the U.N. study, the 1978 WWF report says nothing about the economic value of the Yasuní watershed to the region or Ecuador more broadly, but insists on its value in terms of the abundance of plants there and the consequent need to study it further (in essence, its value adhered in its scientific interest). The spatial logic of economizing plants in the 1970s was thus a matter of framing territories in terms of resources presumed to exist within them, and later elaborating this value through biological fieldwork.

Scholarship in political ecology has theorized territorialization, the formation of new geographic units, emphasizing either the extension of state control over space (Vandergeest & Peluso, 1995), or the formation of new regimes of capitalist extraction of natural resources (Brogden & Greenberg, 2003; Sheridan, 2007). The U.N. and WWF studies of the 1970s loosely combined both of these aspects. The studies extended state planning to previously outlying regions of the territorial nation-state (Sevilla Pérez, 2013), using tools provided by international actors to attribute economic value that later needed to be confirmed and elaborated. The initial assumption of the 1976 U.N. study was that the resources would be of use to a developing capitalist economy. The prioritization of areas for protection had a "performative" dimension (Mackenzie et al., 2008; Bowker, 2000b), inasmuch as presumptively designating them as valuable provoked further study and attributions of value with the assistance of multilateral financing. This two-step process was accelerated and refined in the conservation boom that the National Herbarium helped to initiate, as I discuss below.

As biologists drew attention to species loss in Ecuador in the 1980s, rendering biodiversity technical was clearly not a matter of imposing expertise onto a domain that had previously lacked expert intervention. It rather involved pivoting an existing apparatus, oriented at the time to the substantive economization of plants, toward the goals of the emerging field of biodiversity conservation, and the distribution of plants across national space. MOBOT's forestry work with the Ministry of Agriculture and Livestock participated in an older paradigm of resource-making, linked during the 20th century to the U.S. Forest Service and state-managed commercial forestry.[7] However, one of MOBOT's goals of participating in the USAID program was to initiate a field program in the country that could lay the foundation for what would later be biodiversity conservation. In the process, the role of biological research was increasingly reconfigured to feed into projects predicated on a spatial logic of economization.

A Technology of Spatial Prioritization

In the late 1980s, as public support for forestry began to disappear, MOBOT botanists ended their project with USAID and the forestry department and began conducting fieldwork as the country's National Herbarium.[8] Here I examine two projects in particular that had the logic of spatial prioritization prominently built into them. In the first, the National Herbarium's work was aggregated with other data to form a central repository of spatially-referenced biological information for Ecuador. This project involved pooling what Power (2004) terms "first-order" data products from various biological sciences. In the second project, sites with high plant diversity throughout the country were characterized on the basis of the National Herbarium's floristics as well as first-hand observations to provide summaries of regional conservation issues. This was an example of "second-order" aggregations of species-level data (Power, 2004). In both cases, the Herbarium and the techniques of botanists bridged the roles historically played by biological exploration and territorial management, and produced a new technology for prioritizing spaces for conservation through infrastructure design (Star & Bowker, 2010).

The National Herbarium's establishment in Ecuador was motivated by a joint project with The Nature Conservancy (TNC), a Washington D.C.-based environmental NGO. In the early 1980s, TNC was in contact with MOBOT botanist Alwyn Gentry, and communicated its desire for a computerized database that would allow identification of conservation priorities. As Gentry noted in a memorandum to Peter Raven, this database would optimally be scalable and linkable to others in order to assist broader conservation efforts in Andean South America. Gentry wrote: "[TNC personnel] very clearly want (and obviously need and should want) a specimen-based approach. What they need to know is where individual species are, not what species occur in a given country".[9] Conservation work would thus be informed by floristics derived from species-level data, irrespective of political boundaries. This required collecting and taxonomically identifying physical specimens, an obvious role for MOBOT.

TNC's work in Latin America at the time was focused on building national Conservation Data Centers, storehouses of spatially-referenced biological data. Where the work was successful it provided an unprecedented level of biological detail over large geographic areas. In the case of floristics, botanical rubrics were developed to distinguish species compositions in upper canopy, lower canopy and understory, allowing mapping at the national level of these distinct forest components (CDC, no date). Botanical data were fed to the Conservation Data Center from MOBOT's own in-house database, and later integrated into a digital geographic information system. Aggregated data could then serve a large number of purposes, from coordinating TNC's own regional efforts, to designing biologically meaningful national maps, a process that one planning document refers to as "ecoregionalization" (CDC, 1990).[10]

An example of the National Herbarium's second-order products is its contribution of "datasheets" for a casebook on *Centres of Plant Diversity* by the International Union for Conservation of Nature (IUCN) beginning in the late 1980s.[11] The first goal of the IUCN program was to "identify which areas around the world, if conserved, would safeguard the greatest number of plant species". Inclusion criteria for sites were based on numbers of species (or estimates thereof) and levels of endemism. Datasheets for each region contained brief floristic characterizations, descriptions of known useful plants, an "economic assessment" outlining local relationships to natural resources, threats to biodiversity, conservation recommendations and a bibliography.

The National Herbarium's contributions to the IUCN project encapsulate the overall tendency in this period to synthesize scientific research with botanists' informal observations from the field into informationally rich instruments. For example, National Herbarium botanists made two expeditions in the early and mid-1990s to the Cordillera del Cóndor, a low-lying mountain range on the Amazon side of the Andes. The region had not been identified by the 1976 UN study as a conservation priority. The National Herbarium's work there identified the cordillera as a limestone outcrop similar to the Guyana shield, a geological formation occurring at the intersection of Venezuela, Brazil, and Guyana far to the north. This discovery offered a promising window onto the region's evolutionary history (Ulloa & Neill, 2006). Similarly, the National Herbarium produced a datasheet for Yasuní National Park drawing on its observations of unanticipated floristic heterogeneity in the lower Ecuadorian Amazon. In these cases, the National Herbarium's botanists emphasized their importance on the basis of scientific debates in a planning tool for an international audience.

Thus, the production of first-order data like species lists generated new second-order aggregations of botanical data in terms of which planning and scientific research could be coordinated. These were combined, in turn, with expert judgments about the value of particular locales in light of scientific debates and local environmental threats (Cochoy, 2008). With this combination of contextually-informed judgment and formal knowledge, the National Herbarium bridged the functions of biological exploration and territorial management. The larger technology of spatial prioritization relied on the ability to rapidly incorporate these findings into planning.

The National Herbarium and the Conservation Data Center created the sociotechnical conditions for formal decision-making by embedding experts within an apparatus that mapped geography on the basis of taxonomically identified specimens. The broader technology of spatial prioritization in which these organizations participated was thus a "qualifying distributed device" (after Callon & Muniesa, 2005) in which both conservation priorities, and the terms in which these would be conceived, were negotiated between experts and organizations. The two distinct steps of the 1976 U.N. study and the 1978 report by the WWF were collapsed into a productive cycle of feedback between the basic goal of aggregating biological data and the conceptualization of new scales of environmental governance. The work of visiting sites, collecting specimens, circulating findings among colleagues and synthesizing them produced zones of intensive environmental interest prior to the consolidation of evidence or deliberative procedures (Neill et al., 1999; Schulenberg & Awbrey, 1998). Biodiversity, a new way of describing and valuing Ecuadorian space, was enacted in the way taxonomically-based biological systematics formatted and linked conservation organizations.

Qualifying the Biotic, Framing the "Site"

Botanical fieldwork (first for the forestry project, and later as the National Herbarium) brought botanists into direct contact with petroleum field operations in the Ecuador's Amazon. The difficulties of plant collecting and the politics of petroleum development incentivized collaboration between botanists and petroleum field operations. As plant collectors encountered and made use of petroleum development, practices of spatial prioritization used by international and national conservation organizations were transposed to the oil field. One result of this convergence was that the petroleum development "site" was framed as a scale of floristic evaluation and comparison in the emerging field of environmental consulting. Examining the National Herbarium's specimen collecting in the country's Amazon shows how the practices of spatial qualification required by conservationists were re-contextualized as governmental tools beyond protected area planning.

The orientation of the initial MOBOT-USAID program in the mid-1980s toward Amazonian forestry posed problems not normally encountered in ad hoc botanical plant collecting. First, physical access to far-flung collecting sites was difficult due to limited infrastructure in the region. Second, the Amazonian canopy from which specimens were collected was anywhere from 25 to 50 meters overhead, requiring a slow and physically laborious process of climbing the trees to retrieve them. The petroleum industry assisted with both of these problems. Botanists approached a team of drilling subcontractors to informally arrange specimen collecting at their work sites once trees had been felled. David Neill recalls the National Herbarium's first encounter with them in 1986 or 1987 thus:

> We were driving along the road to Coca and stopped where they were drilling a well, and I sort of explained to them that we were interested… in where they were cutting down trees, because then we don't have to climb them, we can get specimens from the trees, botanical specimens, much easier - including the epiphytes, and the trees if they're in flower or fruit, etcetera. So we became sort of camp followers of the petroleum industry… That had been sort of my modus operandi in Nicaragua and elsewhere and… that's generally the way botanists in the tropics have worked. Interview, 3.14.14.[12]

Leading this wave of foreign oil development was Conoco, then a subsidiary of chemical company DuPont. The development proposals in the late 1980s were controversial due in part to their plans to operate within Yasuní National Park. Conoco eventually sought to collaborate with environmentally-minded scientists, encouraged by the highly public legacy of environmental degradation by Texaco.[13] Conoco courted a wide range of environmental and social advocacy organizations, both international and domestic, with a long list of criticisms of the project. The company's agreement to hire environmental consultants was seemingly based on a desire to insulate itself from future litigation.[14] In addition to dividing environmental NGOs in the country (Rival, 2011), the Conoco drilling controversy inaugurated the field of biological petroleum consulting. The National Herbarium's work was central to this, as its opportunistic collecting evolved into a formal arrangement with Conoco in 1988, followed by a string of contracts for other oil companies in the mid-1990s.

Petroleum consulting precipitated a significant spike in productivity for botanists. Renner (1993) estimated that the history of botanical collecting in Ecuador's Amazon had produced about 60,000 collections in 250 years.[15] On a single project, the National Herbarium collected 5,000 specimens from 1991-93 and was averaging about 500 collections per month at the time of a contract renewal in 1994.[16] Other petroleum projects also generated large numbers of specimens, and rapidly built up the Herbarium's floristic knowledge of Ecuador's lower Amazon.

With new first-hand experience of the lower Amazon and the aid of a specimen collection that was accruing with quasi-industrial efficiency, National Herbarium scientists were able to treat the oil field as a space of both biological exploration and evaluation. Biological inventory offered a preliminary means of what Callon (1998) refers to as "framing" economic externalities: inventory delineated a type of development "impact", and subjected it to the formal rationality of biodiversity conservation. The treatment of biological resources as a value unevenly distributed across space was consequently implemented at a finer spatial scale than that typical of conservation planning, through the massive infrastructural support of the petroleum industry. The spatial qualification of plant resources examined and differentiated between sites scattered throughout what had previously been treated by conservationists as a single biotic region (the lower Ecuadorian Amazon), describing space at the level of the petroleum development "site".

Natural history and biological field science have historically relied on infrastructural development to gain access to field sites (e.g. Kohler, 2006; Hayden, 2003). The history traced here is distinguished by the move from such opportunistic fieldwork to the careful coordination of botanists with oil companies to place them on the ground as forest was being cleared; and eventually to the insertion of biologists at proposed work sites prior to construction in order to describe a site's "baseline" condition.[17] On the basis of the site, for the first time in Ecuador floristic comparisons were regularly being made with reference to something "outside" of biological field science. The result was that botanical knowledge was used in the petroleum development process to anticipate, describe or mitigate the impacts of oil work in the emerging field of environmental consulting. Coupling together the qualifying capacities of biological systematics and petroleum development, the field of environmental consulting effectively took the formal logic of biodiversity to an extreme that was impossible in biodiversity conservation at the national level. The infrastructure of biological inventory in the oil field was thus in place when U.S.-based environmental consultancies arrived in the mid-1990s to work in the oil field. Inventory was immediately integrated into these companies' environmental assessment procedures, and became a standard feature of Ecuadorian environmental impact assessment as regulation was formalized by the state in the late 1990s and early 2000s.

The National Herbarium's work in the Amazon is an important example of how the practices of field biology and biological systematics extended outwards from the technology of biodiversity conservation planning to form more broadly applicable governmental tools. Similar practices were used in development projects supported by bilateral agencies, contributing to a burgeoning field of environmental consulting. This episode of plant collecting shows the feedback relationship that existed between the acquisition of biological knowledge through exploration and the consolidation of biodiversity as a domain that could be subjected to governmental techniques.

Taxonomic Government in Search of a State

By the mid-1990s, as a consequence of the projects described above, the National Herbarium formed the core of a technology of spatial prioritization used for targeting international conservation efforts, assisting with national-level protected area planning, and employed in environmental consulting. A qualifying distributed device for attributing value to space in terms of biological resources was strung together with taxonomically-based biological systematics at its core. These practices were interwoven with bilateral aid agencies, domestic and international NGOs, scientific institutions, private environmental consultancies, and transnational and domestic petroleum companies. Here I examine a parallel trajectory whereby this political technology was incorporated into public institutions beyond the National Herbarium. As a consequence of the country's economic problems, the rationales and practices of biodiversity conservation were integrated into the state, culminating in the creation of the Ministry of the Environment in 1996.

As discussed above, Ecuador had longstanding programs of plant research and forestry, but these relied on foreign technical and financial support, such as that provided by MOBOT and USAID in the mid-1980s (Cuvi, 2011). In the 1990s, the limited public funding for research on plant resources at Ecuador's forestry institute was further eroded by austerity measures. David Neill recalls:

> During the kick that everybody had for privatizing everything in the early nineties… [Ecuador's forestry institute] decided they didn't want to have research anymore. So they basically fired everybody and turned the whole place [the forestry research station outside of Quito] over to, part of it went to the police for an academy and part of it was this indigenous university… that would have been about ninety-two, three […] So all those specimens were incorporated into the National Herbarium… so, yeah, we inherited, the library was sort of like dumped out on the street, out in the open one day. So we got a truck, scooped up all the books we could and brought them into [the National Herbarium]. Interview, 3.14.14

Neill's anecdote dramatically illustrates the way that Ecuadorian state institutions were being redirected and repurposed throughout this period (in this case, literally salvaged by being hauled away in a rented pickup). MOBOT's botanists were forced to move to the National Herbarium in 1991, an institution that existed in name only at that point, under the authority of the country's Museum of Natural Sciences.

In the climate of austerity, MOBOT's move away from the forestry program needed the aid of private organizations with foreign financing. This was made possible in 1989 when the WWF and TNC engineered a "debt-for-nature" swap, allowing institutions to purchase chunks of the country's foreign debt at an eventual 86% discount. Debt-for-nature swaps involved purchasing foreign debt to build institutions for environmental protection within the debtor country (Sadler, 1990). MOBOT contributed to the agreement and, beginning in 1991, botanists operating as the National Herbarium were funded through this mechanism. Ecuadorian sucres were purchased on request by the Ecuadorian environmental NGO Fundación Natura and disbursed to the National Herbarium.[18]

The debt crisis and resultant austerity thus had two interacting effects. First, they cut back more traditional domestic programs of research and product development such as USAID had initially proposed to MOBOT in the mid-1980s. Second, inflation made it economically feasible to generate the technology of spatial prioritization needed by biodiversity conservation. The longstanding, but highly malleable practices of taxonomic systematics and biological fieldwork were reoriented away from programs of resource development and into conservation. While the Ecuadorian state attempted to keep environmental regulation to a minimum to position itself for debt renegotiations (Hey & Klak, 1999), petroleum companies took up biological techniques preemptively and a new way of governing Ecuadorian development emerged, initially outside of the state.

After leaving the forestry program, MOBOT's botanists no longer answered to the Ministry of Agriculture. For most of the 1990s, the National Herbarium was headed by a U.S. expatriate botanist, staffed primarily with Ecuadorian scientists, formally operated under the auspices of Ecuador's Museum of Natural Sciences, corresponded with MOBOT for steering its scientific efforts, and answered to the private Ecuadorian NGO Fundación Natura for budgetary purposes.[19] The most consistent oversight the Herbarium faced was the permitting process required for exporting specimens, leaving it largely free to serve as infrastructural support for biodiversity conservation in whatever manner was most expedient. The messiness of this arrangement should indicate both the weakness of the Ecuadorian state under austerity in the 1990s, and the severe analytical limitations of focusing on the national affiliation of institutions, rather than on the rationales and practices they deployed in such a context.

When Ecuador applied for World Bank funding for protected area management in the mid-1990s, one of the first requirements of the program was that a repository of geographically referenced biological information be constructed. The National Herbarium and the forestry institute served as the basis for this work, which provided the botanical data and technical support for a national vegetation map (INEFAN 1996). The outcome of the World Bank's program was the creation of the Ministry of the Environment in 1996, which then had authority over the country's protected areas. The forestry institute, which had previously held these responsibilities, was moved from its longstanding home in the Ministry of Agriculture and Livestock. Whereas protected area management had been a sub-department of Ecuador's forestry authority in the 1970s, the reverse became true in the mid-1990s. Moreover, by the time the Ministry of the Environment was formed, a highly active field of environmental organizations already existed with which it would interface, which provided financing for the country's protected areas, and which could describe and track the environmental impacts of the country's most important economic sector. While the creation of Ecuador's Ministry of the Environment in 1996 usefully marks a degree of public interest in biodiversity loss, it was enabled by the already-existing field of taxonomic government.[20]

Counter-intuitively, neoliberal reforms inadvertently contributed to the production of biodiversity in Ecuador. Scholars studying neoliberal reforms' impacts on natural resource management have emphasized the removal of state regulation and processes of commodification (Liverman & Vilas, 2006; Yates & Bakker, 2006). This scholarship has observed that neoliberal reforms have frequently privatized resources by "rolling back" existing state regulatory authority and "rolling out" state institutions designed to be dependent on the private sector (Peck & Tickell, 2002). These are obviously crucial aspects of neoliberalism. Yet, in Ecuador's case a narrow focus on commodification as these scholars conceive it, rather than reflexive processes of economization, would miss the emergence of a historically distinct relationship to resources at precisely the time when the state was most susceptible to reorientation (Ong & Collier, 2005). The "rolling out" of a Ministry of the Environment reliant on consultants, NGOs and bilateral aid had less to do with privatizing formerly publicly held resources than a reorientation of the state that resulted from linking it to a novel calculative apparatus.

Callon & Muniesa (2005) suggest that one way of thinking about political power is in terms of the asymmetry in calculative capacities between devices. A drastic asymmetry existed between the Ecuadorian state and the distributed qualifying apparatus predicated on biological practices described here. The latter was able to map the space of the territorial nation-state in biological terms, and even calculate the impacts of foreign oil companies. Setting aside preconceptions about the "decentralized" character of institutional arrangements that emerged from neoliberal reforms, the technology of spatial prioritization founded by the National Herbarium in fact appears highly centralized: it was premised on close coordination of agencies and their mandates through shared protocols, methods and personnel under a single fiscal authority. The centralized character of this apparatus was a function of the kind of political program it sought to enact, in which fine-grained biological information would eventually inform natural resource governance. An analysis of governmentality – a focus on the uptake of specific rationales (in particular, the spatial logic of resource-making) and practices (in particular, biological inventory and taxonomically-based systematics) – helps to clarify these political arrangements in a way that a focus on alliances and confrontations between institutions of different national origins, between state and civil society, or between different arms of the state, would not. The National Herbarium and its sibling institutions did not confront the Ecuadorian state as external entities, and neither were they situated neatly within it. They transected the state, provisioning it at different locations with biological data for which it had little regulatory use until 1996. The spatial distribution of biological resources became a conventionalized basis for environmental management as this apparatus became an increasingly relied-upon infrastructure of state regulation. Biodiversity was thus instituted.

Conclusion: Performing the "Little Science" of Biological Systematics

In describing the role of the accounting technique of double-entry bookkeeping in the rise of capitalism, Callon & Muniesa (2005) note that it did not simply solve a problem that was clearly outlined in advance. Rather, double-entry bookkeeping reconfigured how profits were conceived and calculated as it became institutionalized: "We could even say that [double-entry bookkeeping], simply by being there, available, proposes this calculation to the entrepreneur who accepts the invitation" (Callon & Muniesa, 2005: 17). A similar phenomenon occurred with the techniques and infrastructures that assembled taxonomic government from the mid-1980s to the mid-1990s. Botany was a particularly important discipline for this work because of its use in characterizing territory. The National Herbarium and its sibling institutions formed a distributed qualifying device able to link space and plant resources through biological systematics. Botanical practices were taken up and transformed in the oil field to produce petroleum sites as objects for floristic inventory, helping to define the terms in which state regulation would be enacted. Calculative capacities were repeatedly proposed, and the invitation to configure territory and plant resources through them was repeatedly accepted. Taxonomic government evolved as biologists' practices assumed a central role in territorial management and development planning in public institutions, NGOs, environmental consultancies and oil companies.

Studies of knowledge infrastructure routinely emphasize its coordinating function: knowledge infrastructure has, built into it, particular modes of interaction between communities of experts (Bowker, 1994; Star & Bowker, 2010). An analytic of governmentality, as deployed here, can shed light on the political ramifications of such infrastructure work by tracing the rationales and practices of experts across institutional boundaries as these cohere into enduring and powerful paradigms for the conduct of conduct (Foucault, 2007). Examined in this light, knowledge infrastructure work exhibits many of the problems of large-scale social coordination and the deployment of expert knowledge associated with modern political institutions. Biodiversity conservation arrived in Ecuador as a form of planned economic change predicated on the qualification of territory. Attending to the infrastructure work involved in instituting biodiversity shows how future biodiversity conservation was anticipated and staged (Star & Bowker, 2010) – not just the "conduct of conduct", but the "planning of planning". To the extent that biodiversity came to exist as a formally recognizable value in Ecuador, it did so because of the way that biologists' practices formed the foundation for a field of environmental work.

While the primary focus of this article has not been on the contemporary implications of taxonomic government, Yasuní National Park is once again informative in this regard. The National Herbarium's work on Amazonian floristics in the 1990s has allowed plant ecologists to link Yasuní to international ecological research (Losos & Leigh, 2004). Its embeddedness in these networks has resulted in greater international outcry from experts about the threats posed by development in previously unexploited portions of the park (Bass et al., 2010; Finer et al., 2009). The outcry, in turn, has prompted an increased level of scrutiny at the national level, making Yasuní the target of a huge number of environmental studies in anticipation of the infrastructure required to produce oil and move it to refineries. Thus, we can see the performativity of biodiversity infrastructure work (Bowker, 2000b): positing a region as biodiverse results in a spiral of increasing biological information about it. This cycle of knowledge production has been enabled and amplified by petroleum development. Yasuní has emerged as both a thoroughly exploited oil field, and a well-documented tropical rainforest valued for its biodiversity.

The contemporary environmental consulting industry in Ecuador manifests a less intuitive performative aspect of this history. Advocates for biodiversity, such as E. O. Wilson and Peter Raven, treated biological systematics as the base on which biodiversity conservation needed to be built in the 1990s. The "little science" was subsequently "infrastructured" for this purpose into a field of environmental actors, including the Ecuadorian state. The relatively prestigious work of international botanical exploration has moved on to areas of South America that are less "well-collected", as the National Herbarium's research resulted in the Ecuadorian Amazon being one of the best-studied parts of the watershed. Biological systematics has been reworked into a "gray science" (Rose et al., 2006) or "little tool" (Asdal, 2008b) most often used in environmental impact studies. The resulting apparatus makes it possible to qualify Yasuní's petroleum sites in terms of individuated biotic constituents. At the same time, while ecologists have played a highly visible role in environmental advocacy around Yasuní, a common complaint of environmental consultants is that ecological knowledge is not well-integrated into the environmental impact studies that govern oil development. The overwhelming historical focus on biological inventory in the country has made it difficult to trace connections between society and environment in the fashion typical of "biopolitics", or government of the systems that ensure the vitality of populations and individuals (Foucault, 2008; Olson, 2010). Hampered in their ability to draw these connections, contemporary environmental consulting studies of Yasuní could be considered "pre-biopolitical".

The present oil development in Yasuní has garnered attention partially because it highlights controversial changes in Ecuador's own environmental regulatory apparatus. In the last decade, the administration of President Rafael Correa has enacted restrictions on the foreign financing that previously supported environmental NGOs; scaled back public consultation in the development process; and maintained a hostile posture toward the field of environmental activism. In effect, these policies have dismantled portions of the apparatus described in this article. Scholars have asked what the "post-neoliberal" era (Yates & Bakker, 2013) means for rights and resources in Ecuador and Latin America, generally. The case of Yasuní shows that biodiversity cannot be blithely disregarded, but the conditions in which it will be governed continue to evolve. Whether these emergent arrangements are later deemed neoliberal, "post-neoliberal" or something else, understanding them will require carefully tracing the mutations of institutions and techniques that generate and respond to the problems of government.

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Notes

1 Eighty percent of the historical documentation examined during this article's writing, and all archival documents cited, come from the personal archive of David Neill. Approximately 15% of the documents examined come from the libraries of two environmental consultancies and the remaining 5% from the archives of the National Herbarium. These resources were augmented by interviews with 31 individuals dealing with the history of the National Herbarium, environmental consulting and botany in the country. This included individuals presently or previously affiliated with the National Herbarium, Missouri Botanical Garden, the Pontifical Catholic University in Quito, Aarhus University in Denmark, the Ministry of the Environment, and private consultancies.

2 Rapid informal settlement of Ecuador's "internal frontiers" was a result of radical inequality in land tenure (Hey & Klak, 1999). The practice was bolstered by the legal doctrine, shared by former Spanish colonies, of tierras baldías. This doctrine framed uncultivated, and especially forested land as economically unproductive (Guy & Sheridan, 1998). In Ecuador, legal title to land could be acquired by clearing it of forest to demonstrate the intention to use land productively. National policies encouraging settlement were seen as politically expedient alternatives to the sensitive task of redistributing the land holdings of the country's agricultural elites.

3 Taxonomic government, as defined here, is not best conceived as a form of what Foucault termed "biopower". Rabinow & Rose (2006) define biopower in terms of political rationalities and interventions centered upon the "vitality" of individuals and collectivities. For the thinkers and disciplines that Foucault studied, and those analyzed in the literature he has inspired, "vitality" has been understood to be a function of self-maintaining, reproducing, or teleological systems with different inflections across such disciplines as economics (Collier, 2011), ecology (Nading, 2012) or medicine (Klawiter, 2008). On the other hand, systematic biology is not primarily concerned with self-regulating systems; rather, it names objects and situates them in terms of evolutionary relatedness to other known and named

objects – a very different notion of "system". Ecology and population biology were integrated into the programs of NGOs working in the country in the late 1990s and 2000s, and played roles in community-level interventions focused on the reform of human-environment relationships. Importantly, taxonomic government as analyzed here was primarily focused on intervening upon formal organizations, rather than at the level of communities, in order to configure biodiversity as an actionable political problem. Its central features, biological inventory and taxonomic systematics, continue to be central in environmental consulting and state-level planning.

4 A distinction intended to parallel Weber's (1978) between substantive and formal rationality.

5 USAID memorandum to MOBOT regarding Flora of Ecuador grant extension, 12.3.1985.

6 Because of the historical reliance on foreign technical assistance in forestry and agronomy, many of their technical products (including specimens) ended up exclusively in foreign hands. This was one of the reasons that MOBOT needed to create a herbarium in Ecuador at the outset of its work.

7 Ecuador's existing forestry research had links to the U.S. tradition of conservation through the sustainable management of resources associated with the USDA and U.S. Forest Service (Miller, 2001). On the other hand, protected area planning borrowed directly from the U.S. National Park System (Spence, 2000). Each of these traditions was picked up and modified in the Ecuadorian context (e.g. Cuvi, 2005).

8 Ecuador's National Herbarium was formally created as a subsection of the Museum of Natural Sciences by the Danish botanist Lauritz Holm-Nielsen when he registered its acronym (QCNE) with the New York Botanical Garden's Index Herbariorum in 1977. However, the Herbarium existed only on paper until the period discussed here, when an agreement was reached to allow MOBOT field collectors to grow and manage its collection, again under the supervision of the Museum. The collaboration between Danish botanists based at the University of Aarhus, and botanists and the Pontifical Catholic University in Quito was the other major botanical program in the country at this time. Botanists from this collaboration also worked with the National Herbarium on some of its consulting work in the 1990s, as well as other projects.

9 Letter from Alwyn Gentry to Peter Raven concerning TNC program, 8.5.1986.

10 "Ecoregion" was a scale of planning used elsewhere in conservation during this period (e.g. Dinerstein et al., 1995).

11 A small subset of these remains available online at http://botany.si.edu/projects/cpd/samap.htm.

12 This initial contact was with a U.S. contractor working for the Corporación Estatal Petrolera Ecuatoriana, the state oil company that became Petroecuador in 1989, shortly thereafter.

13 Petroleum was the country's largest contributor to GDP and provided roughly half of all state revenue (CIA, 1998). Much like forestry, oil operations relied extensively on the technical support of foreign companies. The primary form of regulation for petroleum for much of the 20th century was risk-sharing agreements between the Ecuadorian state and foreign oil developers that were widely considered to be unfavorable to the country. This unregulated development resulted in a well-publicized international lawsuit, brought in 1993 against Texaco (later bought by Chevron) for its socially and environmentally destructive operating practices during the 1970s and 1980s (Kimmerling, 1990, 1995). The legacy of Texaco's work provided a highly public example of what "the worst of the worst" foreign petroleum operators were capable of, in the words of some consultants interviewed for this research.

14 While summarizing the National Herbarium's negotiations with Conoco in a memorandum to Peter Raven, David Neill wrote "[An environmental advisor at USAID] said that he tried to emphasize to the Conoco people that they could do something here that would be very beneficial and be of great propaganda value for the company, for a relatively low cost (much less than paying lawyers in a lawsuit 5-10 years from now), and evidently he convinced them" (memo concerning contract negotiations with

Conoco, 3.22.1988). Raven was also in contact with Conoco's environmental office in Houston, which he described as enthusiastically supportive of the consulting arrangement with the National Herbarium (memo from Peter Raven to David Neill concerning Conoco contract negotiations, 8.30.1988).

15 A "collection" is a group of specimens that come from the same individual plant and are identified by a single collection number. When an expert identifies a duplicate from a collection, the other specimens from that collection are effectively identified, as well. Individual specimens from the same collection can be shared between institutions, allowing different herbaria to have taxonomically identified specimens from the same plant.

16 David Neill, Botanical Inventory and Revegetation of the Maxus Pipeline Road, Petroleum Block 16, Amazonian Ecuador. Maxus service contract, 5.1.1994. Renner mentioned and explicitly omitted the National Herbarium's ongoing oilfield collecting from her calculations in 1993.

17 These changes roughly parallel the shifting roles of biology and ecology in the U.S. with the implementation of the National Environmental Protection Act in 1969, and the consequent rise of the environmental consulting industry there (Jay et al., 2007).

18 With the plummeting value of the sucre against the dollar in the 1990s, MOBOT enjoyed a roughly 6:1 return on an initial purchase of $50,000 worth of debt, financing much of the National Herbarium's herbarium activity from 1989 through roughly 1997 with an eventual equivalent of about $350,000 at 1989 exchange rates. These approximations are based on David Neill's recollections and an examination of partial records of the National Herbarium's budgets in the early 1990s. This was a small component of a larger USD3.5 million deal for developing the country's system of protected areas.

19 The Conservation Data Center was operated with a similarly complex arrangement, once again answering to Fundación Natura for financial accountability.

20 Another indication of the broad international interest in biodiversity was the Convention on Biological Diversity, of which Ecuador was a signatory in 1992.

Promises that Matter: Reconfiguring Ecology in the Ecotrons

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Abstract

Ecotrons are large instruments designed to produce experimentally valid knowledge through the controlled manipulation of enclosed, simplified ecosystems. Situating the ecotrons within a select genealogy of artificial biospheres, and drawing on interviews with key researchers engaged in the conception and recent construction of two ecotrons in France, we propose to think through ecotrons as promissory and anticipatory infrastructures that materialize a profound reconfiguration of ecologists' roles within wider civilizational narratives. Ecotrons encapsulate ecologists' ambitions to practice a 'hard' science, recognized by international environmental and science policy forums. They were integral to rise of the sub-discipline of functional ecology, which in turn underpins the policy discourse of 'ecosystem services'. Combining patterns of controlled experimentation with live simulations of future environmental conditions anticipated in climate change scenarios, the ecotron materialises a reorientation of the vocation of ecology: to secure the resilience of those 'ecosystem services' deemed critical to social life. Originally tasked with assessing the effects of biodiversity loss on the productivity and stability of the biosphere, ecotron research is increasingly focused on anthropogenic microbial ecosystems, and takes place within a terminology resolutely optimistic about the possibilities of micro-ecological engineering, to the exclusion of earlier concerns with mass extinction.

Keywords: ecotrons, functional ecology, infrastructure, biodiversity, anticipation, global warming, ecosystem services

> It is too late to dream ourselves back to a place under celestial domes whose interiors would permit domestic feelings of order… - Peter Slotjerdijk [1]

Ecologists have long struggled to affirm the scientific status and practical relevance of their discipline. Today, the imperative to meet the challenges of societies' vulnerability to anthropogenic global change opens up new opportunities for ecologists to re-affirm the vital contribution of their discipline, which increasingly departs from norms of biodiversity conservation and nature protection to stress human well-being, development and survival in a warming world. The science and technology studies literature on anticipation in the life sciences has tended to focus upon biomedicine, nanotechnologies and synthetic biology. We suggest that closer attention to ecology is warranted. Manifest in its contemporary shift to the analysis of the minimum species composition of functioning ecosystems, we argue, is a reconfiguration of ecology into an anticipatory technoscience of civilizational security.

In this article we document this re-orientation of ecology's scientific and social missions through an analysis of recently-built research infrastructures called 'ecotrons'. Ecotrons are shared experimental facilities for research on the functional properties of ecosystems, designed to allow repeatable experimentation and hypothesis-testing in closed, artificial ecosystems where biological and environmental variables are subject to precise measurement, manipulation and control. We consider ecotrons as sites for the elaboration and re-alignment of narratives of justification, embodying promises that matter regarding the scientific status and social role of ecology. Ecological infrastructures and futures are co-produced in the same movement.

Two ecotrons have recently been built in France. One is located at Foljuif, near Paris, and there is another at Montpellier, associated with the Center for Evolutionary and Functional Ecology (CEFE). According to its website, the Montpellier ecotron "bridges the gap between the complexity of *in natura* studies and the simplicity of laboratory experiments". The word "ecotron" references the research machinery of the heroic age of experimental high-energy physics, the cyclotrons and 'atom smashers' of the 1930s and 1940s. The parallel is more than nominal. Ecotrons are the first ecological facilities sponsored by the Très Grandes Infrastructures de Recherche (TGIR) unit of the National Centre for Scientific Research (CNRS), which operates the 'very large research infrastructures' traditionally associated with subatomic and cosmological physics, such as synchrotrons, particle accelerators, and radio telescopes.

Our analysis develops a selective genealogy of the ecotron, tracing under-acknowledged influences that amount to a mutually constitutive history of 'functional' systems ecology and its experimental research infrastructures. We bring this history to bear on in-depth interviews conducted between 2009 and 2010, during the construction phase of the French ecotrons, when their potential impact on the discipline of ecology was a matter of anticipation as the first research projects were underway in the completed modules.[2] We interviewed the designer and senior scientific manager of the Montpellier ecotron, as well as established researchers from laboratories in the cognate fields of systems ecology, plant physiology and microbial ecology.[3] Most were enthusiastic about the new infrastructures and planned to utilise them in future research, although one ecologist, a forest specialist, was sceptical of claims that ecotrons would yield major advances. We have also drawn on institutional websites, and scientific literature presenting the results of ecotron-based research. Finally our results benefited from exchanges with ecologists who attended a restitution seminar where early versions of this research were presented.[4]

I: State of the Art

Our approach to ecotrons as promissory and anticipatory infrastructures draws upon recent work in the sociology of science and technology (STS), the history and philosophy of ecology, and critical security studies. Far from being given, taken for granted facilities, for STS scholars, research infrastructures represent collective achievements arising from specific political and historical contexts (Star & Ruhleder, 1996). Assembling the machinery of knowledge production in itself requires significant research collaboration and coordination (Star & Grisemer, 1989; Bowker & Star, 1999; Edwards, 2010). Recent studies have focused on the backstage 'memory practices' of computer-driven data curation, including those of the Long-Term Ecological Research Network (LTER). Established in 1980, the LTER has since worked to standardise long-period, site-based datasets across a wide range of representative 'natural biomes' or ecosystem types in order to enable analyses of environmental change over time (Bowker, 2005; Zimmerman & Nardi, 2010; Baker & Millerand, 2010; Mauz et al., 2012). Here, we document a front-of-stage 'Big Ecology' research infrastructure, characterised by its orientation to the future.

We propose to think through the French ecotrons as at once anticipatory and promissory infrastructures. Designed to enhance the epistemic status of ecology as a predictive science, ecotrons promise to secure recognition of the validity and importance of functional ecology from other scientific disciplines engaged in the anticipation of global environmental change (and crucially, from science funders and transnational environmental policy fora). Studies of scientific promise have emphasized the role of promissory rhetoric and scientific visions in attracting investment, audiences, and moral commitments to particular scientific agendas. A predominant focus of this literature has been to technology-driven fields with potential for commercialization, such as biomedicine, nanotechnology and synthetic biology (Brown, 2003; Brown et al., 2003; Frow, 2013). Given what is at stake for 'the emerging bioeconomy' in projections linking ocean acidification and global warming to mass extinctions (Walker, 2016), surprisingly little attention has been paid to the promissory and anticipatory practices of ecologists.

For their proponents, ecotrons promise to federate a multi-national community of ecologists around shared research agendas, agendas which appear closely aligned to policy narratives emerging from recent reconfigurations of the knowledge politics of global environmental change. The influential Millennium Ecosystem Assessment (2005) contributed to a recalibration of ecological research within the policy idiom of "ecosystem services", which anthropocentrically re-defines ecosystem functions as economic services rendered to societies, including food production and water purification (linked to pollination and hydrological cycling), or climate regulation (linked to CO2 absorption by forests and microorganisms). The discursive success of 'ecosystem services' has met with critical scrutiny. The project to establish private property rights in remnant ecosystems, and financial markets trading in the 'services' they provide has been critiqued as the imposition of a 'neoliberal nature' from the commanding heights of global economic power (eg. Sullivan, 2013). The ways in which ecologists have actively sought to re-present themselves as hard-nosed realists capable of risk-managing capital investments in securitized 'ecological infrastructures' has received less attention.

Early studies of scientific promise emphasized the importance of politico-scientific leaders and their speech acts (van Lente & Rip, 1998). Akrich (1992) insisted that technical artifacts tell stories, insofar as they are embedded with "scripts", which teach users how to interact with them. Borup et al. (2006) and Millerand et al. (2013) emphasize the role played by material objects and infrastructures in shaping and stabilizing scientists' promises. Philosophers concerned with the cultural dimensions of extinction attribute story-telling capacities to a variety of organisms, arguing that "narrative is a quality of the lives of many (probably most) nonhuman animals" (van Dooren & Rose, 2012: 4). Research infrastructures encode narratives about the value and relevance of the research they enable. Ecotrons, then, may be important sites for the negotiation of broader civilizational values and narratives of our place in the living world.

Ecotrons are costly research infrastructures, necessarily embedded in claims upon resources, and competition for allies and audiences. The initial decision to fund the construction of the ecotrons was resented by landscape-scale ecologists, whose research on *in situ* communities involves large trees and animals, which can only be excluded from the controlled interiors of the ecotron.[5] Our interest here is less in grant politics than in how research priorities "become infrastructures", how once built, they shape future research agendas and policy debates, privileging some research orientations and excluding others (Frickel et al., 2010). We are particularly interested in how the architects and operators of the French ecotrons locate them within a narrative of human vulnerability and resilience to environmental change, establishing professional distance from popular associations of 'ecology' with the defence of biodiversity from destructive economic activity. If there is a tacit social contract emerging, one which re-frames ecologists as expert analysts and managers of the critical ecosystem functions and services needed for 'human well-being', it will be embedded not only in speech acts but in the material configurations of the 'infrastructuring environment'.

II: A Genealogy of the Ecotron

The recently built French ecotrons did not emerge from a vacuum. A full genealogy of the ecotron, which we can only indicate here, would trace a number of intersecting histories: of greenhouses constructed for colonial botanical collections, of the aquaria and terraria of *in vitro* biology, of technologies of climate control and simulation, of the regenerative life-support systems envisioned for long-term space travel and other prostheses. Let us at least suggest that ecotrons hybridize a long lineage of infrastructures that maintain collections of organisms in closed systems, insulated from local conditions and disturbances. We would contend that the lineage of enclosure experiments in constructed, artificial, climate-controlled biospheres is more closely interwoven with the history of ecology than has thus far been recognized.

Ecologists have long aspired to claim the status of a confirmed science of critical relevance to society. Often, they have felt vulnerable to criticisms that ecology was doomed to remain a 'soft science'. The messy contingency, variability, and vast complexity of biotic interactions encountered in the field suggested that ecologists would never be able articulate general 'laws' of ecology through the statistical methods of controlled experimental validation deployed in the laboratory sciences (Martin, 2015). As Schultz (1956) once put it:

> Plant physiologists who are bequeathed with unlimited funds have elaborated laboratories and greenhouses where nearly every essential feature of the environment can be controlled. Thus, an experiment can be reduced to only one variable such as growth. With complete control over all factors, there should, theoretically, be no unexplained error encountered in the experimentation. [...] Ecologists have two strikes against them—they never are bequeathed with unlimited funds and if they were, they would fall short in controlling most factors of the outdoor environment, as the rainmakers can attest. So their research is redolent with what is called experimental error.

Let us then trace our infrastructural genealogy of the ecotron from the 'Phytotron', built in 1949 by the plant physiologist Frits W. Went at Caltech, Pasadena. Billed as a "fabulous weather factory", the phytotron was designed to study plant growth and acclimatisation, enabling the reproduction of all possible climatic conditions, whether simulating actually existing regional climates from data gathered in other lands, or testing purely experimental, artificial conditions. Light, temperature, humidity, gas content of the air, wind, rain and fog could be held constant or made to oscillate as programmed. Went not only claimed that the scientific questions to be pursued in the phytotron were as complex and important as those pursued by nuclear physicists in cyclotrons, but also that the "methods developed in the phytotron for analyzing the complex interrelations between organisms and their environment" would prove "helpful in an analysis and better understanding of our social and economic system" (Went, 1949: 6).

Whilst not ordinarily included in histories of ecology, the phytotron is emblematic of the mid-20th century shift of ecology away from vitalism and the study of biotic communities via organicist metaphors (the "super-organism" of Frederic Clements (1916) for example), towards systems ecology, with its focus on the flows and exchanges of matter and energy between living beings and their abiotic environment, in analogy with a 'cybernetic machine' (Margalef, 1968; Odum, 2000 [1977]). First proposed by the Oxford ecologist Arthur Tansley (1935), the rise of the ecosystem concept and its significance for the constitution of ecology as a discipline has been well-documented by historians (Worster, 1994 [1977]; Golley, 1993; Kingsland, 2005). In a context where ecologists sought to affirm the status of their research, and to transcend a heritage in the field studies of amateur natural history, by the latter 20th century the systems approach had become the cornerstone of ecology's claim not only to scientific authority but also to social and political relevance. Documenting the biogeochemical flows of nutrients and energy through 'systems' abstracted from particular organisms enabled ecologists "to go beyond general conceptions of ecological processes by adding exact measurements, experiments and tests of hypotheses" (Kingsland, 2005: 178). This approach also enabled ecologists to analyse the effects of human activities on ecological processes from the local to the global scale. In an exemplary paper, Evelyn Hutchinson (1948) estimated the global carbon budget of the biosphere, offering one of the earliest quantifications of the alteration of the carbon cycle by the industrial combustion of fossil fuels. Analysis was no longer constrained by the need to construct a pure Nature external to social relations. The stage was set for ecology to become the 'subversive science' of modern environmentalism.

Eugene P. Odum's seminal textbook *Fundamentals of Ecology* played a major role in establishing the functional whole of the ecosystem as the central concept of ecology (Odum, 1971 [1953]). While E.P. Odum can be credited with a major role in the professionalization of ecosystems approach among scientists, it was his brother Howard Tom Odum, with his pioneering big-picture work in whole-system energetics and his idiosyncratic attempts to communicate the importance of this work in his *Environment, Power and Society* (1971) that brought systems ecology a wide lay audience among those concerned with the global crises of energy and environment (Coleman, 2010: 10-11). Both brothers were influenced by Lotka's effort to mathematize 'physical biology' (Lotka, 1956 [1925]), Lindeman's seminal work on measuring energy flow through the trophic hierarchy (Lindeman, 1942), and their teacher Evelyn Hutchinson's engagement with cybernetics. The difference between them, according to the historian Sharon Kingsland, was that "Eugene thought of the ecosystem in organic terms as though it were an organism in a state of homeostasis, Tom deviated from this organic analogy and increasingly thought of the ecosystem as a machine governed by feedback mechanisms" (Kingsland, 2005: 195).

Systems ecology has been criticized as a machine theory of nature, *with a reductionist* tendency to focus on quantifiable energy flows.[6] As Voigt notes, "the main concern is with the material-energetic aspects of interactions; the actual species involved are only of interest insofar as their specific features are relevant to the transformation of matter and energy" (Voigt, 2011: 189). The metaphors, practices and infrastructures of systems ecology as Big Science have been investigated by Kwa (1987; 1993); others have analysed the experimental manipulation of watersheds and the measurement of energy and nutrient flows in the Hubbard Brook Ecosystem study (Hagen, 1992; Bocking, 1997, 2010). Dealing with large, open, unbounded ecosystems, such research programs remained vulnerable to the criticism that in reality, the 'systems' under analysis were far too complex and non-linear to be modelled accurately through the reductionism of the systems approach. We would suggest that nothing exemplifies a cyborg theory of nature better than an infrastructure engineered to put its analytical agenda into effect: what is an ecotron if not the materialization of the ecosystem concept itself? Conceived by functional ecologists to make valid causal claims about ecological processes independent of social values and human presence, there is some irony in that this is to be achieved by constructing an artificially minimalist Nature fully *internal* to the social relations fixed in the plastic, steel, concrete and data-generating systems of an elaborate technoscience infrastructure.

No genealogy of the ecotron could fail to mention the spectacularly ambitious Biosphere II facility. Built privately by Space Biosphere Ventures between 1987 and 1991 in the Arizona desert, without official research funding or supervision, its designers drew on prior experiments in the Soviet space program such as BIOS-3 (Gitelson et al., 2003: 231-309). BIOS-3 was in turn inspired by the Russian cosmist tradition of ecology initiated by Vladimir Vernadsky's *The Biosphere* (1926), a work until then relatively unknown in the West. Modelled on Biosphere I (the Earth), an energetically open but materially closed complex ecosystem, Biosphere II was designed as a self-regenerating ecological life support system capable of maintaining an atmosphere and enough food for the eight 'bionauts' who were to be locked inside for two years. Covering more than one hectare with rain forest, coral reef, desert, savannah and farm biomes, it was one of the most airtight structures ever attempted, aiming to leak air at only half the rate of the Space Shuttle. This sealed boundary was its defining structural feature: an attempt to make the 'Earth system' upon which it was built completely exterior to its artificial interior and the select organisms enclosed in this late modern

Noah's Ark. Biosphere II experienced a number of revealing problems: technical, socio-political, and biological. One was enormous energy consumption, a counter to poorly anticipated 'greenhouse effects'. In order to smooth out volatile extremes of temperature and air pressure which threatened to crack open the dome, or dessicate the plants, huge air-conditioners were retrofitted, which consumed three-times more fossil energy than the solar energy absorbed by the sphere. From an engineering point-of-view, the most difficult problems were related to the capacity of complex eco-systems for unanticipated emergence.[7] 'Equilibrium' failed to emerge and set in. Carbon dioxide levels rose and oxygen levels fell to debilitating levels, and the stress on the crew resulted in a social polarization into factions who by the end of the enclosure scarcely spoke to one another. Systems ecologists interpreted the successes and failures of Biosphere II as important lessons for planetary civilisation, spurs for the necessary advancement of ecological engineering (Marino & Odum, 1999).

Biosphere II was refitted in the early 2000s as an experimental platform for research on ecosystem functions under the leadership of Barry Osmond (2005), a colleague of Frits Went and researcher at the Canberra Phytotron. Osmond has since advised researchers in Japan and Sweden on concepts for Biosphere 3 and Boreosphere, a new generation of ecosystem research facilities. By contrast, the Ecotrons appear much more modest in scale and in futurist optimism – although the chief investigator of the Montpellier ecotron mentioned exobiology, the science of life outside Earth, as a potential objective for a "future second generation of ecotrons".

The first research infrastructure to bear the name "Ecotron" was designed in the late 1980s at Imperial College in London under the stewardship of a small group of highly influential ecologists sometimes called the "Silwood mafia", who played an important role in emphasizing the role of mathematically sound statistical analysis of manipulative experiments (Gay, 2013). The first research project undertaken in the London ecotron was a response to the concerns of a 1991 conference on 'Biodiversity and Ecosystem Functions', convened in Bayreuth (Germany) to remedy an almost complete lack of knowledge about the way that biological diversity and its accelerating loss might affect the global Earth-system exchanges of biomass and energy studied in the International Geosphere-Biosphere Programme (1987-2015). These experiments were foundational to the growing sub-discipline of biodiversity and ecosystem function research (BEF research, or 'functional ecology'), an approach which aims to rigorously apply the physico-chemical functionalism of systems ecology down to the level of the intricate, taxonomically specific phenomena studied by population, community and evolutionary ecologists (Schulze & Mooney, 1994).

The first research carried out in the London ecotron is known as the biodiversity-functions experiment: it aimed to test the influence of the diversity of species on the functioning of ecosystems (Naeem et al., 1995). Here the aim was to bring new support to the notion that the 'balance of nature' (the sustained equilibrium reached by the successional climax community, to use older terms) is dependent on biodiversity, that the most diverse communities of organisms are also the most stable and productive. John Lawton, a leader of the Silwood Park Ecotron, defended the value of experimental ecology in controlled artificial systems, arguing that "if we cannot understand simplified ecosystems such as those in the Ecotrons, we are unlikely to understand very complex ones" (Lawton, 2001: 178; see also Lawton, 1996; Resetaritts & Bernardo, 1998). Results were published claiming to prove that less diverse systems were demonstrably less productive and less stable, but the experiments were strongly criticized for experimental biases (Hodgson et al., 1998; Wardle et al., 2000; Naeem, 2000). Detractors argued that the experiment brought no new evidence regarding the effect of species diversity: they argued that the experimental results rather reflected a change in the functional diversity of plants (i.e. the selection of species more or less productive of biomass) rather than the change in the taxonomic diversity of species. After this controversy, experiments in the ecotron focused increasingly on the functional side of the biodiversity-ecosystem functions problematic. Moving from biodiversity (as species richness) to functional diversity, ecologists increasingly focused on "functional traits", that is, the measurable characteristics of organisms that directly contribute to ecosystem functions (for example, capacity for nitrogen or carbon fixation, water uptake, nutrient requirements, resistance to chemical pollution, seed dispersal, trophic efficiency and light requirements, leaf morphology, growth rate, reproductive rate, and so on).[8]

The French Ecotrons descend directly from the Phytotron at Caltech, via the person of Frode Eckardt, the Montpellier eco-physiologist who worked in Went's laboratory in the late 1950s. As a principal investigator at the Centre d'Etudes Phytosociologiques et Ecologiques (CEPE, established in 1961), in 1963 Eckardt submitted the first proposal for an ecotron to Montpellier University, to study the ecophysiology of plants and ecosystem/atmosphere gas exchange (and not plant development, as in most phytotrons at that time). The proposal was rejected, perhaps influenced by the fact that CEPE was home to the Zurich-Montpellier school of communitarian vegetation studies, which took Braun-Blanquet's *Plant Sociology* (1932 [1928]) and its floristic classification of plant associations as the paradigmatic text. Many community ecologists were sceptical of the equilibrium systems ecology of the Odum brothers (Nicholson, 2013), and the French tradition of ecology, rooted in regional schools of botanical geography (Matagne, 2011), shared little common intellectual history with the Cold War meta-science of cybernetics then ascendant in the United States. Nevertheless, Eckardt went on to become an international figure, working with physicists, engineers and atmospheric chemists to pioneer the development of climate-controlled chambers and micro-meteorological techniques for ecophysiology, developing techniques for extrapolating local-scale quantifications of 'biomass productivity' (e.g. the efficiency of photosynthesis in converting solar energy, water and carbon-dioxide into biomass) up to the level of the 'terrestrial productivity' studied by his fellow researchers in the International Biosphere Program of the 1960s (Eckardt, 1968; Saugier et al., 2001). In 1988, the research focus of CEPE was reoriented toward international trends, as reflected in the change of name to the Centre d'Ecologie Fonctionnelle et Evolutive (CEFE). The execution of the current Ecotron was carried forward by Jacques Roy, who studied under Eckardt.

Today, large controlled chambers for the measurement of gas exchanges between plants and the environment exist in most major universities and agronomic institutes: for example New Zealand's Biotron, the Bioklima project in Norway, the ecotron projects in Germany and in Belgium. Many more ecotron-like facilities are in progress.[9] Phytotrons, designed for plant physiology, differ from ecotrons in that the latter are interested in theorising inter-species interaction, and may thus include insects and small animals, although increasingly ecotron experiments focus on microbial communities. While all the ecotron-like facilities are designed to condition and measure gas exchanges between plants and the environment in experimental enclosures, the latest facilities offer more sophisticated technologies of environmental control, enabling the precise programming of CO2 concentrations in water and air, precise measurements of evapotranspiration in plants, and the tracing of biophysical exchanges between plants and soil microbiota through proteomic technologies.

Funding for the French ecotrons was awarded by the National Center for Scientific Research (CNRS) immediately prior to the establishment of a CNRS division dedicated exclusively to ecology and environmental science. Until then, ecology had been part of bigger departments devoted to the life sciences. The inauguration of the ecotrons was contemporaneous with the re-foundation of the French Society for Ecology, and with *Ecology 2010,* a major international conference hosted in Montpellier by ecotron director Jacques Roy. On their websites, the ecotrons are presented as cutting-edge research facilities for systems ecology, boasting a suite of technical advantages in order to attract top-ranked French and international research teams.[10] The ecotrons thus materialize a relative re-balancing of resources and funds in favour of ecology within French science policy, by institutions that have long been reluctant to recognize a discipline tainted by association with environmental activism and suspected of limited potential for scientific prestige.

III: An Infrastructure of Promise

The genealogy of the ecotron we have thus far sketched can be read both as an outline for critical research in (bio)infrastructure studies, and as an interpretive historical framework giving context to the recent ascendance of functional ecology. With both theoretical agendas in mind, we now discuss in more detail the material patterns of the French ecotrons and the research agenda they encapsulate. Three major narrative themes emerged from our fieldwork, suggesting how the recently built French ecotrons encrypt a particular promise of relevance, authority and importance for ecology.

III. 1- Ecology as a "Hard" Science

The Foljuif and Montpellier ecotrons cover several hectares at their respective locations in Northern and Mediterranean France. Their major architectural feature is the hierarchical division of the buildings into two interlocking but separate interiors: the first being the precisely engineered boundary or 'membrane' containing and enclosing the series of 'ecosystems', with their atmospheres, water circulation systems, plants, soils and micro-fauna (the Foljuif ecotron specializes in the simulation of aquatic biomes); and the second, the maintenance rooms and laboratories, where scientists and engineers maintain the circulatory systems which condition environmental parameters and the information systems which sense and record ecosystem processes, functions and adaptive responses to these settings. The maintenance and measurement rooms are generally located below or behind the 'ecosystem'. Experimental units are distinguished into three classes by the size of the chambers: microcosms, mesocosms and macrocosms. We focus here on those designated as 'macrocosms', noting that this term is applied with somewhat less grandeur than in the Biosphere 2 facility (in terms of both species diversity and the intention to function as a long term sealed life support system for a human community). The macrocosms of the French Ecotrons are enclosed in hemispheric domes of transparent plastic film with a 2 metre radius, atop cylindrical containers allowing a soil depth of up to 2 m. They can contain up to 8 tons of 'ecosystem' (see Fig 1 and 2).

As was explained to us by an ecologist who has followed the ecotrons since their construction phase as a PhD student at Montpellier, the critical material characteristic of the ecotron, and its advantage to ecological research, is "*that you can consider your system as a closed system: you can measure what goes in and out*". The reference to physics as the experimental gold standard for ecology has been inherent in the term 'ecosystem'

Figure 1. The ecotron in Montpellier showing part of the series of mesocosm domes. Source: www.ecotron.cnrs.fr (accessed: 23.8.2016)

Figure 2. Interior of an ecotron mesocosm chamber showing equipment for controlling the circulation of atmospheric gases and humidity. Source: www.ecotron.cnrs.fr (accessed: 23.8.2016)

since it was first proposed by Tansley. Whereas the 'ecosystem' has tended to function as an analytical construct for ecologists faced with the incredible complexity of open ecological communities never completely separable from the whole Earth's biosphere, the ecotron promises the technical materialization of a bounded 'system' which is 'closed' in the sense of thermodynamics (e.g. energetically open to solar radiation and heat transfer, closed to material inputs and outputs). This promises the possibility of measuring elemental fluxes between the living and non-living parts of the ecosystem, as well as inter-species interactions, without external disturbance. Experiments in the ecotrons are hermetically isolated by the plastic dome from 'contamination' by the outside atmosphere and animals, avoiding the possibility that (say) birds and insects might introducing nitrogen *via* faeces - an issue encountered in the case of outdoor experimental devices such as flux towers which also aim to alter and measure greenhouse gas exchanges between plants and the air.[11]

Experimental control clearly contributes to ecologists' hope to move ecology up the hierarchy of disciplines, by 'grounding' it in chemistry, physics and finally mathematical equations. A young professor of ecology specializing in interactions between plants, insects and soils explained her enthusiasm for the Foljuif facility in these terms:

> "Ecotrons are about really achieving a highly refined approach by manipulating very precisely each ecosystem parameter, especially each parameter of the biodiversity, each parameter of the interaction networks, in order to look at what happens - other things being equal. Such experimental conditions are really close to what we have in big infrastructures in physics or in chemistry: it is hard science with a capital H."

Ecotrons' isolation from outside weather is a precondition of their ability to make their own weather: they can modulate (or simulate) sunlight intensity and periodicity, automate artificial 'seasons', they can pre-program patterns of temperature, wind, humidity, precipitation, soil moisture and concentrations of CO2 and methane. Experiments can be run for up to three years. Software which sets the parameters and allows the automation of experimental design also automatically quality checks and manages the data logged several times per hour by instruments such as quantum sensors and spectrometers for measuring light, and anemometers for sensing wind. Other instruments measure leaf gas exchange and chlorophyll fluorescence, stomatal conductance, and fluxes of methane and carbon-dioxide between soil, atmosphere and canopy.

An ecologist studying plant physiology in Montpellier expected that the ecotrons would make it possible to achieve detailed and robust knowledge of the ecological processes likely to back up *in situ* observations: "[*my research includes] a long-term and* in situ *part, and then a part of experimental control in the ecotron in order to understand which processes are at stake*".

Ecotrons do not necessarily convert ecology into an *in vitro* lab-science: instead they offer to buttress *in natura* ecosystem research through isolating and testing potentially fundamental ecological interaction mechanisms *ceteris paribus* through multi-factorial analysis. The identical series of experimental units in the ecotrons incorporates the statistical standards of the highest-ranked ecological journals, making it possible to run at least 12 replications of the same manipulation simultaneously. The importance of statistical replication for scientific recognition of results is emphasized in the ecotrons' institutional websites: there are 12 macrocosms in Montpellier and 18 units in Foljuif (with a further 24 mesocosms approaching completion in Montpellier at the time of writing).

III. 2 - Ecology as an Anticipatory Science of Crisis Adaptation

If ecologists' aspirations to ground their science in the methods and revealed laws of physics are not new, the French ecotron infrastructure suggests the reconfiguration of ecology into an anticipatory policy science, linked to climate science and its scenario modelling. Whilst not predictive in the strict sense, ecotrons make possible the enactment of currently non-existing climates, those of past geological eras when particular species appeared, or most often, the anthropogenic climates of the future. The last experiment carried out in the Silwood Park ecotron, entitled "Sealing Carbon and Life in Ecotrons" pointed to the future of ecotron research. For the chief scientist of the Montpellier ecotron, the infrastructure's significant design feature is "*the possibility of simulating the environmental conditions of the future*" and addressing "*new questions of prediction of ecosystem and biodiversity functioning*" in the context of climate change. There is a shared conviction amongst the ecologists we interviewed that *"biodiversity's future is climate change"* (to quote the director of the French Foundation for Research on Biodiversity).

Clearly articulated on the website of the Montpellier ecotron is its mission of "preserving and improving ecosystem services and securing food supply". Running simulations of the scenario projections of the Intergovernmental Panel on Climate Change (IPCC), the first experiment carried out in Montpellier studied the impact of heatwaves and drought on grasslands, represented by turf samples that had been extracted from pastures in central France, previously treated and monitored *in situ*. A key-objective of this experiment was to anticipate and prepare for changes in grazing and farming practices. Several experiments conducted since have been directed to the physiological response of wine grape varieties to elevated temperatures and extreme events. Experimental simulations of climate scenarios suggest the possibility of forecasting the parameters of ecosystem's functional resilience, helping societies – or at least the valuable agricultural sectors of privileged societies - to pre-emptively adapt to global change.

Plant physiology and growth are at the core of a number of experimental scenarios brought to life in the ecotrons. Several ecotron experiments aimed to study how climate scenarios might impact plants' physiological mechanisms such as photosynthesis, evapotranspiration and growth. These functional traits are analysed down to "the level of the leaf", to quote a summary of an on-going Montpellier experiment. Of course ecologists are fully aware that ecosystem functions depend on more complex assemblages of species, and there are also experiments endeavouring to understand how climate change may impact communities including snails and insects. Yet, by design, the size of ecotrons excludes the study of complex communities composed of large plants and animals, not to mention humans. Rather, the focus on the adaptive capacity of plant physiology anticipates a generalised vulnerability, seeking to understand the capacity for resilience of ecosystem functions in the extreme environments transposed from the future of the climate scenario into the experimental present. This focus on 'reliability engineering' is predicated on a systemic indifference to questions of biodiversity conservation. According to one interviewee, a community ecologist skeptical of the grandiose project of the Montpellier ecotron, "*it was strongly pushed forward by some people in the lab who were ecophysiologists*", to the exclusion of other priorities that may be deemed ethically important: "*obviously ecotrons were made not to work on extinction, but on ecosystems*".

Experimental scenarios in the ecotrons reflect the narrative that "services provided by ecosystems are under threat."[12] Ecology's promissory contract now involves anticipating the effects of global change on critical ecosystem functions and services. The concern of the original Silwood Park experiments, to test intuitive propositions that biodiversity preservation was necessary to maintain ecological stability and abundance, has faded away. The minimalist ecosystems assembled inside the ecotrons are enlisted in the project of identifying the minimal biosphere necessary to retain the agro-infrastructures that secure "human well-being".[13] As such, contemporary ecotron research side-steps deeply political questions about the possibility of prevention in favour of the necessity of adaptation. Ecologists thus risk naturalising as inevitable a choice, amongst many future worlds arguably yet still possible, of one in which multispecies abundance has been deemed safely surplus to the operational requirements of critical infrastructure systems, be they biological or industrial.[14]

III. 3 - Ecology as (Micro)Ecological Engineering Science

The experimental architecture of the ecotron enables the exploration of the properties of microbial communities, such as soil microbes which interact with plant roots, or water-dwelling phytoplankton. Most microorganisms cannot be studied in laboratory conditions, usually their identification must be carried out outdoors. Ecotrons are large enough that researchers can examine specific quantities of soil or water and identify the functional and evolutionary capacities of microbial communities using proteomic technologies.[15] The incorporation of sophisticated lysimeters in the ecotron monitoring room enhances understanding of the properties and potentialities of soil biodiversity. Lysimeters are devices which measure the transport of water between organisms and their environment; such as the interaction between transpiration (water flows through living plants), and the evaporation of water from soil and water bodies. As one eco-physiologist explained to us: "*the subterranean part of ecosystems, in the Montpellier ecotron at least, was specifically designed, [..] to make it possible to work on the subterranean part*". Unlike Biosphere II and the Silwood Park ecotron, both criticized for not paying enough attention to soil microbiology, the French ecotrons aim to open "*the extraordinary black box*" (in the words of the same informant) of microbial diversity in soils.

The lead researcher of a soil ecology laboratory explained that the ecotron was the ideal platform for developing applied micro-ecological engineering. For him, ecology should be about "*manipulating and tinkering with organisms in order to obtain a certain effect*", for instance (to give proffered examples) designing green areas with enhanced capacities to absorb gases, or modifying the properties of the soil under urban roads so as to increase the absorption of CO_2 released by cars. For this scientist, the ecotron offered opportunities for ecologists to lose their 'subversive' counter-cultural image, and through mastery of the biogeochemical potentials of microbial life, to achieve a scientific prestige and industrial utility equivalent to molecular biology:

> "*Ecological engineering is a great opportunity for ecology, as medicine is for physiology or energy for physics: [ecologists have shifted] from birds to corridors and now the role of living beings in heat exchanges: it is not hippie-like engineering, it is about biotechnology*".

Ecotrons also offer advantages to ecotoxicologists. Chemically polluted ecosystems are next to impossible to analyse *in situ*. Due to the large number of synthetic chemical species diffused throughout the environment, which may be latent or bioactive well below detection limits, alone or in combination with other residues, it is very difficult to isolate causal pathways of toxicity through biotic communities. The costs of combinatory toxicology studies are prohibitive, accurate long term monitoring and ecological data sets are rare, and in situ experiments would require polluting relatively pristine sites. Ecotrons make it possible to reduce the daunting complexity faced by ecotoxicologists, the better to understand how particular microorganisms might decrease pollutant levels or neutralise their impacts (bio-remediation). The use of advanced proteomics and lysimeters promises to profoundly increase knowledge of the microbial foundations of the biosphere, knowledge that may be applied to optimise ecosystem functions and 'services', thereby reconfiguring ecology from a science of moral prophecy to one of pragmatic, piecemeal engineering.

There is an important affective dimension associated with the prospect of exploring the little-known microcosmos inside the ecotrons, an optimism far removed from the disheartening scenarios of depletion, endangerment and extinction that characterise the visible macrocosm of plants and animals studied by field ecologists. As one microbial ecologist explained,

> *"You can speak of extinction when you speak of iconic species, but for microbiology it's not the case at all: we are at the beginning of an exploration step and not really of an extinction step; there is an explosion of possibilities, not the contrary".*

Another interviewee spoke of the "*Terra Incognita of biodiversity (….) on which the whole of life on Earth depends*". Lost is the earlier vocation of the Silwood ecotron in demonstrating biodiversity loss and habitat destruction as a threat to life as a whole, found is the "*outstanding diversity*" of potentials disclosed by microorganisms' metabolic role in global biogeochemical cycling and in the evolutionary history and trajectory of the biosphere. The fact that microorganisms play a major role in the Earth system is critical to ecotrons' claim to analyse anthropogenic changes to planetary processes unfolding in geological time on the basis of miniature experimental ecosystems comprising only a couple of pot plants in an intensively instrumented bubble (see Fig 3). Such are the problems of extrapolation facing *in vitro* ecologists, who to borrow a line from Peterson & Hastings (2001), are in the business of 'designing mousetraps to catch elephants.'

Conclusion

Our inquiry sits well with Calvert's (2013) suggestion that the discipline-building style of 20th century "big science" is receding. In its place we see an integrative science that blurs the boundary between experimental research and geoengineering interventions, and up-scales both in the hope to meet the "grand challenges" of global

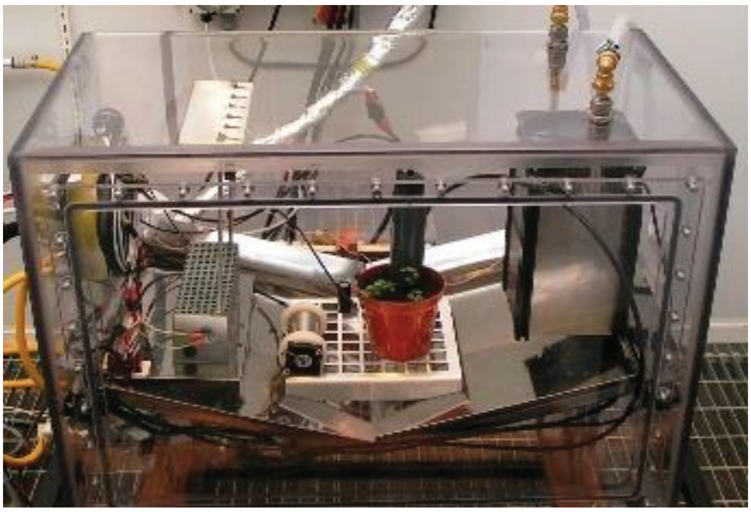

Figure 3. Ecotron experiment on the functional responses 'down to the level of the leaf' of plants and soil microbes to climate change simulations. Source: http://www3.imperial.ac.uk/cpb/history/theecotron/research/scaleproject (accessed: 25.8.2016)

warming, habitat fragmentation, even the global loss of whole biomes such as coral reefs.

At the turn of the millennium, Slobodkin (2000) suggested a new role and social vocation for ecology. Rather than assuming professional responsibility for the agonistic task of "stemming the tide of environmental degradation," as claimed by Bazzaz et al. (1998), Slobodkin argued that ecologists could more realistically aspire to the less politically charged, more pragmatic role of enabling the "duplication" of ecological services. The French ecotrons bring into being a world for ecologists to act within, a world in which they will help adapt critical ecosystem functions in and through dramatic global change, rather than demonstrate the necessity of halting the destructive economic practices that drive biodiversity loss.

This shift in ecology's self-conceived task, from protective conservation to pre-emptive security is certainly not specific to France: it is currently disputed in international ecological journals (Doak et al., 2014). It is possible that the move to re-articulate ecology's relevance in terms of vital systems security might be especially significant in France, given that many of the French researchers we interviewed distanced themselves from environmentalism, an ideology seen as opposed to "neutral" science. The political shift from a 'subversive' to a 'subordinate' role for ecology is apparent in the comments of a senior ecologist at the Foundation for Biodiversity Research, who expressed the need for ecologists to take their distance from "*fauna and flora*" concerns in order to retain access to decision-makers, funders and stakeholders: "*It is not in saying "we need to protect beasties" that we can really manage [to be listened to]*".

Ecologists and environmental science professionals today work in an international policy environment defined by official commitments to market-based 'solutions' such as carbon trading and 'biodiversity offsetting' schemes. It seems to us, as Bonneuil (2015) has suggested, that most are unaware of the extent to which this ideological context reflects the historical success of US corporations in organising globally to roll-back the science-based environmental regulations and institutions of the 1970s. This continuing project has been carried through a network of neoliberal think-tanks including the Heritage Institute, established in 1973 by ultra-conservative millionaires and US business interests with the self-avowed intention to "strangle the environmental movement" (Heritage Institute, 1990, in Bonneuil, 2015: 486).

Energetically open to solar insolation and heat-transfer but closed to material inputs and outflows, ecotrons materialize and offer proof of the 'ecosystem' concept itself. Immunised from the turbulent complexity of the planetary-scale ecosystem outside the system boundary, ecotron chambers contain carefully selected biotic communities of minimal complexity, such that the fundamental 'nature' of ecological processes can be analysed with physico-chemical precision. This attempt to engineer a 'pure' nature, from which to construct a 'hard' science, from which to develop precise techniques of control-engineering, carries all the hallmark ambiguities, ironies and figure-ground reversals of the cyborg sciences (e.g. Haraway, 1991; Mirowski, 2002).

Model worlds, the highly ordered microcosmic interiors of the ecotrons are dependent upon connection to the networks of urban, industrial infrastructures that secure the 'good life' of post-industrial knowledge economies – roads, electricity grids, water utilities, the internet. Ecotrons rigorously exclude not only 'non-target' organisms, but what Aradau (2010: 508) labels the 'underbelly' of urban infrastructure – the accumulated wastes, dirty water and pollution expelled from the 'end of the pipe'. Yet the raison d'être of the ecotron is to explore the 'endogenous crisis' of global economic infrastructure: the catastrophic possibilities of (eco)system failure caused by these flows. The contemporary side-lining of biodiversity concerns in the ecosystem functions research suggests something of an 'infrastructural inversion': the minimal biosphere enclosed inside the ecotron reveals the open biosphere outside as a life support system, one that might be engineered to maintain a minimum level of essential functions and 'services', even through unprecedented climate change and extinction events. Perhaps there is a wider lesson in Spring's (1985) observation that, "the simpler the biological components of the system become, the more externalised and complete the control must be" (cited in Beyers & Odum, 2012 [1993]: 25).

Ecotrons encode narratives of what ecology is and will become, what it is for, and what it is no longer. Not only do they conduct and channel research agendas that have been accorded epistemic authority, they also, intentionally or otherwise, encapsulate tacit ontological commitments to biopolitical questions of value and security, being and time, relation and classification, order and chaos, obligation and abandonment.

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Notes

1 In his monumental 'Spheres' project, the continental philosopher Peter Sloterdijk (cited above, 2011: 28) has initiated a compelling mode of metaphysical inquiry which he dubs 'sphereology'. Slotjerdijk characterises the the modern individualism of the Cartesian cogito, which *thinks* itself into relation with the world, as 'placental nihilism'. An ontology of *a priori* disconnection and foundational aloneness, it denies in the first place the vital, material unity of the womb-bound child with the body and being of the 'expecting' mother, and by extension, all of that out of which we are born. His 'spheres' are 'psycho-immunological spheres of protection': whilst an adequate critique of Slotjerdijk is beyond the scope of this article, a critical appropriation of sphereology for a sociology of the 'biosphere' and its technosciences seems a fruitful prospect. An urgent research agenda here would be the under-appreciated history by which systems ecology has come, through the discourse of 'ecosystem services', to be politically subordinate to the 'biospheric nihilism' of its sister science of economics, as the latter has becoming increasingly indistinguishable from neoliberal political philosophies and governmental techniques.

2 At the time of writing, both French ecotrons are online, but not all of their features are fully operational.

3 These interviews are a subset of a wider survey of research agendas pursued by French scientists (n = 40) working in biodiversity related fields (see Granjou & Alpin 2015).

4 Granjou C & Walker J (2014) Genealogies of the Ecotron. Synthetic Biospheres and Promissory Research Infrastructures, Trends in Environmental Research Seminar Series, Faculty of Science, University of Technology Sydney, 6 August 2014.

5 This is one reason why CNRS committed funds earmarked for the TGIR department rather than drawing down those from the ecology division.

6 *The h*istorian of ecology Donald Worster (1994 [1977]), categorizes ecosystems ecology as an "imperialist" form of ecological knowledge linked to technocratic objectives such as efficiency, exploitation and control, in contrast to the "arcadian" type of ecological knowledge which seeks harmony with nature.

7 According to Brian McGill's blog: "the glass blocked ultra-violet light which led to most of the pollinators congregating near the glass boundaries and dying (and the humans having to do a lot of hand pollination). The rainforest, unlike real rainforests, accumulated enormous amounts of leaf litter due to missing microbes (and then things jump started and normal high levels of litter decay are now occurring (we still haven't figured out exactly why). The coral reef crashed and burned for reasons that are still being worked out. The trees were not exposed to wind with interesting implications for growth forms and wood density. An invasive species of ant that snuck in through the soil obliterated much of the intended insect community" (Available at: https://dynamicecology.wordpress.com/2014/03/11/in-praise-of-a-novel-risky-prediction-biosphere-2/, accessed: 30.5.2014).

8 See for example the TraitBank project, which aims re-integrate the classification of biodiversity according to the functional traits of organisms. Traits are variously defined depending ecological specialties, "but essentially concern species' properties that affect individual fitness and govern species' impacts and responses to their environment.". TraitNet aims to facilitate integration and synthesis of ecological disciplines around the recording and stocking of traits (http://traitnet.ecoinformatics.org/, accessed: 23.8.2016)

9 The French ecotrons are part of two European programs for the design and construction of experimental infrastructures for systems ecology: Infrastructure for Analysis and Experimentation on Ecosystems (AnaEE) and Integrated Infrastructure Initiative (ExpeER) program).

10 http://www.cnrs.fr/inee/outils/ecotrons.htm; http://www.ecotron.cnrs.fr/index.php/en/; http://www.foljuif.ens.fr/; http://fr.wikipedia.org/wiki/%C3%89cotron. (Accessed: 30.5.2014).

11 For instance flux towers, which measure CO2 concentration and temperature at the bottom and at the top of the studied trees; some outdoor devices also increase temperature and CO2 concentration locally in the air.

12 Quotations in this paragraph are from: http://www.ecotron.cnrs.fr/index.php/en/context/scientific-challenges (Accessed: 15.5.2014).

13 The view that human societies will "utilize" the "benefits" of global warming, such as accelerated plant growth due to rising atmospheric concentration of CO2, or the warming of cold regions is expressed in Montpellier ecotron website (accessed: 1.5.2014).

14 Proteomics is the large-scale study of proteins.

Of Blooming Flowers and Multiple Sockets: The Role of Metaphors in the Politics of Infrastructural Work

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Abstract

We explore the role of two metaphors for innovation and infrastructure integration in the development of a regional patient portal. Our premise is that metaphors have real consequences for agenda setting and decision-making; we view them as operationalizations of sociotechnical imaginaries. Drawing on our formative study of the portal project, we focus on the generative character of metaphors and argue that they are constitutive elements of information infrastructures. While the two metaphors in our study helped to make imaginaries of 'integrated' and 'personalized' health care more definite, cognizable, and classifiable, they also concealed the politics of infrastructural work. We argue that the act of 'spelling out' metaphors can open up a space for new imaginaries and alternative strategies. With this study we aim to contribute to existing knowledge about infrastructural work, and to renew the interest among STS scholars for the role of discursive attributes in information infrastructures.

Keywords: metaphors, e-Health, information infrastructures

Introduction

Information infrastructures (IIs) emerge in different ways, and take on different shapes and forms in different domains. In health care, questions regarding the expansion and governance of IIs are increasingly pertinent, as the rapid differentiation of e-Health technologies and changing expectations about health communication go hand in hand with new practices, strategies, and policy agendas. Health care organizations and governmental bodies across the world seek to counter problems of 'fragmentation' in health information exchange (HIE), professing aims of increased quality and efficiency through various types of 'integrated' and 'personalized' solutions (cf. Detmer et al., 2008). Online health portals are frequently championed as vehicles of integrated HIE; although examples of portals that "fully intermediate the patient-provider relationship" are still scarce (Baird & Nowak, 2014: e2), new so-called 'patient portal' initiatives abound. In the Netherlands, several attempts have been made to develop patient portals with a regional scope (De Mul et al., 2013). These initiatives varied greatly in terms of their professed objectives and ambitions, as well as in the complexity of their organizational and political contexts. A recent comparative study between three Dutch cases illustrates the difficulties of achieving implementation, technical interoperability, regulatory compliance, and financial sustainability; these challenges are especially tough in decentralized, highly heterogeneous networks of interdependent actors (Otte-Trojel et al., 2015).

Taking a closer look at how patient portals are developed in such a complex setting can yield useful insights in the sociotechnical makeup of IIs for health care, as well as in the infrastructural work (Star & Ruhleder, 1996; Hanseth et al., 1996) that 'integrated' and 'personalized' systems in e-Health require. The concept of infrastructural work can designate a wide range of practices in the development and maintenance of infrastructures, all of which entail "political, ethical, and social choices" (Bowker et al., 2010: 99). In the context of patient portal development, we view infrastructural work as pertaining to the negotiation, classification, standardization, and translation of novel ideas about IIs for health care. This work – which can take place in boardrooms, at project meeting tables, and on conference floors, as well as in a secluded computer lab or in the coffee room of a nursing home – is inextricably linked with the use of metaphors. In this paper we explore the use of metaphors by project members and stakeholders in the early development of a regional patient portal in the Netherlands, with the aim to unravel their role in the politics of infrastructural work.

There is a substantial body of literature in science and technology studies (STS) on practices in the design and development of IIs – generally with the aim to understand how science and technology themselves are produced (Monteiro, 2001: 74) – and several scholars have paid attention to the role of language and discursive attributes in those processes (Walsham, 1991; Hirschheim & Newman, 1991; Monteiro & Hepsø, 2002). With this paper we aim to contribute to that body of knowledge. We contend that discursive attributes can have tangible and far-reaching consequences for emerging IIs, and that exploring their use can help us to understand how e-Health agendas are shaped, therewith creating "a space for observation, comment and analysis" about alternative strategies (Woolgar & Neyland, 2013: 7). To elaborate our argument we describe the use of two metaphors for innovation and infrastructure integration in a Dutch patient portal project: third party e-Health initiatives as 'blooming flowers', and the portal as a 'multiple socket'.

We argue that metaphors are constitutive elements of IIs and powerful attributes in infrastructural work: rather than acting as neutral or 'innocent' descriptors of abstract concepts, they can generate new realities by reconfiguring the imagined order of technologies, infrastructures, and their users, and by actively contributing to the manner in which choices are made in relation to architectures, standards, and classification systems. The novelty of our approach is that we view metaphors as operationalizations of sociotechnical imaginaries, which in our study consist of promises, hopes, goals, and expectations about 'integrated' and 'personalized' health care in a regional context. By reflecting on the consequences that metaphors can bear for agenda-setting and decision-making processes, we cast new light on how language and discursive attributes are tied into infrastructural work in emerging IIs. We thus hope to contribute to current knowledge about the politics of infrastructural work, and to renew the interest among STS scholars for discursive attributes in IIs.

Case Description and Research Questions

Our study draws on ethnographical data collected during the early development of Zorgportaal Rijnmond (ZPR),[1] an online portal for health care and wellbeing in the Rotterdam Rijnmond region of the Netherlands. A consortium of public and private partners carried out the development of the portal, and a Regional Health Information Organization (RHIO) acted as secretary of the project. We studied and actively contributed to the development of ZPR; our approach can be characterized as a form of action-oriented, engaged scholarship (Bal & Mastboom, 2007; Mathiassen & Nielsen, 2008; Zuiderent-Jerak, 2015). In our role as 'formative researchers' we were fascinated by the widespread use of metaphors among project members in designating technologies, practices, and processes. The idea of paying close attention to metaphors ensued from our own disconcertment (cf. Verran, 2001: 1–20), as we often struggled to 'spell them out' or to make sense of them analytically. The blooming flowers and multiple socket metaphors struck us as remarkably playful terms, seemingly contrasting with the serious ambitions that the project embodied.

We singled out these two metaphors as they became prevalent attributes of innovation and integration narratives in the early stage of the project. For this paper we formulated the following research questions: how did the enactments of the blooming flowers and multiple socket metaphors sustain the promises, hopes, goals, and expectations in the project? What did these enactments reveal and conceal in terms of the politics of infrastructural work? And consequently, how can an analysis of discursive attributes contribute to the study and development of IIs?

The Generative Character of Metaphors in Infrastructural Work

Since the early 1980s, scholars from various disciplinary backgrounds have studied the social and organizational dimensions of infrastructures in informatics and computing (Kling & Scacchi, 1982; Kling, 1987; Bishop & Star, 1996). STS scholars in particular made noteworthy contributions by theorizing the relational character of information infrastructures (IIs) (Bowker & Star, 2000; Ellingsen & Røed, 2010; Jæger & Monteiro, 2005; Lampland & Star, 2009; Star & Ruhleder, 1996), which became increasingly relevant with the expansion of the World Wide Web and online technologies in the 1990s. In the context of health care, efforts to make visible the ongoing infrastructural work in IIs led them to focus on the implications and consequences of standards and standardization, the tension between local and global practices, and the politics and work involved in collaborations, alliances, and partnerships in e-Health (Bansler & Kensing, 2010; Bjørn & Kensing, 2013; Hanseth & Ljungberg, 2001; Hanseth et al., 1996).

The use of metaphors in information technologies has been researched from various disciplines as well. Covering a wide range of theoretical perspectives, scholars addressed the relevance of metaphors in the design of computer systems (Carroll & Thomas, 1982; Lanzara, 1983; Carroll & Mack, 1985; Carroll et al., 1988; Andersen & Madsen, 1988; Madsen, 1989; Greenbaum & Kyng, 1991; Friedman, 1998), their use in the social construction of Internet imaginaries (Wyatt, 2004), their organizing role in information systems (IS) (Walsham, 1991; Hirschheim & Newman, 1991; Monteiro & Hepsø, 2002; Ellingsen & Monteiro, 2008; Gillespie, 2010; Constantinides, 2013), and their enabling and constraining effects in IIs (Star & Ruhleder, 1996; Monteiro & Hepsø, 2002).

Our focus on the role of metaphors in IIs builds on this body of work. We contend that their use is inextricably linked to infrastructural work, and that it can have far-reaching consequences for processes of agenda-setting and decision-making. Our basic premise is that metaphors structure our understanding of the world, and that they shape expectations in social interaction (Lakoff & Johnson, 1980). We side with Schön's (1996) argument that metaphors can enable or constrain problem definitions in policy making, and adopt his notion of 'generative metaphor' to contend that the use of metaphors (and the implied act of 'spelling out' their meaning) has real technical and organizational implications for infrastructural work. In his view, metaphors refer "both to a certain kind of product – a perspective or frame, a way of looking at things – and to a certain kind of process – a process by which new perspectives on the world come into existence" (Schön, 1996: 137). Rather than serving as 'innocent' or neutral analogies, metaphors create new realities by contributing to the manner in which problems are formulated – and consequently, how solutions are envisioned.

Taking Schön's explanation as our point of departure, we regard metaphors not merely as linguistic reflections of a given social context, but as constitutive attributes in practices and knowledge production: they act as 'mobilization devices' that allow ideas to circulate (faster) and that influence the way in which people argue and convince each other (Latour, 1990: 31; Czarniawska-Joerges & Joerges, 1992, 1996). Through their circulation in networks, metaphors affect a growing number of actors – such as the project managers, developers, policy makers, and other stakeholders in our study – and have the potential to (re)configure people, ideas, resources, and technologies. Like material objects, metaphors are 'enacted' in different ways in continuously changing settings. Following the example of Winthereik (2010), who discussed three enactments of systems development in an IT implementation project, we explore how the blooming flowers and multiple socket metaphors were enacted during the early stages of the ZPR project, and how this affected the development of the portal. Our focus on enactment allows us to move away from a strictly representational conceptualization of language (Leonardi & Rodriguez-Lluesma, 2012) and to locate the meaning of metaphors in the act of speaking, rather than in "the object for which the word stands" (Wittgenstein, 2009:5e). Metaphors thus become part and parcel of a recursive process of ontological constitution (Woolgar & Neyland, 2014: 38).

We view metaphors as operationalisations of sociotechnical imaginaries: they make the latter more discernible while leaving room for ambiguities and interpretative flexibility (Bijker et al., 2012: 20). We borrow the concept of sociotechnical imaginaries from Jasanoff & Kim (2009, 2013) to designate collective images and ideas of a future that is deemed at once attainable and necessary to be attained; the empirical case in our paper entails visions of 'personalized' and 'integrated' online health care in a regional context. Rather than treating imaginaries as mere reflections and representations of prospective technologies (cf. Marcus, 1995; Fortun & Fortun, 2005) we regard them as expressions of social order that "prescribe futures" (Jasanoff & Kim, 2009: 120) while being "constituent of the very situation of any doing or action" (Verran, 2001: 37). This conceptualization of imaginaries bears similarities to the notion of 'anticipation work' in Computer-Supported Cooperation Work (CSCW), which serves as a "frame to capture practices in the present that cultivate our expectations of the future" (Steinhardt & Jackson, 2015). While the latter's aim is to make 'forward-thinking practices' visible, sociotechnical imaginaries foreground processes of agenda setting; these imaginaries also encompass metaphors that can be "used to call for action in the here and now" (Bijker et al., 2009: 105).

We view our theoretical argument as complementary to existing studies on the development of IIs in IS and CSCW literature, and with studies on the development and implementation of e-Health infrastructures in particular (Ellingsen & Monteiro, 2003, 2006; Jæger & Monteiro, 2005; Ellingsen & Røed, 2010; Sahay et al., 2009; Aanestad & Jensen, 2011; Ellingsen et al., 2013). We adopt a similar approach to interdependencies between material and non-material actors to focus on the *work* that is required for infrastructure integration in e-Health.

Research Setting and Methods

We conducted ethnographical research during the early development stage of Zorgportaal Rijnmond (ZPR). Our researchers' role in the project was to evaluate the design, development, and implementation of ZPR, as well as the development and scalability of three applications that were to be offered on the portal: a personal health record for the Rotterdam Rijnmond region, a closed-circuit video education program, and a publicly accessible information support system for citizens in the region requiring care. The formal task of the first and second author was twofold: to provide timely, intermediate feedback about our findings to project members and other stakeholders, and to assess the pilot phase of each of the applications in three evaluation reports. Our study took place between September 2009 and August 2012, and coincides with the period in which ZPR was primarily upheld by public funds.[2]

Throughout this 36-month period, the first author attended three-weekly Project group meetings, bimonthly Steering group meetings, biyearly Board meetings, and several Sounding board groups and subproject activities to collect data for the ZPR study. The second author coordinated and supervised the study, and attended the Project group and Steering group meetings as the Research project leader; like the first author, she was closely involved in the development of the ZPR project. The third author contributed to miscellaneous tasks and issues arising in the project, including the development of pictograms for ZPR's privacy policy; being less involved in ZPR's daily operations – and having more distance to the project – she was able to signal peculiarities in the overall process, and question issues that where easily overlooked from up close. The fourth author was a member of the ZPR Board, representing the University as a consortium partner in the ZPR project. Regular meetings were held between the four authors in which we discussed our ZPR-related research activities and progress.

During our study, the first and second authors' knowledge exchange with project members and other stakeholders took on different forms. Aside from actively participating in the aforementioned formal settings, we attended public ZPR events (such as networking meetings, and the official 'launch' of the portal in September 2011), wrote reports and memoranda with other members of the ZPR project, joined them in various expert meetings, seminars, and trade conferences, and accompanied them on some of their visits to suppliers and other stakeholders. Informally, interactions with project members and other stakeholders took place before and after meetings, either through face-to-face interaction, by telephone, or email correspondence. On numerous occasions the first author joined project members in car rides, lunches, and social activities, alternating small talk with viewpoints on the project.

We drew valuable insights from both formal and informal settings, where the latter allowed us to better understand the political intricacies of the project. At the same time, we were consulted by project members and stakeholders, and shared our own researchers' insights and personal views on the project whenever this was possible and appropriate. We acknowledge that the formative character of our fieldwork is deeply intertwined with 'intervening' or 'informing design' (Zuiderent-Jerak, 2015), and recognize the importance of critical reflexivity in this process (Bjørn & Boulus, 2011); our role as participatory researchers merits more attention than the brief reflections we are able to present in this paper.

The material for this paper comprises the first authors' field notes for the ZPR study (September 2009 – August 2012); audio recordings from three Project group meetings, one Steering group meeting, and one Brainstorm session (December 2009 – June 2010); and meeting minutes and memoranda from two Steering group meetings (June 2010, January 2011) and one Board meeting (February 2011) in which the metaphors discussed below explicitly occurred or were implicitly alluded to. While the metaphors did not literally recur in the Steering group and Board meetings, we refer to memoranda and meeting minutes from those groups to illustrate how the metaphors contributed in shaping the course of the project. Relevant excerpts from the aforementioned five audio recordings (up to 25 minutes in length) were transcribed verbatim and coded inductively by the first author.

To understand the role of the blooming flowers and multiple socket metaphors in the ZPR project, we took notice of them as much as possible and reflected on them along the way; this allowed us to retrospectively explore how they were enacted. The two metaphors were part of a management culture in the ZPR project in which the use of analogies, allegories, and idiomatic expressions was profuse. Large and potentially disorderly gatherings, for instance, were referred to as 'Polish Diets' (*Poolse landdagen* in Dutch), which are proverbially linked to a disorderly meeting of the Polish parliament in the sixteenth century; product pitches for vendors went by the English term 'beauty contest', which – aside from being a synonym of 'beauty pageant' – is informally used to denote any contest decided by popular vote; easily obtained gains were referred to as 'low-hanging fruit' (*laaghangend fruit*); and a portal or application featuring too many functionalities was likened to a 'Christmas tree' (*Kerstboom*).

In the following section we describe the construing role of the blooming flowers and multiple socket metaphors in the initial phase of the ZPR project. We show how (and by whom) these metaphors were enacted, as well as the consequences of their enactments within the project. We highlight their role in *exploring* its organizational, technical, and economic boundaries, and in *endorsing* the portal as an independent, non-partisan attribute in a newly envisioned technical, economical, and social infrastructure for the region. From our analysis we discerned that narratives about 'exploring innovation' and 'exploring new market opportunities' ran parallel with narratives about how to position the ZPR project 'in the market' (i.e., how to 'endorse' it as a competitive contender in the Dutch e-Health landscape). This led us to the distinction between 'exploration' and 'endorsement', each consisting of specific enactments of the two metaphors. Although the concepts of 'exploration' and 'endorsement' can be linked to more or less specific imaginaries – which will be explicated below – our distinction between them is not meant to suggest that one type of enactment preceded the other, or that they occurred independently: they are discursively interwoven, and can be linked to a wide variety of practices.

Flowers Blooming in a Multiple Socket

Before we focus on how the metaphors were enacted by different people in the project, we need to recount how they first emerged. This brings us to the first official ZPR Project group meeting in December 2009, shortly before the Christmas holidays. By that time, several meetings about ZPR subprojects had already taken place, as well as the first meeting of the Steering group. The Project group meeting started with the program manager enunciating four agenda topics while listing them on a display board: "Report from Steering group – Project progress – Project plans/Flowers on the side – Financial report". As the last agenda topic appeared on the board, the project leader in charge of 'Infrastructure' asked to clarify the meaning of 'flowers on the side'. The program manager replied that they were "the little flowers blooming in the margins of the project plan, beyond the limits of our raked path".

The notion of 'blooming flowers' is frequently used in the context of business and innovation. It is etymologically rooted in the Hundred Flowers Campaign, which was introduced by the Chinese government in 1956 and was presented as an initiative that would promote the cultivation of new ideas, and grant greater freedom of thought and speech to Chinese artists and scientists. Its specific recurrence in narratives on innovation is explained as follows by Kanter:

> "'Let a thousand flowers bloom'. This slogan, designed to awaken an entire nation to new ideas, offers an apt metaphor for innovation. Innovations, like flowers, start from tiny seeds and have to be nurtured carefully until they blossom; then their essence has to be carried elsewhere for the flowers to spread." (Kanter, 1988: 170)

In the ZPR Project group, the blooming flowers metaphor came to denote e-Health projects in the Netherlands that were deemed appropriate or interesting enough to be 'offered through' or 'integrated in' the portal. Projects emerging 'in the margins of the project plan' thus became known as *bloemetjes* awaiting to blossom;[3] in this paper we opt for the translation 'blooming flowers', which in our view best conveys the program manager's description.

The added metaphorical rendition of ZPR's 'raked path', which was not clarified by the program manager, must be understood in relation to ZPR's five subprojects existing at that time (one pertaining to the technical infrastructure, one for each of the three applications to be 'integrated' in the portal, and one research component) as well as to one of the espoused objectives in the ZPR project: to stimulate the development of new e-Health initiatives and activities in the region (ZPR, 2009). The blooming flowers metaphor thus conveyed ZPR's envisioned role as a platform for e-Health innovation, and the necessity and willingness to accommodate potentially useful developments beyond the lineaments of ZPR's project structure – e.g., the neat, orderly, and more or less clearly predefined itinerary suggested by the 'raked path'.

The notion of 'integrating' (or 'latching on') e-Health applications in the ZPR portal was conveyed through the view of the portal as a multiple socket.[4] This term first occurred during the same Project group meeting in December, when the program manager informed the group about a past meeting with project leaders of another health portal project in the Netherlands:

> "Actually they [the project leaders of the other portal project] choose a very different concept; while we are pretty much looking for new software, their plan is really just to become something like a multiple socket [*stekkerdoos*], where everything that works and is properly developed can be plugged into. So for us it's very important to keep an eye on that, which plugs they will be plugging into their own sockets in the next months, and to plug those in as well. […] We've chosen a slightly different concept, where we say: we have to deliver those things as well in order to generate traffic." [program manager, December 15, 2009]

In its first occurrence, the term *stekkerdoos* did not raise questions among the project members. It reappeared verbatim on the agenda of a brainstorming meeting after the Christmas holidays. Several ZPR project leaders, the financial controller, and the director of the Regional Health Information Organization (RHIO) were present. As they discussed the potential benefits for other companies to 'plug into' ZPR, the program manager expressed her preoccupations on how to make this work:

> "I still have one concern, which is that on a very short term we will need to wheel in money,[5] because I believe that the portal should be made more suitable to also serve as a multiple socket." [program manager, January 7, 2010]

In reaction to this, the Infrastructure project leader asked the program manager asked the program manager to clarify his understanding of the term 'multiple socket' in the project's context:

> "So in fact, a multiple socket is something that you offer to someone who has a ready-made application {yes! – program manager}[6] with users, administration, on which everything works?" [project leader Infrastructure, January 7, 2010]

The program manager acknowledged this explanation, adding that the integration between applications and the portal could take on different forms in different cases, and that it would require negotiations with entrepreneurs:

> "Yes what you have is… yeah actually it depends, we'll have to talk about it with the entrepreneurs. PatientCom, for example, has a sort of application for diaries, so people can keep their own diary, for diabetes and for ehm… well, they really want to keep data storage to themselves." [program manager, January 7, 2010]

This quote illustrates the program manager's awareness of the ambiguity of the multiple socket metaphor: the variation and negotiation she alludes to stand in contrast with the uniformity and rigidity of a multiple socket. Despite this ambiguity, the view of the portal as a multiple socket soon gained currency within the Project group. During our meetings at the University, which ran parallel to the ZPR project, we reflected on the meaning and use of the blooming flowers and multiple socket metaphors. Our first reflections on these metaphors date back to January 20, 2010, when we tentatively construed the multiple socket as a model of integration and as a metaphor for the ambition to 'standardize everything'. Rather than firmly hanging on to these ideas, we tried to keep an open view on how the use of this metaphor would develop; framing it as a 'model of integration', however, was an analytical choice that persisted, and that colored our subsequent observations and interpretations. In what follows we describe two ways in which the blooming flowers and multiple socket metaphors were enacted, with the purpose to gain a better understanding of the relation between metaphors and practices in the ZPR project. We present these enactments in separate sections, each following a chronological order.

Exploration

The blooming flowers metaphor was deeply intertwined with the search for new e-Health applications and market opportunities in the ZPR project. These explorative activities primarily involved Project group members, and were at their height between February and August 2010. The importance of investigating 'interesting developments' for the multiple socket was addressed as follows by the program manager, while planning the attendance of an upcoming ICT fair:

> "My thought is: let's go all together, so we can compare notes: what did you see, what did you notice, what can we do with this? I assume that we'll see a number of interesting developments for the multiple socket." [program manager, February 2, 2010]

The program manager sought a systematic solution to maintain a structured overview of what could be 'plugged into' the portal. An overview of this kind was meant to keep Project group members updated on current findings, while providing a means of comparing different applications as well:

> "[…] the question is: do we create a single document, and make an entry for each one, and look at the entire list together once or twice a month and say: these are candidates for the multiple socket? And will we say: we can invite so-and-so for an interview? […] we need a central point where things are directed to, someone who rubricates them or stores them somewhere so we can come together and say: this looks interesting, if it works well, can we latch it on to the portal? Does it have added value for the portal, or is there something underneath that is useful to us?" [program manager, February 2, 2010]

The program manager thus envisioned a standardized format for keeping track of the blooming flowers; this would enable a more or less structured exploration of products, activities, and services beyond the aforementioned confines of ZPR's project delineation. In her role as Research project leader, the second author was asked to create a template for a working document, which she divided into twelve descriptive categories: 'education', 'prevention and lifestyle', 'self-management', 'support groups', 'e-mental health', 'search and find', 'medication', 'e-learning', 'home automation', 'telemedicine', 'record keeping', and 'internet appointments'. These categories helped to discern different types of e-Health applications based on a standard set of principles; in accordance with this template, each blooming flower was described separately and classified by 'type of ICT tool' (with descriptors loosely based on the aforementioned categorization), 'sector' (such as 'prevention', 'cure', 'care', etc.) and 'target audience' (such as 'patients', 'health providers', 'children', 'physiotherapists'). Descriptions varied in length from a few sentences to several paragraphs, and were accompanied by the URL associated with the application or project.

While the Research project leader worked on the template, the Infrastructure project leader set out to explore the technical requirements for a 'good' multiple socket. Having questioned the multiple socket metaphor in the previous meeting, and having recently visited the software vendor who was contracted to build ZPR's technical platform, he reported back to the Project meeting by explaining that the 'universal' character of multiple sockets did not apply to the ZPR case, nor to other portals: "You cannot build one multiple socket for all, it doesn't work like that in software land" (February 12, 2010). Noting that it was fundamental to know in advance what requirements ZPR had to meet in order to deliver a technical architecture for ZPR ("the question is: how do you wish to make it available? And not: how do you plug into it") he added that making different applications 'interoperable' with each other on a single portal would not be a feasible goal.

Interpreted as a literal analogy, the multiple socket metaphor thus revealed its technical and organizational shortcomings: different e-Health applications are based on different 'installed bases' (Hanseth & Ciborra, 2007) which are in turn relegated to different standards and infrastructures. Despite this shortcoming, the multiple socket metaphor temporarily configured the relation between applications and the portal as a problem of fit, both in a technical sense (finding a 'fit' between plug and socket) and economically (seeking 'compatible' business models to 'plug into' the portal). However, as Project group members continued to discuss the integration of third party applications as an act of 'plugging into' the portal, the metaphor did not help to make the politics of technology and infrastructural work visible. 'Infrastructure' remained a technical challenge, and the main person responsible for its development was the Infrastructure project leader. We will further elaborate on this in the Endorsement section.

Bringing back our attention to the blooming flowers, the working document contained formalized descriptions of 41 e-Health applications by the end of February of 2010. Examples included a module for scheduling appointments with health providers, an educational course for adolescents with symptoms of depression, and a Wi-Fi-enabled audio messaging device for young children in hospitals. Typically, these 'blooming flowers' were found in online media publications and printed press, through networking gatherings, or by word of mouth. Information and insights about these applications were shared with Project group members during the three-weekly meetings, and sometimes by e-mail.

Aside from providing project members with a tangible, selected overview of third party e-Health applications in the Netherlands, the blooming flowers metaphor brought about a classification of innovation that enabled side-by-side comparisons between different initiatives. At the end of February, six Project group members were asked to evaluate the blooming flowers and to rank them; the assessment was based on two generic criteria ('who benefits?' and 'relevance to ZPR goals?') divided in several items,[7] and featured a rating scale from 1 to 10. The form to be filled out for each application became known as the 'blooming flowers form' (*bloemetjesformulier*), and was referred to as such in subsequent Project group meetings.

In the following five months, discussions about the blooming flowers revealed how the exploration work was gradually transforming into decision work, and that the latter was a long process. In the April Project group meeting, a debate arose on how to move from the current working document to the integration of ten applications on the portal by the end of 2010, as was formulated in ZPR's year plan. In her role as Research project leader, the second author pointed out that the working document could help to decide which applications to select for the portal:

> "You can use that document I made to find out what kind of applications there are… you know, some applications have more of a diary functionality, which you can edit yourself, some are more about communication between health care providers and patients, there are applications focused on giving a specific type of information, which can be text-based or visual… and that's a type of ordering that could be helpful. […] It would be nice if there were some sort of balance, if we could offer at least one of each of those types of information on the site" [project leader Research, April 27, 2010]

This suggestion not only serves to illustrate the formative interventions that we made to the project as researchers – seeing the working document as an instrument to create order – but it shows how the exploration process was built up: from assessing and classifying innovations to seeking a certain 'balance' in them. A congruent strategy was proposed by ZPR's financial controller, who suggested making a selection of applications based on what could be 'coupled' to the portal relatively easily, without too much effort or high costs:

> "Perhaps you should sort out what can be achieved easily, and make something like a global estimate of the time required to couple something like that [a blooming flower] to Zorgportaal, and to make a selection on that basis" [financial controller, April 24, 2010]

This hinted at the idea that some applications or initiatives would require more effort than others. More precisely, the financial controller felt that the focus should be diverted from what she termed 'experiments'. From this emerges a distinction between established, successful, up-and-running applications and comparatively obscure initiatives by hospital doctors that were still going through trial stages:

> "Some of those flowers are, with all due respect, just experiments by people who are not fully

> dedicated to creating this type of applications, like health care providers" [financial controller, April 24, 2010]

This qualification of some applications or initiatives as 'experiments' adds a new dimension to the view of the "little flowers blooming in the margins of the project plan, beyond the limits of our raked path". Evidently, the blooming flowers now required a 'raked path' of their own in order to be prioritized: simply 'blooming in the margins' was not enough. But the differentiation between 'just experiments' and other initiatives was highly normative: drawing the line between 'experimental' and accomplished applications or initiatives (meaning 'suitable' and 'unsuitable' in this context) was a matter of contention, and the issue of how to draw that line was never settled in the Project group. In response to the financial controller, the program manager contested that any of the blooming flowers in the overview were 'experimental'; she stressed that most of them were actually well-funded, award-winning initiatives. This contestation of the label 'experiment' points to the problematic definition of the term itself (who decides what qualifies as an experiment, and on what basis?), as well as to a devaluation of the notion of 'experimentality': the blooming flowers were not 'just experiments'. The program manager expressed her concern that ZPR would remain an empty portal if they would continue to add new blooming flowers to the overview, and that the focus should be shifted towards ZPR's content. She proposed to create a shortlist containing six or seven blooming flowers that 'already work well' to be made available through the ZPR portal before November 2010:

> "The fastest way of creating a lot of content on [the portal], or interesting activities, is to think about the things that already work well. Meaning flowers that we have already found." [program manager, April 24, 2010]

By mid May the working document contained 57 blooming flowers. The Project group convened again, and the discussion on how to make an appropriate selection continued: who would decide on what to select, and what would be the role of the Steering group in this process? Having discussed the matter beforehand, the Research project leader and the program manager proposed to write a memorandum for the Steering group:

> "Those 57 items could all be placed under 'nice health links' […] but in the end it's about making a distinction: what will you be offering through ZPR?" [project leader Research, May 18, 2010]

> "Our proposal is to make some sort of exploration, to write a small plan, and to hand that over to the Steering group. To say to the Steering group: this is what we wish to develop. With these entrepreneurs or these providers we want to talk about a real collaboration, and to connect things to the portal in the right look and feel, which means that we will have to pay for that part of the look and feel for them; and yes, that requires money, can that be paid from the portal or…?" [program manager, May 18, 2010]

The criteria for this new selection procedure were elaborated in a memorandum entitled 'Acceleration of Zorgportaal development' (ZPR, 2010), which featured on the agenda of the Steering group meeting in June. In the memorandum the program manager expressed her opinion that the development of ZPR was not proceeding fast enough, as efforts were primarily directed at the technical infrastructure of the portal and the three applications that were developed in association with ZPR. Without resorting to the blooming flowers metaphor she wrote: "I believe it is important that we put more energy in collaborations with strong private partners with good services for both care providers and citizens/patients." The memorandum presented three criteria based on which the blooming flowers could be distinguished: 'hyperlinks to other sites', 'services for which the visual presentation of the application is integrated with Zorgportaal', and 'services for which the application is integrated in Zorportaal'. This was followed by an overview of the aforementioned twelve categories from the blooming flowers template, and two formal requests to the Steering group: "Agreeing with an accelerated development of content on Zorgportaal Rijnmond, so that it can be presented for decision at the Board meeting; Determining together who decides what services will be offered on Zorgportaal" (ZPR, 2010).

In the June 2010 Steering group meeting, where the blooming flowers metaphor was incidentally used by one of the Steering group members in relation to the digitalization of health care ("You see that there are many flowers blooming there"), the memorandum led to a discussion about envisioned partnerships with private parties. Asked to clarify her view on this matter, the program manager replied:

> "I think we need to look at it […] per individual case: what are the costs, what are the returns, what is the short term business case, the long term business case. […] It will vary for each… blooming flower, I think. For each… new activity. What are the costs of latching on, and how do you wish to latch on, right? Do you want to be a link from here, or do you really want to be incorporated in the portal… you can imagine that if you really want to be incorporated in the portal, that the costs will be higher" [program manager, June 14, 2010]

The Steering group agreed to give a positive advice to the Board regarding the 'accelerated development of content', which entailed the allocation of a larger share of the program manager's hours to exploring the financial implications of partnerships with private parties. Anticipating future endorsement activities, one of the management delegates summarized the discussion as follows: "How do you market it? Basically it's all a matter of marketing for Zorgportaal". Between June 2010 and January 2011 the term 'business case' gained prominence on the agenda of the Project group and Steering group. Third party applications were regarded as important for the financial sustainability of ZPR, but the project manager did not expect things to go smoothly. In an interview with the first author she expressed her concerns as follows:

> "Look, we obviously face a heck of a problem in about two… one year from now. One year from now [the portal] must be so solid that we can pay for the infrastructure! Thanks to the applications on it, and the underlying business cases, if enough traffic is coming in... well, it's all still very exciting! Really exciting! I have no idea! I have yet to see any application in the Netherlands that can support itself based on citizens willing to pay for it. [...] There is an underlying assumption that people are going to use applications, and that there's a business model behind each application, but uh... a lot of the revenue that goes to one [entrepreneur] depends on the investments made by others" [program manager, July 8, 2010]

Six months later, on January 10, 2011, a special meeting was held in which five suppliers 'pitched' their products or services to the Steering group. Two ZPR project leaders, two project leaders from the largest teaching hospital in the region, and the first author were also invited. Among the presented products were the online diary application for patients with chronic diseases by PatientCom, which allegedly had tens of thousands of users in the Netherlands at that time, and an application for online satisfaction surveys by ResearchCom. All people attending were asked to make notes, and to reflect on the potential of each proposition. In an interview with the first author (January 17, 2011), the RHIO director explained his preference for PatientCom by pointing out the "clear business case in their presentation", and expressed his dislike of ResearchCom for "not having a clear business: how will we pay for it?" Similarly, the minutes of the following Steering Group (ZPR, 2011a) emphasized the 'business case' of both applications, briefly describing the presentations as follows: "The self-help diaries by PatientCom have been well received. The presentation was very illustrative. It is directly clear for a patient how to use the diaries. Moreover, PatientCom has a clear business case. For the application by ResearchCom we need more clarity about the business case on the longer term."

This reconstruction shows how the exploration of blooming flowers gained a more economic character as ZPR's own 'business case' and financial sustainability became a more pressing issue; we will elaborate on the marketing-oriented enactment of this metaphor (framing the ZPR portal as a business opportunity) in the Endorsement section. The blooming flowers metaphor contributed in shaping the selection procedure of applications for the ZPR project by articulating the functional and financial dimensions of prospective e-Health innovations. It led to the creation of a standardized form that gave Project group

Table 1. Exploration

Imaginary	Metaphor	How it was enacted…	… and by whom	What it led to
Portal as a platform for e-Health innovation	Blooming Flowers	***Searching*** for new applications & market opportunities	Project group members	The search led to a selected inventory/overview of e-Health projects in the Netherlands
		Classifying innovation using a standardized working document	Project group members	The working document evolved into a form that contributed to/informed the inclusion and exclusion of potentially useful applications
	Multiple Socket	***Investigating*** ways to build the portal	Project leader 'Infrastructure'	Task of translating the metaphor into technical requirements/ specifications
		Searching for new applications to ***plug into*** the portal	Project group members	The derivative 'plug into' metaphor configured the relation between application and portal as a problem of alignment, both technically and economically

members insight in user-payer arrangements, access procedures and types of data management and maintenance for different types of applications. Similarly, the multiple socket metaphor enforced the imaginary of a platform for e-Health innovation in which those applications could be 'plugged into'. Table 1 illustrates the different ways in which the metaphors were enacted in light of the view of the portal as a platform for e-Health innovation.

Endorsement

Aside from being viewed as a platform for innovation, the ZPR portal was also heralded as 'the' future gateway for health care providers and recipients in the Rotterdam Rijnmond region (cf. ZPR, 2009). Using the blooming flowers metaphor in reference to e-Health developments elsewhere in the Netherlands, the program manager presented her view of ZPR as an inclusive, open, and outwardly oriented project. Project group members and other stakeholders invested substantial effort in mobilizing potential participants in the ZPR project; among those stakeholders was the chief medical information officer (CMIO) of the aforementioned teaching hospital. An avid proponent of the Continuity of Care Record (CCR) standard, the CMIO frequently spoke at medical IT-gatherings, where he championed ZPR as a platform for standardized health information exchange (HIE). His views on how to unify language and semantics in HIE expressed similar narratives of inclusiveness and outward orientation. He deemed cooperation with third parties as crucial, and focused on getting regional hospitals 'on board' of the ZPR project. Meanwhile, networking sessions and expert meetings were organized to talk with entrepreneurs about how ZPR could contribute in achieving *their* goals; the prospect of creating new business activities 'around' ZPR – or making 'flowers bloom' – required sensibilities toward a complex of technical, organizational, economical, and legal challenges. In reaching out to care providers in the region, ZPR was promoted as a not-for-profit gateway for e-Health: through its novel technical infrastructure it would facilitate online services, as well as improve communication between different parties in the region.

Within the confines of the Project group, the multiple socket metaphor was enacted as a means to discriminate 'good' from 'bad' e-Health applications and services. In a landscape cluttered with e-Health initiatives, it was important to be critical about offers or propositions by third parties:

> "I think we should be in control [of whom to approach], and think of what company suits us best. So that we only attract the cream of the crop, to which we offer that multiple socket function. And not just any idiot with an idea." [program manager, February 10, 2010]

To the 'outside world', however, the metaphor became instrumental in communicating a sense of unity, suggesting neutral ground, development potential, and a low threshold for participation. The image of the multiple socket meant to convey the notion of a broad platform serving the needs of different groups, and posing no threats or risks to prospective participants. It echoed the promise of a technically accessible and politically 'transparent' infrastructure. Its political 'impartiality' was explicated as follows in a discussion on February 10, 2010 between the program manager, the RHIO director, and the CMIO of the teaching hospital about facilitating or generating new business activities:

> Program manager: "You say that those applications all belong to Zorgportaal. But you can also place those applications elsewhere; we will just be a multiple socket."
>
> RHIO director: "No but that's exactly what I mean. […] The business that we develop, it's intended to make Zorgportaal a non-threatening component that you can purchase as your infrastructure; that you don't have the feeling that you need to provide one of your own if you want to do any business at all. […] You have to make sure that you're the party of which I say: that's where I'll place it, and there's no risk for me to lose control over my product"
>
> CMIO: "and that it delivers, it delivers contact between all healthcare providers in the region {yes – RHIO director}, it delivers contact with patients {standards! – RHIO director}, it delivers standards {and the multiple socket – RHIO director} yes, but in a secure manner."

The CMIO, who was a member of the Steering group, never 'bought into' the metaphor as such. Among Project group members, however, the representation of ZPR as a multiple socket in which third parties 'plug in' their applications formed a dominant narrative in the early development stage. Although there was still little clarity on the technical and organizational requirements for this model of integration (or on its political and legal implications), the multiple socket complemented the blooming flowers metaphor in endorsing ZPR's envisioned role as an independent and non-partisan attribute in a newly envisioned infrastructure for the region. Like the blooming flowers metaphor, it prioritized a technical and economical framing of ZPR (a 'component that you can purchase') over concerns about its relation to health care practices, organizations, and citizens in the Rotterdam Rijnmond region.

After February 12, 2010, when the Infrastructure project leader openly disqualified the view of the portal as a multiple socket, this metaphor fell into disuse. Despite its inadequacy as a representation of the 'integration problem' that Project group members were attempting to define, the multiple socket metaphor persisted in derivative expressions such as 'plugging into the portal'. Such expressions continued to recur among project members in discussions about the endorsement of ZPR, where the latter featured as a 'neutral' platform or base where different applications could be *plugged into* or 'latched on to'; this idea was typically visualized in early architecture documents as a series of cylindrical structures positioned on a horizontally placed rectangle, much like pillars on a construction site.

Table 2 illustrates how the metaphors were enacted in relation to the view of the portal as 'the' gateway for e-Health in the Rotterdam Rijnmond region. Our descriptions show how different enactments of the blooming flowers and multiple socket metaphors prioritized a technical and economical framing of ZPR, while concealing the

Table 2. Endorsement

Imaginary	Metaphor	How it was enacted…	… and by whom	What it led to
Portal as 'the' main gateway for e-Health in the region	Blooming Flowers	Constructing the project as ***inclusive***, open, welcoming, outwardly oriented	Program manager; CMIO	Mobilization of prospective participants and consortium partners; product pitch for e-Health vendors
		Marketing the ZPR portal as a business opportunity	Program manager and Steering group members	
	Multiple Socket	Constructing the portal as ***neutral***, impartial, and non-threatening	RHIO director	

politics of technology and infrastructural work. This generativity of metaphors requires further reflection; in the following section we discuss what roles the metaphors played in our study, and how the analysis of discursive attributes can contribute to the study and development of IIs.

Discussion and Conclusive Remarks

Metaphors are not 'innocent' or neutral descriptors of abstract concepts. In our empirical description we presented them as operationalizations of sociotechnical imaginaries pertaining to 'integrated' and 'personalized' health care. As representations of an imagined social and technical order, metaphors can indeed be misguiding conveyors of infrastructural work. Our reconstruction of the emergence of the multiple socket metaphor shows how the program manager foresaw that the integration between applications and the portal would take on different shapes in different cases. The allegorical 'fit' between plugs and sockets, which suggest a view of closed and stabilized artefacts and standards (Bijker et al., 2012: 37), fell short in representing infrastructural work in a decentralized, highly heterogeneous network of interdependent actors.

As a heuristic device, the multiple socket metaphor prompted project group members to 'spell out' its meaning (Schön, 1996: 138) by reflecting on the underlying assumptions in the context of infrastructural work. Misguiding or not, the metaphor temporarily acted as a "powerful means of organizing work and intellectual practice" (Bowker & Star, 2000: 314) by simplifying abstractions, making them manageable, and supporting their circulation (Czarniawska-Joerges & Joerges, 1992, 1996). Viewed from this organizational perspective, Ellingsen & Monteiro (2008) have argued that the added value of metaphors to project work resides in their ambiguous and versatile character: if they work well, it is exactly *because* they are not precise representations of reality.

More importantly, our description of the two metaphors' enactments shows how they configured innovation as a definite, cognizable, and classifiable commodity. As such they were 'generative' metaphors, actively contributing to the way in which Project group members framed problems of exploration and endorsement in the development of the portal. The multiple socket metaphor pre-empted the contours of ZPR as something where things could be 'plugged into', despite the facetious representation of flowers blooming in a multiple socket. Both the multiple socket and the contiguous plug-in metaphor reduced the concept of infrastructure to a mere arrangement of objects, or a "thing stripped of use" (Star & Ruhleder 1996: 113): they prioritized technical preoccupations and solutions over the social and organizational dimensions of infrastructure, temporarily sustained a deterministic view of the infrastructural work at hand, and concealed the relationship between technology, human work, and users in this process. The blooming flowers metaphor helped to configure ZPR's economical infrastructure by structuring the manner in which ZPR's technical and economical relation to markets and innovation were envisioned. Our empirical data show how the problem of selecting third-party applications for the portal was linked to the classifications and rankings produced by the blooming flowers form.

The blooming flowers metaphor travelled beyond the confines of the Project group, but it required translations to circulate. Its playfulness best suited the Project group setting, where members convened most frequently, and where much of the actual development work took shape. In the Steering group, the project manager chose different terms to address the portal and the third party applications; our quote from June 14, 2010 nicely illustrates how she takes back the term 'blooming flower' and speaks of 'new activity' on the portal. Similarly, meeting minutes reported about 'third party applications' and the 'accelerated development of content' (ZPR, 2010; 2011). In an open letter to hospital directors in the region, the ZPR Board simply used the term 'applications/services' (ZPR, 2012). In order to enroll actors in more formal settings, such as the Steering group and Board meetings, imaginaries of integrated care and innovation perhaps required more conventional terms in order to be taken seriously.

The blooming flowers and multiple socket metaphors helped to change abstract concepts about markets, business cases, and innovation into comprehensible and non-threatening images. Their playful character may also have helped to sustain a sense of enthusiasm among Project group members, if only temporarily. Although we are unable to illustrate the latter point empirically, we believe that the blooming flowers metaphor conveys a witty and endearing view of innovation, exuding a sense of cheerfulness and detachment from the perceived (and often experienced) seriousness and harshness of the project's technological, economical, and political reality. It helped ZPR project members and other stakeholders to promote the imaginary of an open and inclusive portal project, and then sustained this imaginary by informing the manner in which 'promising' or 'potentially interesting' e-Health applications were viewed, even when the blooming flowers form was no longer used. The metaphor's playfulness disguised the fierceness of economic competition, the pervasiveness of conflicting interests and agendas, and practical difficulties in devising a sustainable business model for the portal. In this sense it contributed to a concealment of the politics of infrastructures (Winner, 1986; Star, 1999). Furthermore, it conveyed a sense of openness and inclusion in the innovation process that masked the normative choices it involves, while obscuring the materiality and politics of infrastructural work (Oudshoorn et al., 2004). As the differentiation between 'experiments' and what we termed as 'accomplished' applications illustrates, drawing the line between them remained an implicit problem. Indeed, most applications or initiatives were being tacitly *excluded* from the metaphorical "cream of the crop", or not included in the *selection* that was deemed necessary to 'accelerate' content development on ZPR.

As an attribute of infrastructural work, the multiple socket metaphor temporarily helped to construct the imaginary of a portal that 'provides' or 'facilitates' a unified and user-friendly technical infrastructure (i.e., based on a 'single sign-on' principle) and to express the anticipation of a future of 'integrated' and 'personalized' health care by rendering promises of uniformity, standardization and interoperability through the derivative 'plug in' metaphor. At the same time, its predominantly technological and economical enactment obscured the relationship between technology and human work – an element that has been extensively explored in CSCW literature (Hanseth & Ljungberg, 2001; Aanestad, 2003; Ellingsen & Monteiro, 2003, 2006; Winthereik & Vikkelsø, 2005; Monteiro et al., 2013).

Our analysis suggests that metaphors help to make project imaginaries definite, cognizable, and classifiable, and that in doing so, they can conceal the politics of infrastructural work. More than merely acting as heuristic devices in the development of IIs, we agree with Monteiro and Hepsø that they "act as forceful 'actors' that contribute substantially to the shaping of the technology […] as a powerful ally" (Monteiro & Hepsø, 2002: 146). Their coerciveness increases as they become more deeply engrained in the project's imaginary; having described their enactments as elements of sociotechnical imaginaries, we have shown how they contributed to the prescription of futures and agendas for ZPR, while at the same time drawing away the attention from the human work required in developing and maintaining infrastructures, and from questions about the relation between infrastructures and their users.

The implications of these observations reach much further than we were able to illustrate in this paper. Most importantly, we wish to signal that studying the use of linguistic attributes in IIs – and of metaphors and metaphorical expressions in particular – can lead to the insight that "it could be otherwise" (Woolgar & Nyland, 2013: 7). The act of 'spelling out' metaphors (Schön, 1996) can be likened to the 'unpacking' of technologies or interventions (Zuiderent-Jerak & Jensen, 2007), in that it reveals what is hidden or obscured, and therewith opens up a space for new imaginaries and alternative strategies. In the context of e-Health integration, alternative ways of framing the problems at stake may be crucial to overcome governance challenges or dilemmas (e.g., regarding the ownership of data, data distribution, surveillance, privacy, etc.). Inquiries into the reconstruction of underlying conflicting frames can help to devise such alternatives (Schön, 1996: 139), possibly leading to re-conceptualizations of 'infrastructure' and 'integration'.

By focusing on the generativity of metaphors in the development of the ZPR portal, we showed how they contributed in framing the problems at hand in a cognizable yet ambiguous manner. By diverting the gaze from sociotechnical and political complexities, metaphors have the potential to transform contested, disconcerting, or unsettling ideas into seemingly innocuous (or indeed favorable) images; as such, they actively contribute to the manner in which problems are defined, and how people and organizations are called into action. The potentially far-reaching consequences of metaphors as constitutive elements of infrastructures – elements that help to construe their ontological status and their imagined social order, and that are perpetuated and shaped by that order at the same time – deserve more critical scrutiny in research on IIs, as well as in the everyday work practices of project managers, developers, and policy makers. Engaged participatory research can contribute to redirect the gaze on those sociotechnical and political complexities, and to raise timely questions about the implications of imaginaries that bypass the materiality and politics of infrastructure; in that process, the act of 'spelling out' metaphors can open up spaces for alternative strategies in IIs. The use of metaphors and metaphorical expressions is indeed so widespread in e-Health (and in the field of information and communication technologies in general) that it easily escapes to the attention of people who live with them on a daily basis. Although scholars from different disciplinary backgrounds have long embraced the intertwinement of discourses and practices in their work, continuous research efforts are required to better understand the agency of discursive attributes in infrastructural projects. While the focus on seemingly insignificant or trivial attributes of social life is altogether a well-established practice in STS, we hope to have shown why the inclusion of discursive attributes in the STS repertoire is appropriate and recommendable.

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Notes

1 URL: www.zorgportaalrijnmond.nl

2 Between September 2009 and August 2013 the Municipality of Rotterdam and the Dutch Ministry of Economic Affairs subsidized the ZPR project with the aim to develop a financially sustainable health portal for the Rotterdam Rijnmond region. During this early development stage, various partners in the ZPR consortium made financial investments in the project as well.

3 'Bloemetje' is a diminutive of the Dutch term 'bloem' (meaning 'flower'). In its diminutive form it bears connotations of cuteness and sympathy, which are intuitively recognized as such in the Dutch sociocultural context. In common parlance, 'bloemetje' can also denote a flower arrangement given as a gift.

4 A 'multiple socket' consists of a "block of electrical sockets that attaches to the end of a flexible cable (typically with a mains plug on the other end), allowing multiple electrical devices to be powered from a single electrical socket". See: http://en.wikipedia.org/wiki/Power_strip (accessed: 8.10.2015)

5 'To wheel in money' is a literal translation of the metaphorical expression used by the program manager.

6 Curly brackets indicate overlapping utterances.

7 The first criterion contained the items 'citizen', 'patient', 'provider', 'others'; the second 'self-reliance', 'uniformity', 'communication', 'commercial activity', 'value for the region'. Items were scored with '+', '+/-', or '-'.

Brian Kleiner, Isabelle Renschler, Boris Wernli, Peter Farago, & Dominique Joye (eds) (2013) Understanding Research Infrastructures in the Social Sciences. Zurich: Seismo.

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Understanding Research Infrastructures in the Social Sciences introduces us to major quantitative data infrastructures developed in the social sciences (large-scale surveys, monitoring of cohorts, big international databases, data access and exchange platforms) and their activities (documentation, data harmonisation and dissemination, quality management, methodological innovations, training and maintenance). Indeed, how can we understand scientific work without taking into account the infrastructures that make it possible? This question has gradually permeated sciences studies, especially *Big Science* where sophisticated instrumentation is used to produce original data: particle accelerators in high energy physics, radio telescopes in astronomy, magnetic resonance scanners in the neurosciences, but also more conventional infrastructures such as herbaria in botany, observation stations in the Antarctic, etc. These material infrastructures greatly depend on organisational (planning and running of expeditions, launch of observation satellites) and coordination work (25 years to design and develop the LHD collider), logistic and maintenance work.

Although these infrastructures often have a very visible side owing to the gigantic nature of their instruments, buildings or collections, they also have a hidden side, notably made up of categories structuring the distribution of objects and activities: nomenclatures in chemistry, classification of conditions in psychiatry, protocols in biomedical research, etc. This invisibility stems not only from their apparent immateriality but also from the need for a certain degree of efficiency; researchers do not wish to be encumbered with problems relating to filing, logistics, procedures or maintenance. They desire immediate access to the topic of their research or the data they are seeking, put differently, to meet with success, a good infrastructure has to be invisible, together with the equipment making it up and the operations on which it depends, not to mention the foot soldiers carrying out these operations.

The book by Kleiner et al. (2013), is disturbing from this point of view since it precisely strives to make these infrastructures, which researchers and policy-makers alike would prefer not to see, visible. Who really wants to know about the research databases in the social sciences, the protocols and logistics underlying major surveys, or the budgets that need to be allocated to these or the associated institutions and skills that should be stabilised? Even within the social sciences, these infrastructures suffer from a lack of recognition. According to the authors of the book's first chapter, the researchers in our disciplines bestow even less recognition on these infrastructures than those in the natural sciences with respect to their instrumentation. The book targets social science researchers and policy makers concerned with the production of knowledge in order to increase awareness of the importance of these research infrastructures.

The book begins with two background articles. The first, by Renschler, Kleiner and Wernli, proposes a series of concepts to characterise these research infrastructures (RI). By extension, they cover non-specific technical infrastructures (telecommunication networks, IT systems, communication protocols, etc., as well as the associated technical personnel) important for research, and research institutions. However, the authors have opted for a restrictive definition centred on the supply of resources for research (quantitative data, methods and organisations, skills and instruments set up for collecting and processing data). They do not therefore look at the collections of audiovisual, iconic or textual media that are attracting the attention of researchers in the human and social sciences. They raise policy makers' awareness of the importance of the decisions and investments needed to maintain and develop the material and institutional aspects of these RIs. These infrastructures are embedded in and depend on research institutions, communities and practices and regulatory (e.g. concerning the respect of individual freedoms and the protection of privacy), administrative or technical non-specific infrastructures. The setting up of European Research Infrastructure Consortia (ERIC), the Consortium of European Social Science Data Archives (CESSDA) or the International Federation of Data Organisations (IFDO) lends them a new institutional anchoring. They evolve in relation to the needs of researchers and policy makers, as well as technological innovations, while conversely they influence research dynamics, creativity, quality standards and questions on the political agenda.

The second chapter, by Max Kaase, goes back over the genesis of and evolutions undergone by these RIs, since private data archives set up for the social sciences (on public opinion) in the United States in 1946, through to the establishment of national statistical services and the structuring of wide-scale and repeated international surveys (Eurobarometer, European Social Survey). Comparative research has given an impetus to methodological thinking (harmonisation of protocols, quality management, comparability, management of errors, etc.) and to a roadmap for European infrastructures and the setting up of e-infrastructures (remote access to data).

The book then presents eight RI case studies for the social sciences. These are documented in terms of history, end goals, concerned actors, practices and remaining challenges. Generally carried out by authors involved in these RIs, they are preceded by the cross-reading of Wernli, Renschler, Kleiner and Joye who highlights four main components of the work carried out by RIs in the field of social sciences: 1/ *Data documentation, curation, preservation, provision and dissemination* for which the cooperation between researchers and national statistical institutes has been given a new lease of life with the open data movement and the increasing interest in the reuse of qualitative data; 2/ *Data collection* (formulating questions, sampling, data collection procedures, setting up of panels and time series)*, harmonisation and interlinking* in order to make international and time-based comparisons possible; 3/ *Improvement of methods and methodological innovation*: quality control and continuous improvement approach, methodological thinking, documentation of the data life cycle (*Data Documentation Initiative* - DDI); 4/ *Teaching best methodological standards and training,* in order to maintain an international pool of skilled people.

Three chapters deal with efforts to coordinate and harmonise databases. Hans Jørgen Marker reports on the work of the CESSDA in terms of strengthening cooperation between European databases. Roxane Silberman discusses the European *Data without Boundary* network regarding the open access to State data: de-identification, access conditions (e.g. to tax or health data), remote and secure access (for researchers but also for firms), obstacles to sharing data, accreditation procedures. Louise Corti explores the British *Qualidata* case of an archive catalogue (notably for interview transcriptions) and its new challenges (archiving online surveys, blogs and micro-messages (notably tweets), data associated with publications (*enhanced publication*) and interoperability).

The ensuing five case studies relate to the running of major surveys. Dean Lillard addresses the international harmonisation of longitudinal data from national panels (*Cross-National Equivalent File* - CNEF). Janet Gornick discusses the *Luxembourg Income Study* (LIS). Rory Fitzgerald presents the *European Social Survey* (ESS), its operation and methodological evolutions. Paul de Graaf and Loek Halman overview the changes operated on the *European Value Survey* (EVS) focusing on opinions, attitudes and beliefs. Axel Börsch-Supan reports on the *Survey of Health, Ageing and Retirement in Europe* (SHARE). These authors describe RIs from their point of view as stakeholders supporting RIs and facing the instability of national financing. They write pleas in favour of the RIs rather than an analysis of their shaping and results. From this point of view, the book does not stand as a social study of RIs but the quality of the documentation provides fuel for further questions.

Three chapters then follow focusing on methodological innovation and then two on training. Willem Saris presents progress in terms of predicting the quality of the questions used in questionnaires. Ineke Stoop deals with quality management, protection against fraud, data documentation, transparency, metadata about survey implementation (paradata) and assessment of non-response bias. Joachim Wackerow discusses the establishment of a standard for metadata (DDI) in the social sciences. The two chapters on training report on expectations for research design and data analysis (Silke Schneider, Alexia Katsanidou, Laurence Horton and Christof Wolf) and on high-level seminars on methodology (QMSS – *Quantitative Methods in the Social Sciences*) (Angela Dale).

Finally, two chapters outline a number of lessons to be learnt from the experience of RIs in the social sciences. Markus Zücher looks at the institutional and political anchoring of RIs (dependence on project-based financing, institutional division of responsibilities). Kleiner, Renschler, Wernli and Farago conclude the book with an appraisal of what RIs do to the social sciences: opening up new possibilities, offering access to more data (e.g. for comparative work), improving quality and research efficiency, and converging research practices. They also outline the upcoming challenges stemming from the increasing difficulty of accessing potential survey participants (growing lack of interest in surveys, legal requirements), but also in terms of articulation with other types of data (geolocation, biological markers, digitally native data, qualitative data) and reuse.

This book might be thought of as a contribution to *infrastructure studies*. While it describes a series of RIs, it does not document concrete practices and assembling as its title (*Understanding…*) might suggest. It is more generally speaking a book drafted by the designers and promoters of RIs busy defending the cause of these structures. Both social science researchers and policy makers have ignored this cause, which is why a book targeting these very people had to be put together. However, for science studies researchers keen to reflect on the practices and dynamics of research, the book leaves something to be desired. The authors, who have the skills to question complex social phenomena, seem to have forgotten to use these skills when exploring their own work practices. The book is then a first step towards greater reflexivity within the social science community. Furthermore, whether it explores some challenges (political, institutional and financing-related instability; methodological and technological challenges; threats to human resources), it does not mention big data, while policy makers are beginning to be seduced by emerging actors (IT specialists, big data consultants) and arguments extolling the merits of new data science undermining the worth of costly major surveys.

Eric T. Meyer & Ralph Schroeder (2015) Knowledge Machines: Digital Transformations of the Sciences and Humanities. Cambridge, MA: The MIT Press.

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Knowing machines analyses the transformations taking place in the sciences owing to the use of digital technologies. It focuses especially on the collaborative use of digital tools in different disciplines, ranging from high-energy physics and biomedical sciences to the digital humanities and social sciences. It questions the transformations at work in the organisation and practices of research, in the relations between researchers and their public, but also in knowledge content. As they explore the way in which digital tools reconfigure knowledge production, the authors, Eric Meyer and Ralph Schroeder from the *Oxford Internet Institute,* question whether the distributed and collaborative use of digital tools and data are creating new openings for research.

The book targets researchers from all disciplines, from the physical sciences to the human and social sciences, insofar as they are all affected by digital tools. It also targets the information technology and science researchers, engineers and policymakers who support and guide the developments taking place. The various social groups, increasingly concerned by the production of knowledge, must not be forgotten either given the growing role they are being asked to play via digital tools and open data.

Eric Meyer and Ralph Schroeder study collaborative *e-research* and strive to qualify the collaboration made possible by digital tools. Thanks to institutional enthusiasm for research cyber-infrastructures but also to the initiatives of scientific communities, many developments have seen the light of day. The authors explore a series of thought-provoking cases, which are very well described and documented in the book: the networking of computers to provide enough calculation capacity to process the masses of data generated by high energy physics experiments (*Grid Particle Physics*); the involvement of countless non-specialist astrophysics enthusiasts (*crowd-sourcing*) to qualify photographs of galaxies (*Galaxy Zoo*) and hence drive the algorithms (*machine learning*), which will perform the same task automatically in the future; the pooling and processing of experimental data produced by many research groups in the field of medicine and genetics (*GAIN*); the collection of data about the entire Swedish population, which supposes public's trust; the sharing of digital photos of whale fins so as to monitor and study their population across the entire world and in the very long term (*SPLASH*); the involvement of amateur critics to interpret, annotate and discuss all the passages of a writer's work (*Pynchon Wiki*).

These case studies allow the authors to address a series of relevant topics: the conditions for sharing and circulating data; trust in research institutions; the building of compatibility of concepts, methods and instruments; the creation of a fair public-private partnership; the sustainable financing of research infrastructures (cf. Kleiner et al., 2013) and the conditions required for upholding collaboration; recognition mechanisms; and the transformation of relations between professional researchers and other actors in society.

Following an introduction, the book comprises of nine chapters. It starts with a focus on the conceptual framework and then provides a general description of the emergence of digital technology in research (financing, publication, visibility). These chapters are then followed by four others in which the authors present some very good case studies. The last three chapters offer a discussion of open science, the limits of digital collaborative research and a comparative reading of *knowledge machines*.

Eric Meyer and Ralph Schroeder draw inspiration from the work of Ian Hacking in order to identify "styles of science" as well as from actor-network theory to characterise the sociotechnical networks corresponding to each project examined. In the last chapter, the cases can be compared based on a model. This conceptual framework, as well as the references to Randall Collins, Richard Whitley, Terry Shinn and Bernward Joerges, allows the authors to qualify the role played by digital tools in each case. They question whether these tools channel the scientification of the sciences, whether they encourage the emergence of a consensus between researchers by conferring greater objectivity on the phenomena studied and whether they lead to the transfer of tools, methods and forms of work organisation between disciplines (e.g. crowd-sourcing, computer networking, data circulation). Using Richard Whitley's organisational characterisation of scientific disciplines in relation to their degree of strategy/functional dependence, they question whether digital tools are easier to embed in certain configurations rather than others. Then, in order to build more global analyses of the phenomenon, they call on Rob Kling's work on the development of information systems, focusing especially on uses and routines, as well as the notion of the computerisation movement (taking into account public communication on technologies) and Scott Frickel and Neil Gross's notion of the intellectual and scientific movement (the dominant approach to a problem). The authors query whether e-research corresponds more to a computerisation movement (demonstration of the advantages offered by digital tools) or to an intellectual and scientific movement (thinking on how to improve scientific approaches and practices). Eric Meyer and Ralph Schroeder claim to go beyond *science and technology studies*, which, according to them, are limited to case studies.

The problems pinpointed by the authors at the outset and the case studies discussed are of the highest interest. In the last chapters, they offer a comparative and overall interpretation of the situation. When it comes to open research data, they move away from the case studies and refer to Robert Merton's ethos of science, the pressures behind the promotion and criticism of free and open access to data and the problem of limited attention space. However, their thinking here does not return to the case studies. Similarly, rather than deepening the analysis of the cases described earlier in the book, the penultimate chapter on the limits of digital collaborative research introduces new cases. This chapter deals with the failure of a mapping tool owing to institutional and legal barriers. The authors also turn their attention to web archives, questioning their future, which they portray as potentially gathering dust, like any other archive when not used. They next launch into some general reflections about the limits of data sharing, the ethical challenges, and the questions of trust and economic requirements.

The last chapter, on the other hand, returns to the case studies as the authors model and compare these in order to draw some conclusions about the role of technologies in the transformation of sciences. The authors nevertheless underline that the outcome of this movement is still unsure, and that it depends on the disciplines. The transformations explored are not revolutionary.

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Brian Kleiner, Isabelle Renschler, Boris Wernli, Peter Farago, & Dominique Joye (eds) (2013) *Understanding Research Infrastructures in the Social Sciences*. Zurich: Seismo

Paul Wouters, Anne Beaulieu, Andrea Scharnhorst, & Sally Wyatt (eds) (2013) Virtual Knowledge: Experimenting in the Humanities and the Social Sciences. Cambridge, MA: The MIT Press.

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Virtual Knowledge addresses the new ways in which knowledge is produced in the humanities and social sciences (HSS) with the advent of digital technology. Refusing to limit knowledge to its cognitive dimension alone, Paul Wouters, Anne Beaulieu, Andrea Scharnhorst and Sally Wyatt, together with their colleagues from the *Virtual Knowledge Studio* for the HSS at the KNAW (Koninklijke Nederlandse Akademie van Wetenschappen), deal with knowledge as a set of practices linked to actors, instruments and institutions. They question what has changed with the use of digital tools: acquisition, representation and circulation of knowledge; knowledge itself; and the relations between researchers, disciplines, deciders and other emerging actors. They position these changes in relation to several global developments: growth of the science system and its opening up to various types of public; new forms of governance requiring researchers to report on their activities and their results; and the institution of *big science* as a model for all disciplines.

The hypothesis put forward is that technological change offers the ideal opportunity to analyse these transformations because it encourages the actors concerned to think about their practices, research topics and scientific productions. Researchers are thus urged to explain and formalise their practices and are exposed to epistemic culture shocks caused by the interdisciplinary coalitions they build. Thinking is fuelled by promises, disappointments, controversies and revised promises.

The authors have opted to structure their analyses around the notion of *Virtual Knowledge* rather than *e-science* (associated too much with the ideas of quantification and *data-oriented research*), cyber science (referring to infrastructure questions) or *e-research* (focusing on research practices), in order to concentrate on academic knowledge (which, in the field of Literature, does not just concern scientific research) and non-academic knowledge. As for the notion of virtual (rather than digital), it is used to underline a distance in relation to technology and refers to the potential and dynamics at work with respect to knowledge production conditions.

The book, above all, targets researchers in the humanities and social sciences and, indirectly, the institutions supporting and supervising the development of these disciplines. It comprises seven chapters exploring various themes: shifts in authority and expertise, emotional labour in scientific collaboration, uncertainty in relation to tools and models, the rhetoric of visualisation tools, massive data processing, broader access to data, and research promises and agendas.

All the authors focus on what is new in terms of knowledge production and on the effects of the transformations on actors, practices and contingencies. Several cases are analysed and compared in each chapter. Each author also takes particular care with the conceptual dimension of their analysis framework.

On the other hand, the authors of each chapter use different approaches to address the themes covered. Anne Beaulieu, Sarah de Rijke and Bas van Heur apply a neo-institutionalist approach and examine pre-existing sociotechnical networks to explain the tensions between reproduction and change in relations of authority and the legitimate distribution of expertise among actors. They study the database of an ethnographic museum, the sharing of street art photos on Flickr and a municipal site dealing with local cultural heritage. In their chapter on emotional labour in scientific collaborations, Smiljana Antonijević, Stefan Dormans and Sally Wyatt probe into ordinary practices, especially the work of articulation, persuasion and the care taken in interpersonal relations (sociology of invisible work in health by Susan L. Star and in the CSCW), and their effects on digital resources. They take the case of an international collaboration in economic and social history as well as their own experience writing this book. Matthijs Kouw, Charles van den Heuvel and Andrea Scharnhorst examine Paul Otlet's universal knowledge classification system, Buckminster Fuller's World Game simulation and Paul Forester's mathematical model of world balance. They explore different forms of uncertainty, underlining their creative potential and homing in on the advantage offered by the HSS, which are used to dealing with ambiguous data, uncertain relations and multiple interpretations. Having chosen to focus on visualisation tools (geographic information systems), Rebecca Moody, Matthijs Kouw and Victor Bekkers explore their rhetorical aspect and study the transformations to power relations (approach stemming from *government studies*) between experts, citizens and policy makers in relation to the ability of the tools to include different actors and the way access to data is shared. Their case studies concern the management of water and flooding, epidemics in livestock farming and fine particles in the air. Clement Levallois, Stephanie Steinmetz and Paul Wouters address *big data* as they explore the fate of sociological survey methods faced with flows of data from the daily use of digital communication networks together with the fate of decision-making models and theories in economics with the rise of neuroimaging data. The authors question how both sociology and economics (their knowledge questions, topics, practices and statements) respond to and/or are affected by such data. Hence, they report on the disciplines' empirical research traditions, put the claims for radical change linked to data-intensive research into perspective and study the reaction of researchers and their community. They underline the challenges linked to authority and the processes according to which novelty is assimilated. Clifford Tatum and Nicholas Jankowski study open access to data, conceptualising the notion of opening in terms of inclusiveness and transparency. They draw on Wanda Orlikowski's idea of the dual nature of technology, as both agency and structure, in order to examine changes in the formal and informal communication practices of researchers: publication of books and reviews, e-mails, blogs, and enriched publications. Finally, Jan Kok and Paul Wouters turn to the sociology of promises, narrative analysis and the study of research agendas in order to study the series of promises-demands in family history and populations, since the creation of large databases springing up from population registers through to the emergence of visualisation tools and the analysis of social networks.

All of these contributions are of great interest but it would have been interesting to cross-apply the different approaches to the different themes, for example by examining what institutions and pre-existing sociotechnical relations do to the emotional labour of building and maintaining digital collaborations or, conversely, by looking at how the work of attending to relations influences the distribution of scientific authority.

The book as a whole nevertheless constitutes an asset to research in these areas with its rich offering of multiple cases and its broad variety of themes and conceptual approaches. The result is not a cross-referenced thesis but rather a plurality of lines of attack questioning the extent of changes versus continuities, socio-epistemic reconfigurations, and the embedding of novelty in the pre-existing sociotechnical fabric. The book goes much further than simply deconstructing the claims of novelty and paradigmatic change. It reports on the temporality of the transformations at work, their ever partial reality, epistemic and institutional changes, and the challenges of legitimacy and authority.

Mongili Alessandro & Pellegrino Giuseppina (eds) (2014) Information Infrastructure(s): Boundaries, Ecologies, Multiplicity. Newcastle upon Tyne: Cambridge Scholars Publishing.

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The book *Information Infrastructure(s): Boundaries, Ecologies, Multiplicity* contains fourteen chapters presenting a variety of research on information infrastructures. The book is organized in four parts. The first part entitled "Designing and articulating information infrastructures" presents three studies promoting concepts that reflect the tensions inherent to infrastructure development. Mongili goes beyond the separation between users and designers in creative practices by showing how software developers and designers are always users of the infrastructural capacities and the technical environment they work in. Pellegrino presents the central concept of ductility to characterize contingency in information infrastructures, and by contrasting it to resilience, he shows how boundary objects are always enacted through a mixture of flexibility and consistency. Klein and Schellhammer use the introduction of a new automatic drug dispensing to highlight how existing legislation and industrial processes can prevail and hinder innovative practices.

The second part, "Information infrastructures as ecological tools," consists of three chapters that apply Bowker and Star's methods of infrastructure as ecology of practices, and show the constant adjustments between the different components of infrastructures. Poderi uses such ecological approach to ethnographically study the multiplicity of users' contributions in open source video game; Neresini and Viteritti analyse laboratory kits, these ready-made substances or material for procedures, and show how they are simultaneously fixed and flexible to use and interpret. Still in the laboratory environment, Crabu shows the active role of protocols in shaping infrastructures.

The third part, "Users, information infrastructures and mobilities," comprises four chapters. The first, from Denis and Pontille, addresses the tension between users and established contributors in a participatory geographic database, with opposite foci on visual rendering of the map vs. data coherence; Isabella shows, with the case study of a call center, how the category of "user" is constantly moving between managerial attempts to standardize work procedure and technicians' desire to keep some autonomy on their work. Additionally, Lazzer and Giardullo analyze online networks of actors related to online publishing (ebooks), and Mitrea discusses the concept of 'dispositif' in relation to scripts and programs of action, to think about shifts in mobilities in modern and postmodern societies.

The fourth and last part, 'On boundary objects, and on multiplicity,' presents four case studies (a spin-off company, by Miele; the threshold for advanced maternal age, by Turrini; science parks, by Cozza; ICT convergence, by Lugano), each presenting the relevance of boundary object as a concept to think about the management of innovation and the study of organizations.

It is remarkable that this book makes an equal theoretical and empirical contribution to the study of infrastructure, without prioritizing one over the other. All the fourteen contributions of this book are based on a rich variety of case studies, and if the breadth of results and the degree of involvement towards the case studies are different, they all present a strong commitment to the empirical analysis of information infrastructures. The reader will certainly enjoy the possibility of learning at the same time about such a variety of topics as automatic drug dispensing in Germany, science parks in Italy, or participatory mapping initiatives in France. But the book also shows a great richness in its theoretical contributions: through the various case studies, the authors interrogate and adapt building block concepts of infrastructure studies, with an emphasis on boundary objects, ecology, users, and design. The introduction of the book similarly constitutes a very strong summary of the history and current research in the study of information infrastructures, as well as the specificity of the research network on STS in Italy.

The accumulation of different contributions is particularly relevant concerning the notion of boundary objects. It takes part in lively debates in the field on the relevance and domains of applications of the concept (previously debated in the special issue on boundary object in *La revue des connaissances* in 2009 (volume 3, issue 1), and more recently with the book *Boundary Objects and Beyond* (Bowker et al., 2016). It makes a compelling case to consider situations where the introduction of a boundary object does not result in the expected stabilisation: on the contrary, various contributions show how boundary objects can become an obstacle to cooperation. Finally, the different contributions of this book show the relevance of the concept beyond STS, principally in organization and management studies.

The part IV on boundary object is very coherent: however, it is relatively harder to see the contributions made concerning the concepts of ecology and multiplicity, as they are not clearly defined in the introduction, and the reader is left wondering about the specificity of these concepts across all the different contributions. In the same vein, the four parts chosen to arrange the chapters of the book are not the most convincing: it is hard to see the coherence between them, and topics are frequently treated across several parts (such as the topic of "users"). Additionally, some editing work would have prevented the repetition in several chapters of similar theoretical parts (such as the literature review on the concept of infrastructure, the relevance of Bowker and Star…), as it is not always clear how they differ across authors.

If a strength of the book is to articulate empirical and theoretical contributions to show the variety of the STS toolbox, there is a tendency among some authors to simply present their research object through the grid of the STS vocabulary: for some chapters, knowing whether or not the object investigated constitutes a boundary object, or an infrastructure, seems to be the most important contribution, when this constitutes more a start than a result. Similarly, there is in several chapters the tendency to interchangeably use a variety of STS/infrastructure studies concepts for the same object (boundary object, program of action, script, etc.), without clearly identifying the difference between them. Finally, some authors state that their main contribution is to reveal the adaptability of device/processes that are supposedly rigid. It is coherent with the nature of boundary object, but this is hardly an innovative result.

More generally, it is unclear whether his book summarizes past research, or draws a roadmap of future research in the field. It is made clear that it is based on past events and panels, and the variety of chapters makes a strong case to show the vitality of the field of infrastructure studies. However, it is unsure if the reader can close this book and have a clear view of where the study of information infrastructures is going in a near future. Recent panels in STS conferences have raised the question of the next steps for infrastructure studies, potentially even beyond the term ("Beyond Infrastructure: Theorizing Alternatives and Absences," 4S 2014). Relatedly, the concept is now competing with others, such as "platforms" ("Cage fight: infrastructure studies vs. platform studies," 4S 2015), which calls for a closer interrogation of the specificity of infrastructure studies in the digital age. This book sadly does not engage with such questions, and does not to draw a prognostic of the future of the field.

Despite these limitations, this edited book is a great contribution to the study of information infrastructures, and shows the variety and vitality of this field of inquiry. The reader will appreciate the feeling of intellectual adventure that goes through this book, with the touching foreword by Geof Bowker or the introduction as an homage to the contribution of Leigh Star. Most importantly for the field, it shows the vitality of scholarship that does not come from an English speaking country, reflecting current efforts in STS to connect with larger researchers' communities.

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