Material Engagements: Putting Plans and Things Together in Collaborative Ocean Science

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Abstract

Programs of scientific research, like other formally organized collective practices, meet the materiality of the world in complex and dynamic ways. This intersection has important and underexplored consequences for the planning and practice of distributed scientific collaboration, including programs of large-scale infrastructure development currently underway across a range of scientific fields and national contexts. Building on ethnographic fieldwork around the Ocean Observatories Initiative, this paper advances two basic arguments about the relation between formal planning efforts and the material worlds they are meant to engage. First, we argue for the mutual plasticity and co-evolution of plans and the material world. Second, the mutually constitutive character of plans and the material world provides a critical connection between top-down governance over scientific collaborations and the bottom-up emergence that emanates from the material world, blurring notions of control and agency and capturing the complex relationship between science policy and local culture.

1. Introduction

Recent studies of computational development and scientific collaboration in the information systems, computer-supported cooperative work and information science literatures have made much of the potentially transformative consequences of new computational investments in the sciences. According to this vision, "cyberinfrastructure" will replace and extend traditional scientific efforts by relaxing the constraints of space and time. Cyberinfrastructure will radically extend the scope of scientific observation and experimentation, leading to new scales and possibilities of knowledge. Cyberinfrastructure will support new interdisciplinary communities built around fundamentally new models of openness and sharing. And cyberinfrastructure will change the scale, scope, and nature of the questions we think to ask, expanding not only the functional capacity but also the imagination of science. In all these ways, new computational infrastructures are predicted to lead to fundamentally different modes of science, practiced at different scales, oriented to different questions, and able to produce different kinds of answers to the increasingly pressing challenges and problems that science, more and more, is being called on to address.

But the research literature has had less to say about the distinct role of plans and planning in achieving these transformative and massively collaborative outcomes. The absence is all the more striking given that the dominant strategy for scientific change through computational transformation pursued by leading agencies like the U.S. National Science Foundation runs along the high (or high modernist?) road of planning.

Responding to perceived failures in past infrastructure development efforts in civilian science, major cyberinfrastructure investment vehicles (like the 'Major Research Equipment and Facilities Competition,' or MREFC, funding category described here) are fronted with elaborate and highly structured planning processes, predicated on meticulously detailed and highly predictive forms of planning sourced ultimately from the world of space and defense contracting. Such methodologies are often foreign to the experience and training of scientists in many of the traditionally 'small science' fields now targeted for transformation. New managerial approaches drawn from systems engineering and the world of large-scale project management are an increasingly central force and reality of collaborative life within these projects – a point that the formal disciplinary training of scholars in these fields continues for the most part to neglect. This in turn produces deep tensions in the practice and organization of collaborative work, as the ordering ambitions of the plan confront the messier worlds of practice and materiality that plans are meant to govern, and in this case, transform.

This basic dynamic can be shown through analogy to a parallel set of tensions in urban history and planning. James Scott [36], for example (discussed further below), has juxtaposed the synoptic vision of high-modernist urban planning against the forms of life and sprawl that naturally occurring settlements typically present, pointing to the desolation of planned cities like Brasilia as a natural outcome of this disconnect. Henri Lefebvre has contrasted the nature of the city in its medieval form – compartmentalized, messy, and teeming with life – with its industrial counterpart, tamed and reduced through acts of material clarification and simplification, as with Hausmann's nineteenth-century reconstruction of Paris into a city of open spaces, wide boulevards, and unobstructed sightlines [22]. Michel de Certeau has compared the knowledge of New York offered to the planner's gaze with the more 'pedestrian' knowledges grounded in the everyday practice of navigating the endless mess and diversity of its streets [5].

The same broad tension between planning and everyday practice, the clarity of order and the unruly mess of situated action in the world, shows up in the relationship between the work of planning in large-scale collaborative science and the messy forms of life they are meant to order and contain. In this context, plans do crucial work. They provide ways of containing the sprawl of distributed collective projects. They can help to coordinate actors and interactions whose number and range greatly exceeds the capacities of less formalized strategies. And they can support the forms of accountability that large public funding initiatives inevitably impose. But they also fall inevitably short, setting up tensions with the more local and mundane forms of practice they are called upon to govern and order. Plans are always a 'lossy' translation of the worlds they are meant to represent and control: absurdist fantasies of control aside, the map never fully covers the territory. And a key site of resistance or limit to planning resides in the complexity, multiplicity, and emergent qualities of the material world itself.

The paper that follows explores these themes in the worlds of large-scale planning and infrastructure development in ocean science today. Building on more than a year of ethnographic fieldwork with the Ocean Observatories Initiative, a $xxx dollar project currently under construction with funding from the U.S. National Science Foundation, we show how processes of planning and collaboration around new infrastructure development are rooted in stories and histories of physical development, the transformation and resistance of objects in the built and natural environments, and the economics of material resources. In all these ways, material 'things' are central to the practice and promise of new scientific initiatives, and the wider fields of knowledge and power they are meant to transform.

The paper that follows advances three main arguments. First, we bridge literatures around planning and materiality to argue that the top-down narratives that have tended to define infrastructure planning efforts in the sciences are neither sufficient nor fully deterministic descriptions of the material interactions that such efforts entail. Second, we argue the mutual plasticity and co-evolution of plans and the material world. Taken together, we lastly argue that the mutually constitutive character of plans and the material world is central to the understanding of how we theorize, represent and understand distributed collaborative practice and the transformative interventions of new scientific initiatives.

2. Plans and Materiality

Recent work in information science and the broader social sciences has emphasized materials, materiality or material culture as a crucial site or anchor of distributed collaborative practice and social life more generally [9, 17, 24, 30, 31, 35]. Building on streams of work emanating from organizational science [23, 30], information science [9, 16] and science and technology studies [18, 19, 20] this work has argued that social interaction inevitably lives within and operates through a world of material objects, things, and forms - and that changes to such material infrastructure may be deeply implicated in programs of social transformation (and vice versa) [6, 19, 35].

The new materialism largely takes one of two forms: a focus on the embeddedness of a single artifact in collaborative work, often invoking the boundary object [2, 21, 37]; or the deep and complex entanglements of practice within wider material assemblages [11, 34]. A single artifact may miss the complex forms of materiality involved in the both formative and transformative arc of collaborative work [26, 34]. Focus on a single artifact may also overlook invisible elements of materiality and emergent properties inherent in collaborative work, such as the unfolding of skill, the spatial-temporal processes in the lifecycle of an action, and the ability of materials to influence an action [34].

Similarly, sociologist Thomas Gieryn [11] has argued for the crucial connection between materiality and place, emphasizing the role of human action in shaping both the built and 'natural' environments. The materiality of scientific work shows up not just through the equipment and infrastructure developed to support the doing of science, but also in the very objects of inquiry those forms were built to study such as rivers, volcanoes, and air [15].

Important elements of this core materialist program have originated from and substantially transformed the study of large-scale collaborative practice in the sciences. The same broad arguments are made by Galison [10] who describes the evolution of new large-scale information technologies as part of the larger and evolving material culture of physics. While experiments in particle physics were once the size of a benchtop, they have expanded to the size of a city block. As such, the material cultures and scientific roles of experimenters and theorists transitioned through new technologically-enhanced methods for capturing the image of the natural world (complete with all of its complexities) and the logic of the natural world through new mathematical models that define relations between structures. The shift in materiality draws attention to new narratives that expand further than single laboratory walls. Galison's picture of physics brings about a distinct question of how coordination occurs between the disparate subcultures at work, where the interactions of a local culture with devices, theories and language define scientific organization and practice.

In the world of ocean science, Mukerji [27] connects the local scientific practice with considerations of social and economic contexts. She connects material forms found in localized collaboration around the deep sea to the spheres of political power that allocate and operate scientific resources. She argues that the practice of science moves to accommodate the sometimes vexatious changes in nature and that these moments can often spark struggles of scholarly power, such as controversies over claims, legitimacy and control.

Materiality tends to drop into the background, obscured by routinized, standardized artifacts and practices [31]. However, when change causes materiality to become an object of attention and evaluation, then new organizational forms are negotiated and sociomaterial interdependencies become more present and recognizable.

2.1 Plans and Collaborative Action

In these moments of readjustment, plans emerge as a central tool and critical challenge of reconciling the changing nature of collaborative work. While textual artifacts have long been studied within distributed work settings [43], there is room for a more comprehensive understanding of the role of plans in coordinating sociomaterial worlds across scales such as across workgroup, institution, and the state.

Approaching this gap is a growing body of literature that explores the concomitant relationship between artifacts and planning. One strand of this research focuses on the nature of plans and planning under the unpredictable conditions of hospital settings [1, 33]. These works situate plans within the infrastructure of collaboration, as a channel through which distributed actors coordinate, and which are dependent on events outside of the immediate condition of interaction [3]. These cases, alongside a rich body of literature initialized by Suchman's canonical Plans and Situated Actions [38], provide sophisticated empirical evidence for the adaptive nature of plans to real world changes. This perspective breaks from regarding plans as deterministic, law-like or all seeing, and instead distributes control across the intersection between planned and localized, purposive action and the shaping and sometimes determinative effects of the environment. Through reference to actor-network theory [4, 19], Suchman details that both human and nonhuman agency bears on any mobilized action, linking the nuanced relationship between social and material forms, and recognizing multiple sites of agency within all collective action. An exaggerated faith in the self-efficacy of plans or materiality that cling too closely to a single artifact (as opposed its complex embedding in wider sociotechnical "configurations") may miss the subtlety and indeed artistry of human action in the world. Assuredly, it will miss the complexity of influence emanating from the environment (as against more traditionally "human" understandings of agency). In the course of purposive action, humans respond to and work with the material worlds around them: "agency" is what results from this encounter, rather than a unique property that any individual component brings to the table.

In accord with Suchman's theories, Scott [36] argues in opposition of the top-down, determinism of plans and employs the notion of "metis" to describe the grassroots forms of "deep knowledge" that allow local people to respond to the complexities in their immediate environment. Much like Suchman, Scott gives priority to local culture, indicating that a discrepancy between local customs and plans can provoke misguided social, cultural and material effects. For these reasons, Scott asserts that plans need to be flexible enough to absorb local change, adopt contingency, and allow for emergence.

Together, Suchman and Scott indicate a deep interdependency between planning and materiality. The growing corpus of sociomaterial studies detailed above indicates that human and nonhuman relations constitute and inhabit complex and mobile interdependencies that must be reconciled within the arc of collaborative work. It is out of those relations that planning artifacts emerge to engage with the relevance of environment, artifacts and actions. Plans form a gateway to the politics within which collaborative work is enacted, in tune with the value-laden decisions embedded in their design.

Taken together, scholarship on planning and on materiality provides a critical connection between top-down governance over scientific collaborations and the bottom-up emergence that emanates from the material world, blurring notions of dominance and agency. Through empirical investigation we find that plans regulate both space and action, but are not deterministic over the arc of scientific work. Plans do not ossify because material conditions, social relations, scientific problems and the challenges of collaborative work exhibit a dynamism that prohibits sustained stability. Instead, we find a mutual plasticity and co-evolution of plans with the material world, instantiating plans as a powerful gateway toward new understanding of collaborative work. Our empirical work calls attention to the mobile, mutually constitutive character of plans and the material world, drawing a more complex relationship between governance and local culture.

3. The View from Ocean Science

Ocean scientists have long grappled with approaches toward overcoming the extreme natural obstacles associated with their field of study through material and technological interventions: sampling instruments, ships, buoys, submarines, cameras, sonars, and so on. In the early 2000s, the U.S. government issued major reports urging scientists to produce sustained, continuous ocean observation in pursuit of climate impacts across local, regional and global scales [32, 39].

More recent climate concerns have resulted in large federal investments into a brewing network centered on collecting real-time, time-series data from both fixed and mobile instrumentation across the global oceans, the Ocean Observatories Initiative (OOI). The network bridges the nation's leading ocean science laboratories under a unified infrastructure, intended to bring transformational technological advancements to ocean exploration, including telecommunication cables outfitted with sensors across the sea floor, autonomous vehicles and satellites.

The OOI is funded through an account within the National Science Foundation (NSF) that supports the construction of novel engineering facilities and equipment, the Major Research Equipment and Facilities Competition (MREFC). The MREFC provides unique opportunities for technological advancements whose costs are larger than some whole disciplinary NSF research accounts. Awarded organizations enter into an agreement with the NSF to follow a rigorous planning and documentation process that surpasses the detail of traditional disciplinary grants. The planning and management of large U.S. facilities has garnered major attention from the House and Congress, resulting in a variety of hearings, reports [41, 42] and reviews [8]. The result of these activities is a series of formalized evaluation phases in the planning of a large facility: (1) conceptual design review, (2) preliminary design review, (3) final design review (readiness), and (4) construction and operation.

The MREFC process is applied to a number of diverse construction projects, such as astronomical observatories (ALMA, ATST), high tech ecological research platforms (NEON) and earthquake simulators (Network for Earthquake Engineering Simulation) [40]. The application of the MREFC across very disparate cultural divides has garnered attention from policymakers and collaboration researchers interested in understanding how to best support collaborative practice, particularly around planning and management of large facilities [25]. The increased scrutiny of the MREFC planning process places plans as an important site for identifying specific points of current scientific concern and also provides new insight in understanding the support of large-scale collaborative initiatives.

The following empirical examples are drawn from field work conducted between November 2012 and April 2013 at laboratories affiliated with the OOI at Woods Hole Oceanographic Institute, University of California San Diego, Rutgers University, Oregon State University, and University of Washington as well as unaffiliated offices in New Jersey and at Cornell University. These laboratories and offices were selected for the relationship of their members, past and present, to the construction and development of the OOI. We toured laboratories as well as both formal and informal workspaces (offices, conference rooms, docks, museum spaces) collecting information about physical organization and developing field notes about participants' interactions with space and technologies. Observations were documented through field notes and digital photographs. We conducted 23 in-person and 8 remote semi-structured interviews, ranging from one-two hours in length. Interview questions were designed to capture current individual work practices within the OOI, the role of formalized planning in organizing individual, group, and project-level work practices, as well as shifts in practice from previously held positions. Fieldwork materials were analyzed and the emergent themes on the materiality of plans and planning were identified through successive rounds of qualitative coding following grounded theory principles [7, 12]. Nearly every participant emphasized tensions with developing, adhering to, and with the unfamiliar formality of plans and planning in the OOI.

3.1. Plan and stuff: how planning transforms the material world

Through our participants we see that the OOI's plans reconcile a number of material and temporal forms to identify the types of resources that need to be created, curated, moved and removed in order to fulfill project goals for building new research facilities. The OOI's construction from this perspective depicts a traditional understanding of how plans intersect directly with the material world by defining a series of physical builds. Here, we enumerate a few of these intersections, where changes in the material world emanate from plans.

The OOI's plans detail the number of intended deployment and maintenance cruises, the types of core instrumentation that will operate from its inception, and the locations in which that instrumentation will be deployed. Our participants detailed the ways in which the OOI will bring about shifting ship schedules as it occupies vessels for operations and maintenance of the instrumentation, which will also reconfigure the distribution of locations ships travel to in any given year. Multiple participants expressed their concerns regarding the limited number of ships available in the field for scientific use which, alongside the looming threat of sequestration at the NSF, will likely reallocate the funds given to ship time and place increased incentives toward OOI locations. Additionally, many participants described that the configuration of scientists on these ships will likely shift, as more technicians become involved in operations and maintenance of their instruments. Participants are concerned that the OOI will also remove the need for repeated cruises for research purposes to the instrumented locations, which also removes the necessity for researchers to have their own instrument development or hands-on deployment. This configuration also introduces an increased need for time in front of the terminal to validate, process and analyze data.

We also see that plans directly impact the spatial arrangement of affiliated institutes in two ways: firstly, through a reconfiguration of laboratories funded by the OOI, and secondly, through a spatial negotiation with organizations in locations of interest for the OOI's constructions. Participants described the ways in which the internal implementing organizations of the OOI reconfigured their laboratory spaces to accommodate the new instrumentation development, evaluation and testing. For one engineer, the reconfiguration included micro-scale changes such as bringing in new microchips within sensors that had not been previously used in a lab, and another engineer detailed the development of new battery packs that will carry the required voltage of new machinery. Participants also described larger-scale changes such as building new pools for instrument testing, or one project scientist's need to raise ceilings to accommodate the maintenance and testing of new rovers in their laboratory, and many described the construction of entirely new rooms or even new buildings to store and evaluate ocean gliders. The shifting and augmentation of staff funded to carry out this work also necessitated new architectures, and new spatial configurations and relations such as the assignment and construction of new offices and joint workspaces. Built into the OOI's plans are the primary steps necessary for each implementing organization to accommodate the new spatial requirements within laboratories and offices.

Secondly, many participants pointed to the ways in which the OOI's plans to build in specific locations necessitated the rearrangement of spaces not funded to construct the OOI. A notable example lies within fishing areas. Particularly participants on the West Coast described the involvement of fisheries, fishermen and fishing organizations in the delineation of specific geometries in which the OOI cables could be laid on the ocean floor, helping to determine the optimal reorganization of their fishing routes, where traps and netting would be laid, and calculate what effects the rearrangement might have on the marine industry's annual harvest.

Through our conversations, it became clear that the OOI became a focus of many different dialogs about the earth, submarine hydrothermal systems, energy, and the surface of the planet. Therefore, many stories of our participants involved the many existing systems of research and industry which became aligned with the goals of the OOI and were directly reorganized, both spatially and organizationally, around its plans.

3.2. Stuff and plan (I): the built world pushes back

While plans define interventions with the material world around them, they are also affected by changes in the material world, even changes in the materiality and design of artifacts developed within the scope of the plans themselves. The built environment itself can be subject to erraticism, sometimes altering the course of plans in momentous departures. A notorious example of this impact can be found in the Deepwater Horizon oil spill of 2010, in which a BP-operated drill in the Gulf of Mexico exploded, resulting in many lost lives, both human and marine, as well as over 210 million gallons of oil whose removal required the reconfiguring of the entire national scientific budget, and reorganized scientific studies in the area (where some moved into the area to study effects and others were now launched into new directions) [28, 29].

The Deepwater Horizon oil spill details an emergent phenomenon that impacts at an international scale, but built material and spatial volatility may flow from more and less localized events. A more subtle example of pushback from the built world on the OOI's plans emanates from a series of material changes within oceanographic observatories. One particularly interesting informant was a prior senior engineer, who had previously worked on the development of a power supply for cabled observatories funded by a grant from NSF (prior to the start of the OOI). He described how he was awarded an NSF grant for the development of a novel underwater profiler and the planned trajectory of this grant was affected greatly by unforeseen changes in the built world surrounding its development. The motorized profiler moves up and down a mooring cable that is anchored to the seafloor and transmits data back to shore via communication cables. The engineer's profiler mooring system was planned and funded for deployment at a cabled observatory in Hawaii, fittingly called ALOHA. Leading up to its deployment, a collaborating group of engineers and scientists developed the profiler specifically to mobilize and test in the conditions of ALOHA station. However, the ALOHA observatory was significantly delayed and when the mooring system was ready to deploy, and ALOHA was clearly not ready.

The engineer described how the profiler's plans were reorganized around a deployment on the newly laid cables of the Monterey Bay observatory node, MARS, and his research team was tasked with a new set of environmental conditions for mobilizing and testing the profiler. Many participants described the unique facility at Monterey Bay and the advantages of its quick testing turnaround without transits and bad weather, and the available resources of ships and ROVs that are helpful to testing on the seafloor. While the NSF funded the Monterey location for any and all scientists to test their instruments, our participants described that the cost for testing at this location is more expensive for scientists by a factor of five when the testing is not affiliated with the OOI. Therefore, the reallocation of space for the testing of the profiler jettisoned a new negotiation over the politics of those available resources and prioritization of tasks within the increased time and budgetary constraints.

The day the MARS system was powered up for the very first time, the senior engineer was prepared for deployment with the first components of the mooring system. As soon as the MARS node was powered up and operational they were going to install the moorings. The power was successfully switched on under the engineer's surveillance, but it only ran for eighteen minutes. A high voltage connector unexpectedly failed, rendering the cable unusable and resulting in close to one million dollars in repairs and almost a year and a half of recovery.

Unable to deploy at ALOHA or MARS, the senior engineer faced the pressures of reorganizing around increasingly bounded time and available grant money, culminating in the decision to build an ad hoc cabled test-bed for the mooring system in the Puget Sound, near the University of Washington where he was employed. He laid his own cable and completed the mooring grant with a successful shallow water deployment.

As luck would have it, the OOI team based at the University of Washington observed the successful deployment and the profiling mooring systems were procured for three sites of the OOI, adding new items to the OOI MREFC plans. Because of his knowledge of the profilers and previous work, the senior engineer was then brought back into the OOI and put in charge of ensuring the profilers' long term durability in the water. OOI plans were reconfigured to include a new organizational chart in which the engineer became the lead for the secondary cables and connectors and the "deep profiler", which is an improved version of the motorized mobile profiler he had tested in the Washington waters. The engineer and his research team were provided new long-term funding through the construction money of the MREFC. And, the engineer was fastened to an integrated schedule for all infrastructure builds during the summer of 2013, punctuated by a series of deployment cruises off the West Coast.

In the above case, plans detail the organizing of a specific set of material assemblages between development, deployment and testing of the profiler, but do not necessarily initiate a top-down narrative, as per Suchman and Scott. Plans themselves here were impacted by change emanating from an unforeseen shift in the built, planned world, as the profiler had to be relocated when cabled facilities experienced delays. The existence of plans does not define any certainties or determinism. Moreover, plans for the profiler, laboratories and OOI all evolve, and evolve mutually, within this example.

The profiler deployment also demonstrates how emergent changes in the material world have direct consequences in the arc of scientific work. Incremental changes in the plans in reaction to noted events within the material world highlight relations, connections and dependencies, and in this case, also provide insight to the dynamics of a somewhat serendipitous aligning of the OOI with the engineer and his profiler system.

Lastly, plans are a formation and control of space and time, indicating different social, material and temporal arrangements, including bureaucracies, social control, regulation, division of labor, division of knowledge. The OOI's plans subsumed the profilers into the formalized, bureaucratic process of the MREFC and specified the schedule for deployment within an early infrastructure build. The knowledge of the engineer remained a valued asset and his ascension in rank defined a new hierarchical organization that would accommodate the human power necessary to evaluate and deploy the new instrumentation within the boundaries of the OOI governance frame and schedule.

3.3. Stuff and plan (II): the natural world pushes back

In the example above, we have seen how details of the material assemblage – here, breakdowns in the equipment and built environment of research – can push back on plans. Such resistance may also emanate from changes and dynamics grounded in the natural phenomena that ocean scientists are called upon to study. Planned scientific activity in the earth sciences is particularly prone to the pushback of the natural world, often resetting the course of study for ocean scientists. This can be welcome, and indeed a key site or source of discovery – for example, new research initiatives that flow from the observation of unlikely underwater events or new behaviors or species of marine life. Or it can be harmful or destructive to planning and, as cautioned by Mukerji, the larger research processes it is meant to support – for example, when extreme weather or other unforeseen circumstances destroys scientific equipment or facilities and undermines the carefully laid plans and objectives of comprehensive research projects.

The flows of geological and oceanographic activity are often at odds with deliberate and designed systems of scientific research. The delay from station ALOHA in the previous example provides some insight into the distinct material challenges associated with the study of ocean science, and how these can impact, alter, and otherwise push back on the forms of predictable order associated with large-scale planning processes.

Extreme conditions on the sea floor around Hawaii proved to be a potentially insurmountable challenge of station ALOHA. An earthquake in Taiwan broke most telecommunication cables in one phenomenal event, eliciting a reorganization of resources to either fix the current systems or engineer new cable casings to withstand severe weather. Observatory artifacts and aliases would arise in data as a result of deep sea pressures over time leaving cracks in instrumentation and underwater volcano lava flows by Kilauea covering instruments. Often data anomalies could be traced to the marine mammals interacting with the cabled system in unforeseen and damaging ways. Each organic event brought about a reorganization of resources, labor and efforts to adapt and withstand the emergent constraints of the active ocean.

ALOHA's history is rooted in adaptation to changing natural conditions, provoking material shifts in the practice of science. At the time of ALOHA's inception, typical sustained ocean observation comprised of dropping a pressure resistant case full of batteries, sensors and a tape recorder into areas of interest then recovering the case weeks or months later. However, power supply, data storage and extreme temperatures often limited the long-term success of these observations.

Capitalizing on the overabundance of telecommunication cables after the dot.com bust in the early 2000s, researchers in Hawaii pushed for a reuse and repurposing of fiber optic cables left by failed cable companies [13]. These cables were known to withstand the severe durability challenges associated with cross-basin distances and allow for interaction overseas, removing the previously held battery time constraints by placing continuous, real-time and more condition-resistant connectivity.

After many trials in the development of a cabled observatory, the ALOHA observatory became a last effort in the cabled reuse domain in 2002, just before the NSF decided to not invest in retired cables. The goal was to reuse one of these old cables at station ALOHA 100km north of Oahu [13, 14]. As one principal investigator described, there are 25 years of history at ALOHA so other collocated NSF-funded researchers had the opportunity to go out to maintain a time-series station in that location. He described that once a month researchers took a ship out for 3 days and made measurements from top to bottom. At the time, there was thinking that a cabled observatory would reduce the cost by having robotic measurements like a moorings system with a crawler reporting back in real time continually.

The ALOHA system started in 2002 but through both documented histories of the system and through our interviews we learned there were significant technical difficulties and problems arising from capability to withstand natural oceanic activity. Cracks in the pressurized casings, connector failures and data validity issues were provoked by bad weather, changes in high pressures, and freezing temperatures. Participants on the West Coast, largely engineers involved in instrument testing, described the significant deployment delays from both the emergent, organic oceanic system and concerns arising from negotiations between industry telecommunications companies, universities, and the National Science Foundation. In 2007, cables were laid with consistency, sensors were finally placed on the cables, and instrumentation was connected to the cabling. By 2008, ALOHA became an operational cabled observatory providing real-time data through submarine fiber optic cables about ocean sounds, temperature, salinity and currents. Through participants internal to ALOHA's operation and those who externally rely on its resources we found that ALOHA's planned construction, much like any other facility build, does not occur in a vacuum and is subject to emergent changes within the natural material environment.

4. Discussion

As the above sections describe, plans and planning play a crucial role in organizing large-scale collaborative ocean science, aligning the cascading roles, materials and time scales necessary to build, operate and maintain both the machinery and collaborations to support scientific work within the OOI. Plans call new material and human orders. Material changes emanating from plans can be as nuanced as new protocols for a hyper-local laboratory practice, or as pronounced as reestablishing relations between the scientific initiative and the state or the broader public.

Plans act as a kind of scalar vehicle, moving between and coordinating across scales ranging from the local (in space and time) to the national and global. Plans' raison d'etre is to balance economic, political, cultural, organizational, material and temporal forms into a single coherent trajectory. Plans act as an instantiation of values and a boundary object across scales, relating physical space, social interaction and individual action. Therefore, plans act as an important site for understanding the blended nature of collaborative work. Plans in the OOI, for example, reflect academic (academic institutions, laboratories, and scientist affiliates), political (MREFC, climate policy), public sector concerns (education and outreach programs), and private sector concerns (industry procurements).

Plans 'bend' the natural world to their purposes, and give rise to (vast!) new infrastructural assemblages and complexes of equipment that may change what we can know and imagine about the natural world. Plans identify the human and nonhuman resources necessary to accomplish overarching scientific goals, curating existing resources and imposing new material forms to support the alignment of the local culture to that of the broader arc of scientific work. In accordance with Suchman and Scott, we see that plans enacted from the top-down, like the OOI, act as a mediator between local resources and global goals and strategies.

For all that, the material world pushes back: escaping, altering, undermining, and limiting the efficacy of plans and planning. Both plans and material artifacts can be more and less plastic, more and less active, more and less transient, and more and less uniform. Both plans and material artifacts can transform and evolve.

For this reason, changes in the material world elicit layered effects that may extend further than the environment bounded by any plan (e.g. the relation between shifts in ALOHA plans and shifts in OOI plans). The boundaries of an emergent change bleed into changes within even formalized plans. Both the built and the natural world are subject to emergence and elicit a reorientation of scientific goals, economic constraints, social and material organization and promised technical capabilities.

5. Conclusion

Like Lefebvre's and Scott's urban planners, architects of the OOI face a central tension and discrepancy between the ordering ambitions of the plan and the messy, emergent material worlds in which those plans are enacted. While plans assert control over the material world, plans are also subject to changes and pushbacks within the material world. We view plans as a reflection of the evolving material world and an important site for gaining new perspectives on the dynamic reconfiguration of human and nonhuman dependencies in collaborative scientific work. There is a complex and evolutionary relationship between plans and the material worlds they represent and attempt to reshape. Yet, these complex interactions have yet to receive adequate attention in the research literature around large-scale collaborative science.

Large-scale computational investments in the sciences have promised transformational consequences for scientific discovery, local practice and national concerns. Designers of new large-scale infrastructures have to reconcile a number of competing scales and interests into a single trajectory within their plans, critically centered on the economics of available resources, changes in the relationships between humans and things, and the material engagements which constitute their plans. In this context, plans act as a scalar vehicle in the development of infrastructure that coordinates and captures the range of coordinated objects from national concerns and political forms down to the material engagements of the scientists and engineers. The complex and multifarious interactions between materials and the social world can often be obscured in favor of a systems approach to designing infrastructure: a focus on commissioned materials, science products, instruments and locations and on human organization, cost of labor, and labor time. However, we see through the OOI that materiality and the social world are entangled in more complex ways than the plans alone will delineate.

Materiality has proved integral to the accurate representation of our participants and the stakeholders of plans, particularly in identifying status, condition and local work practices, and for signifying the roles of our participants beyond their titles. Many participants naturally grounded their stories in instruments, physical orientation and histories of infrastructure, which provides an understanding of how specific changes manifest in the everyday lives and local practices of those who touch the plans.

The crystallization of material changes within plans provides new insight into the politics of available resources and how those resources reflect empowered or underrepresented forms of science, groups and stakeholders. We can imagine that plans emanating from a ‘small is beautiful’ or bottom-up organization may reveal wholly different material engagements and relation to local culture from those seen within the large facilities of the MREFC.

We see through our examples that the physical location and proximity of projects to others can result in both costly reorganization or in advantageous attention and increased funding and additional human labor. We also see that plans can intervene with materiality in ways that affect the conduct of research, the narrowing or broadening of research agendas and the creation of scientific knowledge (such as the potential increased cost and decreased availability of ships as a result of the OOI). As we learn from the OOI and examples of big science initiatives in other disciplines (e.g. [11]), the reallocation of time, money, labor and space as a result of changes in the material world have direct implications for the way that science is funded, planned and carried out. Taken together, these shifts suggest new narratives regarding power and materiality, with deep implications for the governance and management of new scientific initiatives moving forward.

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