Long-term Temporality in STS Research on Infrastructural Technologies

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Abstract

This article reports on a literature study of Science and Technology Studies (STS) research on infrastructural technologies with a particular interest on how long-term temporality is conceived in these. Stances to long-term temporality are reviewed in three areas of research, each of them addressing a particular kind of infrastructural technology: Large Technical Systems, Virtual Information Infrastructures, and Emergent Technosciences. Analysis reveals a variety of positions on long-term temporality, including differences in how the duration and direction of temporality are perceived, as well as initial work unpicking the involved multiple temporalities. The article concludes by calling for increased awareness towards temporality and for extending the temporal scope of STS research.

Introduction

This article concerns long-term temporality and particular types of technologies, infrastructures that are inherently and fundamentally intended to last over extended time periods. In common parlance, the term 'infrastructure' refers to large technological systems that are essential to human activities, such as roads, bridges, rail tracks, water and electricity systems, communication networks, and the Internet. In this article 'infrastructural technologies' is used to denote interrelated technical, social, organizational and societal arrangements involving hardware and software technologies, standards, procedures, practices and policies together in support of human capabilities and activities. Temporalities associated with their lifecycle processes are long-term by definition, "occurring over or involving a relatively long period of time" (according to Online Merriam-Webster Dictionary).

My fascination with the topic of long-term temporality has its roots in a longitudinal study I have carried out as part of the Long-Term Ecological Research (LTER) Program. For the US LTER Network, the long-term perspective is a pervasive and important consideration not only with regard to the long-term scientific study of ecological and environmental phenomena and processes, but also with regard to data curation, information management, technology design, infrastructure development and maintenance, research collaboration, network governance, etc. This observation was in stark contrast to my prior experiences from working within the discipline of Information Systems where the issue is rarely considered, and when it is, this happens typically in relation to something perceived as too routine to be of interest for research, such as legacy systems and maintenance work.

In the LTER context, the founding idea for the LTER Program was to scale up both spatially and temporally from typically small-scale and short-term ecological studies. The time scales for the LTER research span from months to centuries whereas the most ecology studies deal with time scales from hours to months (Callahan 1984). According to Wood (2008), who analyses temporality in research on interactions between social and ecological systems, every discipline has a preferred *object of inquiry* that is associated with a particular temporal horizon, thus disciplinary specializations embrace certain temporal assumptions and associated time-dependent theories, concepts and instruments. This was the notion I started with in 2010 as an IAS-STS visiting scholar as it went well with what I had learned about ecological and environmental sciences. The intention of this article is to proceed a bit further into what long-term temporality entails. My initial hunch was that studies of technologies in STS may span longer historical time periods, and that long-term temporal scales are more common than, for instance, in Information Systems. This has proved true. Thus, this article assembles a range of STS literatures and analyzes how the 'long-term' is understood in the three identified domains of research, each addressing a particular kind of infrastructural technology. I will first report on the literature on the seminal STS work in Large Technical Systems, continuing with Virtual Information Infrastructures, which comes closest to my ongoing research interest, ending with Emergent Technosciences, a topic a colleague pointed out to me. The article finishes by a discussion and some concluding suggestions. Through the review of this literature I firstly explore how the 'relatively long period of time' is understood in each of the research streams. Secondly, I explore whether the 'long-term' has a direction: is it about the future or past temporal scope, about the prospective or retrospective horizon of time? In addition, with each of the streams of literature I try to stay attentive to whatever kinds of temporally related issues are addressed.

Large Technical Systems

Since the 1980s historians and sociologists in STS have studied infrastructures. Large Technical Systems (LTS) thinking finds its roots in Thomas P. Hughes's monumental work *Networks of Power, Electrification of Western Society, 1880-1930* (1983) where he showed that the electric system resulted from a decades' long creative process during which existing technologies were slowly and gradually improved.

In LTS research the primary unit of inquiry are *systems*. Thus, in comparison to the majority of the previous work, technological invention and innovation are not conceptualized in terms of the most visible elements of isolated devices. Another original concern for LTS research is that explaining the development, functioning and societal implications of LTS demands understanding their *socio-technical* nature. Hughes and others therefore developed concepts to inquire how the sociotechnical fabric is woven, how it works, and how it intertwines with broader societal changes (van der Vleuten 2008).

Regarding overall systems development, Hughes identified a 'loosely defined' pattern with 'overlapping yet discernible' phases (1983): *invention, development, innovation, competition and growth, and consolidation* ensuing one another, whereas *technology transfer* phase may occur at any time during a system's life. Others soon added a stagnation phase to the model. Hughes's notion of *system-builders* brought human agency into the analysis of socio-technical system development. System-builders work by identifying *reverse salients* (elements lagging behind and restraining development) and translating them into *critical problems*. As these vary according to distinct phases, different system-builders dominate different phases. This notion emphasized how system-builders manipulate and align system elements in a top-down fashion, not paying attention to *conflict*. Later studies have examined system development as multiactor *negotiation* producing winners and losers; this allowed gaining access to the systemic, sociotechnical and contested character of sociotechnical change. Other concepts by Hughes deal with structural drivers of system development, such as *technological style* and *momentum*, and address economic performance, such as *load factor* and *economic mix*.

The phase model has, however, become criticized for its linearity. Joerges states already in 1988: "studies of LTS show that they never develop according to the designs and projections of dominant actors: LTS evolve behind the backs of the system builders" (Joerges 1988, 26), thus revealing a more complex terrain of LTS development. In spite of the criticism, LTS studies have carried out important conceptual work for the analysis of systemic and sociotechnical aspects of infrastructural systems. Researchers studying the phenomena of large infrastructural systems have adopted the LTS approach and the conceptual framework to understanding and analyzing socio-technical change. The empirical range of inquiry has steadily expanded, including roadway, railway and air transport systems, electrical grids, water and waste systems, telecommunications, and information networks (Coutard 1999; Summerton 1994). They have continued to develop more nuanced concepts differentiating between systems with different technical, geographical, economic and institutional properties, and their development patterns. Lately work has been conducted on the issues of system stability and change, particularly with regard to transition towards more sustainable transport and energy systems (van der Vleuten 2008).

With long-term temporality in mind, it is interesting to note that while the notions of 'large', 'technical' and 'system' have been subject to much discussion resulting in little consensus in the LTS, temporalities have received little attention. Thus, the temporal assumptions associated with LTS research have to a large extent remained implicit. Having said that, the seminal LTS works have demonstrated the need to pay attention to innovation processes over the long-term period to understand major technological developments and institutional changes (Hughes 1983; Mayntz & Hughes 1988). For instance, time scales in sociological and historical

LTS studies of infrastructural change range from decades to centuries. The studies are typically retrospective, linear accounts providing descriptions of LTS development activities over time, presented as belonging to different phases.

In retrospective research (which can be characterized as accounting for the historical temporal horizon, i.e. dimension from past to present) researchers have engaged in a reactionary approach of following the LTS development through time. This stance has protected them not only analytically but also temporally. Policy implications of LTS include the set up of protected 'niches' by policy-makers where new systems can be invented and where they can mature sheltered from the established systems until fit to compete (van der Vleuten 2008).

Virtual Information Infrastructures

The technologies studied in the work reported in this section continue the large-scale, infrastructural character of the systems studied in LTS. However, they are also different in that they are characteristically also *virtual* (a.k.a. *cyber*infrastructures). Virtual Information Infrastructures (VII) are integrated information and communication systems (or networks) that process and transport data, use human and computer protocols, standards, and memory, and offer digital facilities and services typically associated with the Internet. In comparison to the temporal uniformity of research on LTS, research on VII demonstrates more variety in how temporalities are conceived.

Research on VII is heavily influenced by the conceptual work carried out in LTS. In the pioneering study of an early cyberinfrastructure community, Star and Ruhleder (1996) selectively draw on the historico-socio-technical understanding of infrastructures in LTS research and merge this with their own understanding of infrastructures as situated, relational and practical. Through this convergence they propose that infrastructures are formed by the circumstances associated with the following dimensions: embeddedness, transparency, reach or scope (both temporal and spatial), being learned as part of membership, linking with conventions of practice, embody standards, built on an installed base, and becoming visible upon breakdown (Star & Ruhleder 1996, 112-113). Star and Ruhleder's notion has become widely cited and used as an important conceptual aid in socio-technical studies of cyberinfrastructure development. It is used also in the prime report by Edwards et al. (2007) on a workshop that explored LTS studies and the historical model in order to offer lessons to shape and guide thinking about present efforts at infrastructural development, especially for new scientific cyberinfrastructures. Edwards et al. build on, challenge and further develop the LTS historical model. For instance, they contest the notion of *systems* and put forward the notions of *networks* and *internetworks or webs* as more appropriate for analyzing and conceptualizing the dynamics and tensions involved in cyberinfrastructure development. Interesting from the point of view of temporality, Edwards et al. (2007) identify *time* as a base-level tension adding complexity to the work of infrastructure building, along with *scale* and *agency*. Temporal tensions are considered predominantly in terms of a mismatch between "short-term funding decisions vs. the longer time scales over which infrastructures typically grow and take hold" (Edwards et al. 2007, i). "The time scale in historical studies of infrastructural change is decades to centuries — considerably longer than most research projects in cyberinfrastructure!" (Edwards et al. 2007, 8).

Edwards et al. (2007) motivate consideration for longer time scales with an image of the 'Clock of Long Now' by Brand (1999) that chimes once every millennium. They posit that the 'Long Now' for cyberinfrastructure development is about two hundred years rather than the machinery-centered fifty-year frame (Edwards et al. 2007, 3). Bowker et al. (2010b) see this period as two suites of changes beginning to occur in the organization of knowledge and the academy: an exponential increase in information gathering activities by the state (statistics) and knowledge workers (encyclopedists); and the accompanying development of technologies (databases) and organizational practices to sort, sift and store information. During the same period scientists' communication patterns developed from 'men of letters' to 'n-way communication' through complex structures of international conferences and publishing, especially peer-reviewed scientific journals (Bowker et al. 2010b, 40-42).

From the long-term point of view, it is notable that Edwards et al. (2007) view of the 'Long Now' embraces emphatically the retrospective dimension of long-term temporality. The prospective temporal dimension is only touched upon in the report through recommendations for cyberinfrastructure practice and associated research policies and funding programs. Ribes and Finholt (2009) on the other hand put Brand's 'Long Now' notion to do very different temporal work in relation to their interest in studying cyberinfrastructure development projects and processes. In offering the notion as an organizing principle for analyzing the concrete work of planning and sustaining infrastructure they propose that the 'Long Now' is "the varied compendium of work done today with an eye toward generating a sustainable future" (Ribes & Finholt 2009, 377). This view of the long-term captures the present practices and the prospective perspective of the VII studied, the temporal dimension thus spanning from present to the future. In a sense both above examples fall short of the initial meaning of the 'Long Now' where "the idea is to extend our concept of the present in both directions, making the present longer" (Brand 1999, 29). Quite ironically, the temporal dimension of the 'Long Now', ranging from the past through present to the future, is most comprehensively captured in the notions of 'extended temporal horizon' and 'infrastructure time' by Karasti and others (Karasti & Baker 2008; Karasti, Baker & Halkola 2006; Karasti, Baker & Millerand 2010) who make no reference to Brand's idea. Instead they ground their conceptions on Star & Ruhleder's infrastructure notion and expand it through conceptual work based on their empirical investigation within the US Long-Term Ecological Research Network (Karasti, Baker & Millerand 2010).

In addition, in recent years there has been an increase in studies of ongoing, concrete VII development practices that have started to make the diverse temporalities involved visible. They point out how the VII participants actively do work to align what is naturally misaligned, i.e. funding cycles and scientists' career trajectories (Bowker et al. 2010a), multiple temporal dissonances, i.e. organizational, infrastructural, biographic, phenomenal rhythms (Jackson et al. 2011), and different temporal scales in collaborative infrastructure development (Karasti & Baker 2004; Karasti et al. 2010). All of these integrate understandings of the 'long-term' among multiple other temporalities. Increasingly VII are perceived to embody an emergent character, thus their development can be characterized as 'infrastructuring' (e.g. Karasti & Baker 2004; Pipek & Wulf 2009) or 'continuing design' (Karasti et al. 2010) rather than following the traditional approaches of intentional design and development. To support the study of these unfolding processes, some researchers are involved in a longitudinal manner with the studied communities (Karasti et al. 2010). Researchers with background in collaborative traditions of information system design engage in various types of participatory or action research approaches to intervene and collaborate in ongoing VII developments as part of their study of actual, emergent infrastructure practices (Karasti et al. 2010; Pipek & Wulf 2009).

Emergent Technosciences

The STS research reported in this section studies Emergent Technosciences (ETS) that are intensively *technology-mediated*; at least to an extent by exactly the kinds of virtual information/cyberinfrastructures discussed in the previous section. In addition, ETS such as bio- and nanotechnology, are *science-based*, i.e. they have a strong connection with novel developments in science and engineering. What clearly differentiates this area of STS research from the two previous ones is its *intense future-orientation*.

According to Wajcman (2008), at issue in ETS is *real-time analysis and assessment* of technology. Associated with this, researchers need to address the *dynamics of expectations* through which hopes, promises, and hype help to construct the *future* as a resource used for shaping innovation and socio-technical change in the present. In addition, at issue is *anticipatory governance* of the direction and practice of research (Wajcman 2008). This is a forward-looking, engagement-oriented, and results-seeking concept. It is defined as a broad-based capacity extending through society that can act on a variety of inputs to manage emerging knowledge–based technologies during the period in which such management is still possible (Guston 2010). The consequences of this convergence are difficult to anticipate because the research itself will reshape the object of analysis (Wajcman 2008).

The emergent quality, complexity, and uncertainty of ETS generate publicity as "facts are uncertain, values in dispute, stakes high and decisions urgent" (Ravetz 1986, 422). ETS presents distinctive challenges for research, assessment, and policy, combining intellectual, ethical, social, and political issues. Thus, the traditional model of science conveying its findings to policy makers is seen as inadequate for addressing the issues involved in ETS. Rather, Barben et al. (2008) argue that ETS occasions new approaches to the conduct of research evaluation and assessment that require the *engagement* of a variety of potential users and stakeholders in the production of knowledge, as well as new organizations for the integration of social sciences that span the boundary between knowledge production and public action. Some government institutions have proposed integrating social science research into technoscience programs at an early stage ('responsible innovation'), thus inviting also STS research to play a *formative role* in the context of ETS development (Barben et al. 2008).

Several approaches exist or are being further developed to anticipate the longer-term implications of ETS, such as forecasting, public deliberation, scenario development, foresight, and vision assessment (Barben et al. 2008). Forecasting, allegiant to technological determinism, is oriented toward accurate predictions ('looking into the future'; Brown, Rappert & Webster 2000), whereas the other approaches share a more pluralistic epistemology that suggests multiple futures and intrinsic uncertainty ('looking at the future'; Brown, Rappert & Webster 2000). STS investigations in foresight have focused on expectations, visions, guiding visions, future imaginaries, and emerging irreversibilities. Each of these has a different theoretical and empirical approach, and thus these also provide their own prescriptions for what to do analytically with the future. Nevertheless, they all are novel in their focus on early intervention, and in their use of methodologies (e.g. Felt et al. 2011) that have a nuanced relation to futures (Barben et al. 2008).

According to Selin, who analyses temporalities in nanotechnology, emerging technologies are particularly caught in time (Selin 2006). Using Adam's notion of timescape that includes multiple concepts of time ranging from rhythm and tempo to harmony and dissonance (Adam 1998), Selin identifies a diversity of timescapes in the evolving arena of nanotechnology. In the field that can be said 'to be in the process of becoming' time is implicated "not with linear neatness but with nomadic contrariness" and issues around time "conclude with the intricacies of complexity and contingency" (Selin 2006, 135).

The future-orientation of ETS poses challenges to STS research, some of which relate directly to the temporal aspects of futures of technoscience, while others concern researchers' orientation towards analysis/reflection vs. action/intervention. The 'anticipatory' approaches, where research characteristically emerges simultaneously and in interaction with the developing technosciences, are distinct from the more reactionary and retrospective activities that merely follow the production of knowledge-based innovations. Williams (2006) discusses the dilemmas of how far to go in seeking to influence change. With temporalities in mind Williams cautions particularly about what he calls the *compressed foresight*. There seems to be an attempt to look further into the future and map the technical and social outcomes in greater detail than previously has been the case. This can make these futures appear as largely determinate and imminent; as if the future is already assured, already here. In this process the gap between imagined and actual futures is foreshortened; our attempts at foresight, at anticipation of the future, are thus compacted and compressed: the future is constricted into the present (Williams 2006, 328-329).

Discussion and some concluding suggestionss

This literature study, albeit somewhat cursory, has illustrated that long-term temporality is perceived in a diversity of ways in different strands of research into infrastructural technologies in STS. First, in Large Technical Systems, a taken-for-granted historical dimension of temporality that clearly extends long-term over decades, even centuries, is emphasized. Conceptual models of socio-technical development and change in LTS entail an assumption of linearity of time bound in sequentially organizing phases. Second, the stream of research on Virtual Information Infrastructures, in turn, posits time as an important base-level tension in studies of cyberinfrastructures, consequential for infrastructure building. The tension exists particularly between short-term funding and the longer time processes of 'infrastructuring'. The duration of 'long-term' is seen as long as 200 years and some variety exists with regard to the direction of the long-term horizon. The conceptual foundations for long-term temporality are not well developed. In addition, some investigations have started to unpick multiple temporalities involved in the actual practices of scientific collaboration and cyberinfrastructure development. Thirdly, research on Emergent Technosciences has a pronounced future orientation, and some initial work within this field exists on the temporal heterogeneities within the future horizon. While temporal durations are rarely mentioned specifically, some articulations exist about the short-term and long-term prospective scopes of ETS, acknowledging that particularly long-term future dimension presents demanding challenges. The future temporal dimension is put forward as novel and challenging for the STS research, necessitating innovative methodological work, and invoking discussion about whether, to what extent, and how the STS research(ers) could/should engage with the practice and policy of ETS.

The study has also demonstrated that infrastructural technologies are a temporally complex phenomenon. According to my current understanding these cannot be explained solely by Wood's (2008) view about every discipline/specialization having a *preferred object of inquiry* associated with a particular temporal horizon, including time-dependent theories, concepts, and instruments. The temporal assumptions involved in each of the three analyzed strands of research can only explain part of the (long-term) temporal issues. The main point at issue here is that Wood's view on temporality focuses on *social-biophysical systems* as *objects*, whereas STS research on infrastructural technologies accounts for the studied *historico-socio-technical phenomenon* in a deeply *relational manner*, always accounting for the infrastructural technologies as situated in their particular circumstances. Similarly, instead of having fixed, disciplinary bound temporal assumptions about the preferred object of inquiry/studied phenomenon, the temporal assumptions in STS research on infrastructural technologies are explored in relation to their historical, social, technical and societal circumstances.

To elaborate the last point: The research on infrastructural technologies in STS has evolved during the past four to five decades to investigate not only the physical but also the electronic/virtual and emerging infrastructure constellations. Different generations of infrastructural technologies can be distinguished although there are also overlaps between the strands of research, for example, LTS overlaps with VII in study of the Internet, and VII overlaps with ETS in parts of scientific cyberinfrastructures. In addition, there is some continuity in conceptual/theoretical work (such as from LTS to VII) but there are also novel challenges, such as the future temporal horizon in VII and particularly in ETS, the addressing of which would likely benefit from increased cross-fertilization between these strands. The different infrastructural technologies have raised diverse ethical, political and intellectual issues within their societal circumstances. The three strands of research also mirror (historical) developments within the STS field denoting different perspectives and traditions. For instance, differences in how the STS research and researchers are involved in the societal discussions, practices and policies around infrastructural technologies. The issues of time and long-term temporality are intimately interwoven into all of these aspects of research on infrastructural technologies.

The analysis of long-term temporality through a literature study has been quite challenging as there is, with the exception of a few publications, not much explicit interest in temporalities in the literature. Hence, my first closing suggestion is to join those calling for more awareness of time and temporalities in research (e.g. Adam 1998; Ancona et al. 2001). My second concluding suggestion relates more directly to long-term temporality. Recently Pollock and Williams (2009) have criticized the existing technology studies literature in STS for the dominance of localist, snapshot studies of information and communication systems implementation. Simultaneously, they persuasively argue both for the temporal and spatial extension of the analytical scope for the investigation of technologies and infrastructures in STS. In other words, they argue for similar spatial-temporal extensions that the LTER Program initiated within ecology. Extending the temporal scope of research would allow for understanding and dealing with the broader factors and influences that have a significant effect on the long-term evolution of the technologies. I would like to stress, motivated by my background in Information Systems, that it is only through increased insight into these long-term processes that we can start to comprehend, support and plan for sustainability and longevity in (infrastructural) technologies.

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