1. Introducing Inverse Infrastructures

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> In the study and practice of infrastructural development to date, there has been an unfortunate tendency to emphasize what may be the excessively neatened and orderly views of system-builders, often to the exclusion of other, more partial, perspectives. (Jackson et al. 2007, n.p.)

INTRODUCTION

The current dominant paradigm of contemporary infrastructure[1] design is that of Hughesian large-scale technical systems (LTSs) (Hughes 1983). However, we see unprecedented infrastructures emerging that are not owned by governments or large businesses. They are not governed centrally or controlled top-down by government or industry as telecommunications, energy networks, and railways, for example, have been for decades. Instead, they are owned and developed by individual citizens or small businesses yet manage to mushroom into local, regional and even global infrastructures. Examples are Wikipedia, networks of privately owned solar energy systems, and citywide Wi-Fi networks. These user-driven, self-organizing, decentralized infrastructures, or *inverse infrastructures,* as Vree named them, reflect a radical alternative to the model of complex LTSs (Vree 2003; see Appendix I, this volume),[2] as we will illustrate.

The emergence of inverse phenomena is significant not only because of their increasing share in the infrastructure landscape. They are also a source of unexpected and innovative services, sometimes operating largely independently from and sometimes in symbiosis with existing LTS-like and/or inverse infrastructures. Moreover, because users play a key role in inverse infrastructures the latter promise to suffer less from traditional types of entrenchment and be more adaptive to evolving societal needs.

Meanwhile, however, the current institutional infrastructure landscape remains LTS-oriented. As a consequence existing regulation often hinders inverse developments[3] and renders them illegal (e.g. Weijers; Westerveld, this volume).

To address the growing gap between the increasingly inverse reality and traditional infrastructure policy we explore the recent emergence of inverse infrastructures in this book. We identify and characterize this new mode of infrastructure development that both contrasts with the LTS model and complements it. We signal the challenges and dilemmas which inverse phenomena pose and suggest ways to re-orient infrastructure policy.

EXAMPLES OF INVERSE INFRASTRUCTURES

To illustrate the inverse phenomenon we start with a set of examples from the field of ICT, in which Vree first identified the phenomenon and where it appears to be most prominent (Appendix I and II, this volume; Egyedi et al. 2009). A few such examples are:

- University groups that start connecting their computers at the end of the 1970s and the beginning of the 1980s using modems with conventional telephone lines and UUCP (Unix to Unix Copy Program), i.e. a small set of programs and protocols to transfer files. It is one of the origins of email, as we know it today and of a discussion platform called Usenet from which many other inverse initiatives would later spin off;
- Citizens inhabiting apartment buildings investing in a high communal antenna to receive more and higher quality foreign channels. The local cable networks installed to connect each apartment to the communal antennas later merged into a municipal cable network, and ultimately sold to commercial parties (see also Weijers, this volume);
- Citizens and organizations cooperating in providing wireless Ethernet for citywide distribution of Internet. Wireless Ethernet (trademark Wi-Fi) has become a very cheap standardized commodity that can be used to establish high-speed connections between nearby computers. With special software it becomes possible to organize computers in a web-like structure, which, using a technique called 'store and forward', can span city-wide areas. The advantage for participants in such a network is the low cost of Internet access that is achieved by sharing normal Internet connections (DSL) with more users. Since these connections are idle most of the time, sharing increases use efficiency. Of course, all communication that remains within the Wi-Fi network is free. Several citywide Wi-Fi networks exist. Some are commercial, some are sponsored by the municipality, but others are maintained by groups of volunteers (see also Verhaegh and Van Oost, this volume); and
- Radio amateurs using Automatic Position Reporting System (APRS) to offer location-based services. Examples of (real time) information that is of immediate value to local participants is data from weather stations, the actual position of vehicles, data from environmental sensors, emergency

messages, or general announcements. APRS uses a network on top of ham radio sets, and is connected to the Internet via gateways. Its use only requires a single, small investment from radio amateurs.

However, inverse infrastructures also emerge in areas other than ICT. Moreover, they need not be (highly) technical. The example of the pedibus, or walking bus, a phenomenon seen in neighborhoods across the continents, emphasizes this. A typical pedibus has its start when parents take the initiative to share the task of walking with their children to and from school in a system somewhat analogous to carpooling. Starting with perhaps two or three families, parents make a schedule for supervising the walks. As more families and increased numbers of school children join a pedibus group, specific meeting points for pick-up and drop-off are arranged as are times of departure. In some cases, series of more formal pedi-bus stops with posted schedules exist to accommodate the growing demand. It is not unusual for groups of 30 or more children to walk together under the supervision of parents. Motivating factors for the parents include decreasing both their own car use and the related, often unsafe, traffic jams in front of schools, and increasing their children's physical activity. The costs (primarily volunteered time supervising the group) are shared and low. While not technologically complex, the pedibus is an inverse transportation infrastructure that replaces both decentralized personal automobile and centralized public transportation.

CHARACTERISTICS

Vree (2003) coined the phrase *inverse infrastructures* to describe a mode of development that contrasts with those of long-established infrastructure LTSs. Drawing on the word *invert* – to turn upside down – these infrastructures are called *inverse* because they display general patterns of emergence and development that are opposite in nature from those of large-scale infrastructures familiar to us today.[4] Established infrastructures have been centrally controlled by governing bodies or service providers for many decades. New inverse infrastructures develop independently and outside the realm of centralized control. They are typically user-driven and self-organized. As the examples illustrate, the inverse pattern is marked by bottom-up investments made by individuals and companies rather than top-down government funding. They are not designed according to a predefined specification or blueprint as for example high-speed rail infrastructures, and often appear to emerge spontaneously. Although inverse initiatives are not without aim or direction, given their developmental characteristics, their outcomes are less predictable than those of their more designed counterparts.

Below, the most prominent and prototypical characteristics of inverse infrastructures are defined and examined more closely and contrasted with those typical of the design view on infrastructure development, which currently characterizes many infrastructures (Egyedi et al. 2007; see Table IIA.1 in Appendix II, this volume). They are a starting point for further exploration in the following chapters, and will be revisited in the concluding chapter.

User-Driven

Describing inverse infrastructures as user-driven, we refer to the roles of those who initiate, contribute to and/or manage the infrastructure development and/or application. They are themselves the end-users.

Increasingly scholars from different disciplines, turning their focus from the production of technological artifacts to their consumption, have shed light on the roles of users in technological change (Oudshoorn and Pinch 2008). Users may consist of citizens, individual consumers, households, individual professionals and institutions. These scholars have for example explored the influence of unexpected usage on subsequent product and technology development, and the involvement of users as active participants in open innovation (Chesbrough 2003). But they investigate less thoroughly the influences of users on complex technical systems such as infrastructures. Furthermore, in LTS studies users largely remain invisible, Joerges noted (1999, p. 280). Joerges attributes this to the tacit assumption that LTS users are passive and signals the increasing influence of users on infrastructural change, most notably in Internet developments. In this respect, the role of users described in the contributions to this book, some addressing Internet cases, increases our understanding of how individuals or small groups of users drive complex infrastructural change.

Self-Organization

A characteristic feature of inverse infrastructures is that of self-organization among users. It has interesting parallels with self-organization in Complex Adaptive Systems (CAS) in physics and biological sciences (Gell-Mann 1994; Holland 1995). CAS theory approaches self-organization as a mode of coordination in which control is dispersed and decentralized. This also applies to inverse phenomena. First decentral attempts are made to optimize a local situation. Subsequent participation from and interactions between an increased number of users then lead to emergent system behavior – emergent as opposed to designed – which lies at the roots of self-organization. Following from CAS theory, the *infra*-structure qualities of inverse infrastructures emerge to a high degree spontaneously. Indeed, inverse infrastructures are not designed or pre-planned by public or private institutions. Rather they are initiated and developed often by individual volunteers who themselves have invested in their part of the infrastructure-to-be. The voluntary basis of self-organization makes this mode of coordination both special and vulnerable should the volunteers lose interest. The volunteers self-organize because some form of coordination is vital to achieve the desired (infrastructure) functionality. In the pedibus example families in the same neighborhood agree on 'bus stop' locations and departure times. In more technology-based inverse infrastructures common agreements between users about the technical (de facto) standard to be used play a key role in creating sufficiently interoperable infrastructures and catalyzing their emergence.

Centralized and Decentralized Governance

Infrastructure governance refers to the coordination of infrastructure development, operation and maintenance. Finger et al. (2005, p. 242) distinguish between centralized, decentralized and peer-to-peer coordination mechanisms, each of which can be differentiated by the kind of decision-making involved. We view peer-to-peer coordination[5] as an extreme form of decentralization, and focus on centralization and decentralization as being most significant for the study of inverse infrastructures: '[a] centralized system uses a top-down approach, in which some centralized authority controls all major systems elements or operations.… In a decentralized system, decision-making is distributed throughout numerous agents. System coordination is realized by certain institutional arrangements, but without any active planning or direct intervention' (Finger et al. 2005, p. 242).

While (de)centralization is a recurrent theme in organization studies, scholarly and popular interest in the subject was rekindled with the rise of the Internet (Abbate 1999; Hughes 1998) and the work of open source software communities. To name a few famous books on the subject, in the book *The Cathedral and the Bazaar*, Eric Raymond (1999) reflects on the inner workings of such self-organizing communities, on the incentives that drive the volunteers that populate them and on the problems that arise. Taking a very different angle, Brafman and Beckstrom (2007) argue in their *The Starfish and the Spider* that decentral organizations are far more robust. Using metaphors, their spider – a traditional organization – has a central body that controls the whole establishment but also makes it vulnerable – smash the body and the organism dies. In contrast, their starfish – a non-hierarchical group – has several arms. When one is cut off, the organism survives and regenerates. Note that decentralization in volunteer-driven, self-organizing communities and professionally-driven organizations may differ widely. For example, global corporate decentralization by multinational corporations such as IBM and Siemens in late twentieth-century did not end hierarchy and centralized control (Schneider 1994).

Clearly, what is centralized or decentralized is relative to one's perspective and to the context under discussion. From the European perspective, for example, national or regional control of electricity is considered decentral (Lagendijk 2008) while in the context of inverse infrastructures, we see government control, whether local, regional, national, or supranational, as centralized. The perspective taken in the contributions to this book is that decentral control is out of the hands of public administrators and large companies.

Top-Down and Bottom-Up

The terms top-down and bottom-up are also determined by the perspective chosen and their context of use. We use them as twinning concepts together with centralized and decentralized governance (i.e., coordination, decision making, control). The directionality in development and/or control characterizes (inverse) infrastructures. Top-down influences typically originate in supranational, national, regional, or local governments, and in large (multinational) companies. Influence can be exerted through, for example, research and development investments and national research programs, municipal or national incentives for consumer demand, and legal and other regulatory forms of infrastructure control. Bottom-up influences on infrastructure development, in contrast, typically stem from technology users, citizens or grassroots organizations. The defining directionalities have also been called downward causation (top-down) and upward causation (bottom-up) (Van der Steen et al. 2008).

INVERSE INFRASTRUCTURES IN CONTEXT

Historical studies can illuminate the dominant paradigm of contemporary infrastructure design thereby providing the context into which we place the new developments signaled in this book. While inverse infrastructures resemble the early development of LTSs in past centuries, their emergence comprises key characteristics not seen in the past that are due to the dramatically different historical period in which they emerge. Today's institutional context of established governance frames most infrastructural change. Most of today's physical infrastructures in the industrialized world, such as railways, telecommunication, water supply and sewer systems, and electricity grids, arose as innovative, small-scale, local systems in the middle and late decades of the nineteenth and in the early decades of the twentieth centuries. They grew into large socio-technical complexes comprising not only technical components but also engineers, manufacturers, government regulatory bodies, industrial users, and individual consumers. Thomas Edison, for example, did not just invent the light bulb. He also designed business structures for electricity supply and contracts with consumers for companies that manufactured technologies for electricity and lighting, and for local utilities (Hughes 1983; Van der Vleuten 2006). Ultimately, these local utilities merged to become General Electric – a private American utility that provided a public service. The organizational structure of General Electric gradually changed as its scale increased.

In general, as early infrastructures grew, small private companies merged. They were subjected to new regulation, or even taken over by government. Consider nineteenth-century railways in the independent German states. For political reasons, systems of local and regional railways, originally both publicly and privately owned, were integrated into state railways in Bavaria, Saxony and Prussia, for example. Later, in 1920, these state and other railways were nationalized in the newly united German Republic to create one public rail infrastructure (Heinze and Kill 1988, pp. 126-128). Generally speaking, LTSs, often operating as public services, grew into centralized bureaucratic operations subject to government regulation, whether publicly or privately owned, and commonly enjoyed the status of protected monopolies.

Since the appearance of Hughes' milestone *Networks of Power* (1983), LTSs have been the subject of numerous sociological and historical studies that have brought nuance to our understanding of infrastructure development. (Badenoch and Fickers 2010; La Porte 1991; Summerton 1994; Van der Vleuten and Kaijser 2006; Van der Vleuten 2006, 2008). A number have created insight into the break down of monopolies in the last decades of the twentieth century as a result of deregulation and market liberalization (Coutard 1999; Summerton 1999). Largely these studies have focused on the centralized socio-technical systems that still dominate our ideas about the form infrastructures take. They have strongly influenced policy makers and strategists responsible for infrastructure development today.

It is in the contemporary social, economic, institutional and technical contexts of LTS-dominated developments that inverse infrastructures arise. They arise despite and because of the conservative nature of LTSs surrounding them. LTSs are difficult, if not impossible, to stop or steer in radically new directions (Hughes 1983, 1989). Inverse infrastructures arise despite the likelihood that '… mature systems suffocate nascent ones' (Hughes 1989, p. 461). While Hughes' wordings may be strong, his point is taken. Tensions between nascent and mature infrastructures cannot be avoided. Furthermore, these tensions are, as lucidly articulated by Jackson et al. (2007), 'both barriers and resources for infrastructural change'. Emerging infrastructures may lead to intense conflict because they 'have important *distributional* consequences, reorganizing resource flows and opportunities for action across scales ranging from the local workplace to the global economy' (Jackson et al. 2007, n.p.).

Tensions arise, for example, from clashes with the political economy in competing policy goals or investment models and where institutional structures such as legal frameworks cannot accommodate new infrastructure ownership models. However, tensions play a productive role in processes of change. In this book notably Jan van den Berg (this volume) will add a new perspective to Jackson et al.'s remark that tension is a resource for change.

The inverse characteristics analyzed in this book such as being user-driven, self-organizing and decentralized are not limited or unique to inverse infrastructures. If Hughes (1998) is correct, they fit in the historical development of the post-modern world. They reflect broad development patterns across contemporary society. While the processes of changing governance models, (de)centralization, and, to a lesser degree, self-organization have been addressed by infrastructure scholarship, the studies in this book shed light on facets, scales and directions of infrastructural change rarely recognized and explored.

THE BOOK

The early studies that identify inverse infrastructures focused exclusively on ICT cases. In this book we explore whether inverse developments also occur in other sectors. A cross-sectoral comparison is done to further determine the characteristics of this new mode of infrastructure development. The questions that underlie the chapters include: What incentives drive individuals to embark on and sustain inverse infrastructure initiatives? How do inverse phenomena relate to established infrastructure systems? Are they viable alternatives? What kind of policy changes are needed to avoid hindering – and possibly even to spur and catalyze – desirable and innovative inverse developments?

To answer these and other questions, the contributors to this volume explore inverse phenomena in a wide range of sectors, both within recognizable infrastructures and other less conventional ones. Employing and developing a variety of conceptual frameworks, they investigate the emergence of user-driven, decentralized, self-organizing infrastructures and compare them to LTSs. These investigations reveal alternate processes of infrastructure development occurring parallel to, and sometimes in conjunction with, the historically established LTSs.

We begin with a pair of theoretical chapters that address inverse infrastructural developments from different perspectives. In his chapter 'Inverse Infrastructures and their Emergence at the Edge of Order and Chaos: An Analytic Framework', Jan van den Berg explores the circumstances that enable the emergence of inverse infrastructures. He posits that the 'spontaneous' self-organizing activities which characterize inverse infrastructures emerge at the edge of order and chaos. He extends insights on emergent behavior from complex adaptive systems (CAS) theory to develop an analytic framework that explains inverse infrastructure emergence, a framework which is validated by means of a diverse set of cases.

In 'Mapping Institutional, Technological and Policy Configurations of Inverse Infrastructures' Rolf Künneke uses the dynamic layer model from institutional economics to argue that infrastructure systems contain a logic or rationale which explains their interrelated constitutive elements. Based on the logic underlying inverse infrastructures he infers a coherent set of inverse institutional, technical and policy elements. Some of these were not yet recognized in preceding studies; other elements are not yet in place and explain why mismatches occur in current institutional settings. Künneke's recommendations address the gap between inverse developments and established infrastructure policies.

In the book's second section, the authors use specific case studies to shed light on a variety of characteristics of inverse infrastructural change. Thea Weijers, in 'Centralization and Decentralization: A History of Local Radio and Television Distribution', analyzes historical developments in radio and television reception and distribution in one city. Tracing them from their earliest stages as decentral user-driven networks through phases of increased centralization, Weijers sheds light on the transformation of an inverse infrastructure into an LTS. She thereby brings into question not only the relation between inverse systems and LTSs but also the causal pathways.

The long history of volunteer separation and collection of waste paper in the Netherlands is the subject of Frida de Jong and Karel Mulder's contribution. It examines the incentives of citizens and government to maintain an inverse infrastructure. 'Citizen-Driven Collection of Waste Paper (1945-2010): A Government-Sustained Inverse Infrastructure' demonstrates how the waste paper collection system has operated alongside, and to varying degrees independent from, the larger infrastructure of waste collection organized centrally as a public service.

Igor Nikolic and Chris Davis elucidate the emergence of more recent inverse knowledge infrastructures in 'Self-Organization in Wikis'. By focusing on both the global Wikipedia and a local wiki used in their own professional environment, the authors describe the incentives that drive participants to contribute to wikis as well as the extent of self-organization required for such Internet-facilitated knowledge infrastructures.

In 'The Role of Policy in Inverse Developments: Comparing Dutch and Danish Wind Energy' Linda Kamp shows how efforts of Dutch authorities to promote top-down centralized wind energy developments paled in comparison to the Danish efforts that encouraged interactive learning and smaller scale decentralized research and development of wind turbines. From this case, she clarifies how diverging policies dramatically influence inverse infrastructural developments and makes further policy suggestions.

While many studies in this volume analyze emergent qualities, Stefan Verhaegh and Ellen van Oost examine a process critical to inverse infrastructure survival: technical maintenance. In 'Who Cares? The Maintenance of a Wi-Fi Community Infrastructure' they explore the case of Wireless Leiden in which a user group strives to provide a complete city with free Wi-Fi by linking existing connections. This chapter investigates the underlying dynamics that explain the organization of maintenance work by a corps of volunteers, and the unexpectedly active role of lay home users therein.

The transformation of what are usually large-scale systems into new scales and forms is addressed in 'Decentral Water Supply and Sanitation'. With their focus on both industrialized and developing regions of the globe, Aad Correljé and Thorsten Schuetze analyze attempts to create decentral, local water infrastructures. They examine how these attempts are affected by the (absence of) support by central authorities and (the absence of) centralized water and sanitation facilities. The comparative study shows a gradient of incentives for inverse characteristics in this sector, and accentuates the importance of the infrastructure context for inverse developments generally.

In the book's third section, authors explore new possibilities engendered by inverse infrastructure emergence. Rudi Westerveld looks at the possibilities of inverse telecommunications networks to increase connectivity in deep rural areas of Africa and Asia. In 'Inverse Telecommunications: The Future for Rural Areas in Developing Countries?' he signals innovative inverse developments in areas where earlier efforts of incumbent telecommunication operators have failed. In such contexts, where living conditions are usually harsh and no centralized infrastructures (e.g. electricity and public transport) are in place, user-owned and user-driven inverse initiatives seem promising.

Paulien Herder and Rob Stikkelman explore in 'Building a Syngas Infrastructure: Translating Inverse Properties into Design Recommendations' whether elements of an inverse infrastructure approach could be used to develop a new and innovative large scale syngas (i.e., synthesis gas) infrastructure. To implement this infrastructure, large primarily commercial companies need to cooperate closely. In Herder and Stikkelman's search for an optimal process design, they explore the possibilities of a phased hybrid approach that alternates more top-down and orchestrated interventions with bottom-up, inverse process elements aimed to create favorable conditions for self-organization among large companies.

In the last empirical chapter, 'Policy Implications of Top-Down and Bottom-Up Patterns of E-Government Infrastructure Development', Anne Fleur van Veenstra and Marijn Janssen investigate initiatives by the Dutch government to build an IT-infrastructure that provides services for various public agencies and across different government levels. They compare the merits and demerits of top-down (central government-initiated) and bottom-up (e.g. municipality-driven) efforts to develop such e-government building blocks. Their case illustrates the key importance of government users accepting the outcomes of IT-projects, and points to the value of using an inverse approach within a centralized government context.

In 'Disruptive Inverse Infrastructures: Conclusions and Policy Recommendations' Tineke Egyedi synthesizes the insights and findings of the empirical and theoretical chapters. Critically reviewing key inverse properties, she adapts the conceptual framework developed in Egyedi et al. (2007; Appendix II, this volume). The chapter highlights new insights about the conditions of inverse infrastructure emergence and maintenance, and about their relations with LTSs. Reflecting on the disruptive nature of inverse infrastructures, she explores its policy implications and makes recommendations for bridging the widening gap with current infrastructure institutions.

In *Introduction: An Agenda for Infrastructure Studies*, Edwards et al. (2007) ascertain the vitality of the emerging field of infrastructure studies. While infrastructures have been the subject of study for decades, their plea for *infrastructure studies* as a specific multi- and interdisciplinary area of scholarship is refreshing. Similarly, the Next Generation Infrastructures Consortium and Research Program have articulated and demonstrated the value of multi-disciplinary cross-sectoral research not only to increase our understanding of infrastructure systems but also to address the practical problems faced by today's policy-makers and strategists in government and business (Weijnen et al. 2004). Clearly, infrastructure researchers studying governance, business, technology, policy, or politics share challenges. We believe that inverse infrastructures add a new and significant dimension to infrastructure studies. The authors in this volume have taken up the task to explore inverse infrastructures from their own areas of expertise and contribute to emergent infrastructure studies.

ACKNOWLEDGEMENTS

The authors would like to thank Vincent Lagendijk and Frank Schipper for comments on an earlier draft. We are grateful to Georges Amar for bringing the pedibus to our attention. Portions of this text have appeared in Egyedi et al. (2009).

NOTES

1. Infrastructures exist in many forms and sizes, take various paths of development, and exhibit different degrees of socio-technical connectivity. It is not our intention to enter essentialist debates about the characteristics of or scale required for infrastructures. They are systems, usually involving technologies that provide services such as broadcasting, water supply, electricity and transport. While sometimes these services are provided centrally by public works or commercial utilities, they can also be operated decentrally both on local levels such as neighborhoods or globally. We see infrastructures broadly as the socio-technical backbones of societies.
2. Inverse infrastructures are a specific type of infrastructure. It bears no relationship to *infrastructural inversion* mentioned in Bowker and Star (1999).
3. Vree (2003; Appendix I) mentions the example of Ultra Wide Band which is mistakenly thought to fall under legislation for 'ether frequencies'; and the problem of how to identify wireless city networks in telecommunications legislation, i.e., as a private network (making inverse users liable) or as a public netowrk (which requires monitoring facilities in critical hubs).
4. We explicitly do not describe them as *reverse* because that term is not only more general but also suggests an opposite *linear* directionality (Barnhart, 1968). We do not want to imply that inverse infrastructures simply follow a reverse order of development.
5. 'Under the conditions of peer-to-peer coordination, self-selected agents mutually co-ordinate their activities based on bilateral agreements' (Finger et al. 2005, p. 242).

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