Infrastructure BUsiness models, valuation and Innovation for Local Delivery
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Bridges n'that: An infrastructure definition for iBUILD

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Summary

The main purpose of this brief note is to develop a practical definition of infrastructure that:

1. satisfies the standard uses of the term by integrating the above themes of physical assets and societal need,
2. provides sufficient breadth and flexibility that a multi-disciplinary team are comfortable with it, and,
3. importantly in the context of iBUILD does not only not constrain our imagination but helps to stimulate the development of new business models.

A secondary purpose of this note is to prioritise those infrastructure sectors that should be the focus for research and case studies in the iBUILD programme.

The prefix *infra-* means below, under or beneath – so literally infrastructure refers to the underlying structure. The term seems to have come into usage around mid-late 19th Century in France (Le Dictionnaire de l'Académie Françoise) in the context of railways, and was first referred to in the Oxford English Dictionary in 1927 in the context of French works, and a word in its own right in the 1970s.

Governments, national agencies, professional organisations, academics and, of course, dictionaries have proposed numerous definitions of infrastructure (see Appendix A). Two typical characteristics of the many definitions are exemplified by the ICE (2009) which focuses on components and networks: "*The physical assets underpinning the UK's networks for transport, energy generation and distribution, electronic communications, solid waste management, water distribution and waste water treatment.*" whilst Collins (2013) emphasises societal need and economic growth: "*The stock of fixed capital equipment in a country, including factories, roads, schools, etc., considered as a determinant of economic growth*." Other uses of the term infrastructure have focused on their potential as an asset class[1] (Weisdorf, 2007), or have been so broad as to consider individuals and institutions to be infrastructure (Jochimsen, 1966). iBUILD recognises the role of individuals and organisations in the context of the regulation and governance of infrastructure, but does not identify an individual as an infrastructure system in their own right.

[1] As part of iBUILD we are thinking through how the transformation of infrastructure into an 'asset class' as a result of financialisation is changing its nature from a public good (which in economist's terms would be non-excludable and non-rival – *i.e.* you can't stop people from using it and there are no competitors or substitutes – *e.g.* street lighting) into something different because owners of such 'assets' are often seeking to make its use excludable and limited to those able to pay, although they can often also be seeking to maintain this monopoly position and limit competition.

Physical artefacts: The physical links, nodes and components of an infrastructure system that can be designed, installed and used, suffer deterioration and require maintenance. For transport infrastructure, these include roads, railway lines and bridges and pavements; for communications infrastructure, these include wires and wireless routers. Collectively, these artefacts form a system along which people, commodities and resources flow.

Processes: The actors, institutions, management, regulation, protocols and procedures that govern the lifecycle of the infrastructure through design, construction, finance, operation, use, maintenance, modification, decommissioning or upcycling.

Resources: The people, items and commodities (e.g. vehicles, resource, electricity and data) that are conveyed through infrastructure systems but are not a part of the physical system.

Services and societal needs: The resources enable the services and societal needs that help provide security, stimulate commercial and industrial activity and allow ***users*** to achieve a desired function. For example, gas provides warmth and cooking, cars provide mobility, water provides waste management. In many cases, the aim is also to sustain and enhance quality of life of ***users***, but they do not necessarily achieve this – crowded commuter trains support the functioning and operation of the economic and social system, but not necessarily in ways that people/users find amenable and value in terms of quality of life. Similarly infrastructure may be delivered to satisfy wants and demands (as opposed to fundamental needs) which may ultimately detract from quality of life or conflict with sustainability objectives, for example installing more coal-fired power stations.

Infrastructure sectors: All the definitions (that specify sectors) are in agreement that infrastructure sectors include energy, transport, waste, information communication technology (ICT) and water. Wider definitions sometimes specify green infrastructure (which provides natural ecosystem services), food and agriculture, chemical, financial, emergency services, and softer systems infrastructure (which incorporates the educational, judicial, entertainment, spiritual, penal and healthcare systems which satisfy a range of societal needs). Although few would exclude primary energy infrastructure such as oil refineries and transmission networks from a definition of infrastructure, many would not include community or household measures (such as small-scale generation or demand management) in their definition. iBUILD must include all these aspects (and not just for energy systems) because (i) our focus is on the local and urban scales where the role of these systems is more significant, (ii) there is a trend towards decentralisation of many systems and such infrastructure systems seem likely to become more numerous and important within infrastructure systems, and, (iii) failure to consider the user, decentralised or demand management systems will inevitably constrain the number of agents and thus the range of business models that iBUILD is able to consider. In addition to providing opportunities (*e.g.* to reinvest savings from efficiency measures), decentralisation might threaten existing business models (*e.g.* reduction in

demand for resources such as energy and water). This is consistent with our stated intent to take a 'whole systems' approach to infrastructure business models.

Interdependencies: Each infrastructure service is characterised by geographically extensive systems that link supply and demand via interconnected artefacts enabling different services and societal needs and moving different resources. Reliance on another resource by physical artefacts (e.g. electricity required to pump water through the water infrastructure, or communications supplied to overhead highway gantry signs) or to deliver a service (e.g. electricity, gas/oil and water are required in many households to provide comfort) introduces a *resource dependency*. As ICT systems become more prevalent and pervasive it is worth identifying *information dependencies* (*e.g.* command and control systems) – although information transfer is not just through ICT systems, but may result from human communication and interaction. Loss of one or more components can lead to disruptions elsewhere in the system, and across other systems. *Physical dependencies* arise when systems interact through a physical process (e.g. hydrological processes), or through shared physical attributes (e.g. freight and passenger travel on railways is limited by a maximum capacity). *Geographic dependency* occurs when components of multiple infrastructures are in close spatial proximity. Consequently, a disruptive event such as a flood could impact upon multiple services simultaneously, or a point failure (*e.g.* from routine maintenance of utilities, a fire or explosion) could create correlated disturbances in other nearby infrastructures. In the context of iBUILD *socio-economic dependencies* must be considered. These might include issues such as investment cycles to replace ageing components, bond markets, valuation techniques, policy, regulation of pricing or major externalities such as a 'credit crunch'. Similarly, many sectors converge at the point of end-users (individuals, buildings etc.) whose behaviour (e.g. demand for services such as energy and water) is likely to be subject to budgetary constraints and other factors – creating 'bottom up' socio-economic interdependencies.

It is important to clarify that a *dependency* is a linkage or connection within an infrastructure system, or between two infrastructures, through which the state of one infrastructure influences or is correlated to the state of the other. Whereas an *interdependency* is a bidirectional relationship such that two infrastructures are dependent on each other. An interdependency may emerge directly between two infrastructures (*e.g.* water required for cooling in electricity generation; and electricity required to pump water out of a river for the purpose of cooling) or indirectly (*e.g.* water is required in the production of oil, which provides fuel and lubricants for transportation systems that are able to convey fuel to power stations).

In iBUILD we are taking a 'whole systems' approach to identify the multiple ways in which infrastructure and related business models are increasingly intertwined through the modes of interaction described previously. These independencies can lead to more complex path dependencies as decisions made about one infrastructure have consequences for decisions about other types of infrastructure. In the context of our case studies, whilst many will have a focus on a

particular infrastructure sector, the whole systems approach will inevitably draw in other interactions and opportunities from other infrastructures.

A concise definition for iBUILD

Encompassing all things to all people will not be a useful way to define infrastructure. This will constrain our ability to understand, propose and advocate new business models.

The above discussion has considered a number of pertinent issues that provide an expanded definition of infrastructure for the context of iBUILD. Succinctly, we might define *infrastructure as the artefacts and processes of the inter-related systems that enable the movement of resources in order to provide the services that mediate (and ideally enhance) security, health, economic growth and quality of life at a range of scales.*

To manage its scope, the iBUILD programme will focus on energy, transport, water, waste and communication services – but our thinking must not only be limited to the major systems and their assets, but must also recognise assets, processes and users at other scales, such as individual households, firms, local communities and urban neighbourhoods.

Selected infrastructure definitions

Institution of Civil Engineers, A National Infrastructure Investment Bank, December 2009: "*The physical assets underpinning the UK's networks for transport, energy generation and distribution, electronic communications, solid waste management, water distribution and waste water treatment.*"

Collins English Dictionary. HarperCollins Publishers, "infrastructure": "*1. the basic structure of an organization, system, etc. 2. The stock of fixed capital equipment in a country, including factories, roads, schools, etc, considered as a determinant of economic growth*." www.collinsdictionary.com/dictionary/english/infrastructure (20 August 2013)

Mark A. Weisdorf, Chief Investment Officer of Infrastructure Investments Group and Managing Director **JPMorgan Asset Management:** *"Infrastructure can be defined as the essential facilities and services that the economic productivity of a community or organization depends on. As a real return asset class, infrastructure includes those assets that are involved in the movement of goods, people, water, and energy."*

President's Commission on Critical Infrastructure Protection of United States (2007): *"A network of independent man-made systems and processes that function collaboratively and synergistically to produce and distribute a continuous flow of essential goods and services."*

USEPA, Office of Grants and Debarment, Definition of "Infrastructure" for purposes of the American Recovery and Reinvestment Act: *"The substructure or underlying foundation or network used for providing goods and services; especially the basic installations and facilities on which the continuance and growth of a community, State etc. depend."*

Chambers (2007): *"Infrastructure assets are the physical structures, facilities, and networks that provide essential services to the public. These assets include transportation structures (roads, bridges, tunnels, railways, airports, and seaports), energy and utility companies, communication entities, and social services such as educational facilities and hospitals."*

North Carolina Accounting System[2] & Decatur County, Georgia - Tax And Expenditure Data Center[3]: *"Infrastructure assets are long-lived capital assets that normally are stationary in nature and normally can be preserved for a significantly greater number of years than most capital assets. Examples of infrastructure assets include roads, bridges, tunnels, drainage systems, water and sewer systems, dams, and lighting systems."*

Congressional Research Service Report for Congress. 2002 Critical Infrastructures: Background, Policy and Implementation. *"The Nation's health, wealth, and security rely on the production and distribution of certain goods and services. The array of physical assets, processes, and organizations across which these goods and services move are called critical infrastructures."* www.iwar.org.uk/cip/resources/pdd63/crs-report.pdf

American Society of Civil Engineers (2009): *"The infrastructure supporting human activities includes complex and interrelated physical, social, ecological, economic, and technological systems such as transportation and energy production and distribution; water resources management; waste management; facilities supporting urban and rural communities; communications; sustainable resources development; and environmental protection."*

Weisdorf (2007): *"The essential facilities and services that the economic productivity of a community or organisation depends on. As a real return asset class, infrastructure includes those assets that are involved in the movement of goods, people, water, and energy."*

Oxford Dictionaries. Oxford University Press. "infrastructure": *"The basic physical and organizational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise"* http://oxforddictionaries.com/definition/english/infrastructure (3rd October 2013).

The Economist, Matthew Bishop, Economics: An A-Z Guide, 2009, p167: "*The economic arteries and veins; roads, ports, railways, airports, power lines, pipes and wires than enable people, goods, commodities, water, energy and information to move about efficiently.*"

Reimut Jochimesen (1966) Theorie der Infrastruktur, Grundlagen der marktwirtschaftlichen Entwicklung: *"the sum of the material, institutional, and personal foundations of an economy that contribute to realising the assimilation of factor remuneration, given an expedient allocation of resources."* Here "personal infrastructure" is used to encompass the number and qualities of people in the market economy.

Infrastructure UK, National Infrastructure Plan (2010): *"Economic infrastructure: the networks and systems in energy, transport, digital communication, flood protection, water and waste management. These are all critical to support economic growth through the expansion of private sector businesses across all regions and industries, to enable competiveness and to improve the quality of life of everyone in the UK."*

The Council for Science & Technology (2009) A national infrastructure for the 21st Century, refers to national infrastructure: *"Water; energy; transport; ICT; finance; food; government and public services; health and emergency services."* But the analysis only focuses on the first four, which is also the case for the **RAEng** (2011) Infrastructure, Engineering and Climate Change Adaptation – ensuring services in an uncertain future.

Le Dictionnaire de l'Académie Françoise 8eme Edition (1932-1935): *"Partie inférieure d'une construction. Il se dit aussi des Terrassements, des travaux d'art d'une voie ferrée."* http://atilf.atilf.fr/academie.htm

[2] http://www.osc.nc.gov/sigdocs/sig_docs/data_elements/account/sigFixed_Assets__NonCurrent_COA.html
[3] https://ted.cviog.uga.edu/financial-documents/system/files/budget_docs/Decatur%20County%20FY2012%20Financial%20Statements%20and%20Audit.pdf

Le Dictionnaire de l'Académie Françoise 9eme Edition (Current): *"INFRASTRUCTURE n. f. XIXe siècle. Composé d'infra- et de structure. 1. TECHN. Ensemble des ouvrages de fondation et de terrassement d'une construction, d'une voie de communication. L'infrastructure d'un immeuble. L'infrastructure d'une route. L'infrastructure d'une voie ferrée comprend les remblais et les tranchées, les ouvrages d'art et les passages à niveau. Par anal. GÉOL. Couche profonde de l'écorce terrestre, où règnent de hautes températures et de fortes pressions propres à déterminer des déformations plastiques. 2. Par ext. Ensemble des aménagements et des équipements qui permettent l'activité technique, économique d'une collectivité. Infrastructure pétrolière. L'infrastructure routière, touristique d'une région. Infrastructure aérienne, ensemble des installations au sol nécessaires au trafic aérien. Les pistes, les tours de contrôle font partie de l'infrastructure aérienne. Spécialt. Ensemble des installations et des organismes nécessaires à l'activité et à l'entretien d'une force armée sur un territoire. Infrastructure logistique. 3. Fig. Structure sous-jacente qui sert de support à une réalité manifeste. Spécialt. Dans la doctrine marxiste, ensemble des conditions économiques considérées comme la base sur laquelle se fondent les institutions, l'appareil d'État et l'idéologie, etc., qui constituent la superstructure."*