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Ersoy, Aksel; Bryson, John; Van Burren, Ellen

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Unlocking values through infrastructure interdependencies

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Abstract

Urban infrastructure is a complex interdependent system of system. It provides a framework that connect and integrate social, cultural, financial, natural, technological and human values. This paper contributes to the development of new approaches towards urban infrastructure governance, identified as one of the key issues in the field of sustainable urban infrastructure. To do that, we explore cross-sectoral urban infrastructure projects, in which infrastructures supplying different urban functions are connected. This focus on a local level of cross-domain connection allows us to understand the challenges of such connections on a project-level, giving us practical insights into management and governance challenges. We analyse four local projects of cross-sector connections of infrastructures, aiming to understand the collaborative dynamics of governing such projects towards successful outcomes, in terms of overcoming the barriers towards such projects while creating value. Given the high expectations of increased value of integrated urban infrastructures compared to traditional, siloed infrastructure development and management, the insights from local, project-level experiences, in addition to holistic perspectives, can be informative for investment strategy development by private and public stakeholders.

Keywords: Infrastructure planning; silos; project management; government

1. Introduction

Infrastructure is a complex interdependent system of system on which countries and cities rely to provide services, enhance quality of life and underpin economic development and growth (Boin and McConnell, 2007, Carhart *et al.*, 2016). Whereas in the past, infrastructures tended to be designed and operated from a siloed or stove-piped perspectives (Derrible *et al.*, 2016, Pandit *et al.*, 2017), the importance of the interconnectedness of urban infrastructures, expressed by some with the term Urban Infrastructure Systems (UISs), has been more and more emphasized in recent years (Thomé *et al.*, 2016, Dong *et al.*, 2018). UISs provide the frameworks that connect and integrate social, cultural, financial, natural, technological and human values in the context of urban systems (Pandit *et al.*, 2017). They not only enable the flow of people, energy, water, materials, and money into, within, and out of cities but also contribute to economic prosperity, social well-being as well as the reshaping of the urban landscape. In a wider context, UISs are part of urban ecological infrastructure (UEI) where blue (water-based), green (vegetated), and grey (non-living) landscapes are integrated with outputs (whether outflows, treatment or recycling) at an ecosystem scale (Li *et al.*, 2017). This way of thinking enables us to reflect on urban processes in a more systematic way as they are characterised by interconnecting infrastructural landscapes. In this sense, urban infrastructure is the “connective tissue that knits people, places, social institutions and natural environment into coherent urban relations” (Graham and Marvin 2001, p. 43). Adopting a holistic understanding of urban infrastructure enables cities to be considered more

systematically in an era of uncertainty, with urban challenges in many interrelated fields including those of migration, economic and climate change.

A systematic way of analysing sustainable urban infrastructure or UIs has become important in the context of valuing urban infrastructure (Saidi *et al.*, 2018). In these fields there is still much to be learnt from adopting a holistic systems perspective, including the field of infrastructure ecology which uses the ecology analogy to discover hierarchies and patterns in interdependencies and interactions between different system components (*ibid*). Understanding the systems' dynamics is important for the design and operation of these systems (Pandit *et al.*, 2017). While the scientific literature on UIs is growing, underlining the urgency of connecting infrastructures to most sustainably efficiently manage our resource use (Ferrer *et al.*, 2018), the reality of infrastructure design and development is still dominated by stable regimes favouring centralized solutions that have become locked-in to our urban systems (Särkilähti *et al.*, 2017). The need for additional infrastructure serving densified urban growth and higher service-level demands, combined with the often poor state of maintenance and the huge and high cost end-of-life-replacement challenge of infrastructures also feed the support for integrated infrastructure development (WEF, 2015, Yang *et al.*, 2018, Chertow *et al.*, 2019).

This paper contributes to the development of new approaches towards urban infrastructure governance, identified as one of the key issues in the field of sustainable urban infrastructure (Ferrer *et al.*, 2018). To do that, we explore cross-sectoral urban infrastructure projects, in which infrastructures supplying different urban functions are connected. This focus on a local level of cross-domain connection allows us to understand the challenges of such connections on a project-level, giving us practical insights into management and governance challenges. Whereas much attention in the literature is paid to the development of systems' level approaches and understanding, we focus on the local level here, believing that a small-win approach towards the connection and integrated development of urban infrastructures might prove to be a feasible strategy to overcoming the many barriers towards the development and implementation of urban infrastructure integration (Termeer and Dewulf, 2019).

In this paper, we analyse four local projects of cross-sector connections of infrastructures, aiming to understand the collaborative dynamics of governing such projects towards successful outcomes, in terms of overcoming the barriers towards such projects while creating value. Given the high expectations of increased value of integrated urban infrastructures compared to traditional, siloed infrastructure development and management (Chertow *et al.*, 2019, Lu *et al.* 2020), the insights from local, project-level experiences, in addition to holistic perspectives, can be informative for investment strategy development by private and public stakeholders. The next section draws on the literature of industrial ecology and value creation in urban infrastructure to develop a framework for analysing four cases of 'small wins', local projects of cross-sector infrastructure connection. After the methodology section, accounting for the selection of two Dutch and two UK-based cases, we analyse the cases and discuss how these cases inform the possibilities for developing new approaches towards infrastructure governance.

2. Unlocking values through connecting urban infrastructures

The recognition that global challenges are interconnected and therefore require connected responses has resulted in the application of systems approaches to problem-solving recognizing the interdependencies between infrastructure domains (Van Bueren *et al.*, 2012).

In the field of the environmental management of industrial production this has led to the development of the concept of industrial ecology, an analogy with ‘natural’ ecology. Natural ecosystems are governed by self-regulatory principles, ensuring that resources are used and reproduced within ecosystem boundaries. The concept of symbiosis is key to this, in which living organisms have evolved some form of equilibrium. If industrial ecosystems could be modelled on natural ecosystems, making use of the principle of symbiosis, sustainable systems of production and consumption could be created. These ideas are also at the heart of the more recent debate on the circular economy (Andersen, 2007). In practice, industrial symbiosis connects traditionally separate industries through the physical exchange of materials, energy, water and/or by-products, thus creating mutual competitive advantage based on resource efficiency and reducing environmental pollution (Chertow, 2010).

On an urban level, principles of industrial symbiosis are used as well, with geographical proximity often in the lead. To reduce resource dependency and the ecological footprint of cities or urban areas, the flows of resources (input-throughput-output) of different urban functions (housing, industry, transport etc.) are being analysed, followed by suggestions for the reuse of resources, through principles of cascading (the subsequent use of resources for different functions based on the quality of the resource needed for the functions). There are several examples of new developments of towns or districts based on these principles, such as Eva-Lanxmeer in Culemborg, The Netherlands, Rieselfeld in Freiburg, Germany, BedZed in London, UK, and Hammerby Sjöstad and more recently Royal Seaports, both in Stockholm, Sweden (Van Timmeren, 2006, Vernay, 2013). However, with the growing densification of cities resulting from population growth and containment policies to reduce urban sprawl, there is a growing need for developments in industrial-urban or urban-urban symbiosis. The connections between urban and /or industrial functions is gaining more attention but focuses especially on technological opportunities and the feasibility of nexus-developments. In contrast to planned symbiotic developments, the application of symbiosis approaches to existing urban environments is far more difficult to plan and realize. The evolution of integrated urban networks seems even more than eco-industrial parks, which require third-party orchestration, to depend on serendipity as stakeholders identify and realize opportunities for resource exchange (Paquin and Howard-Grenville, 2012). Whereas much literature in this field of connected urban infrastructures is focused on the environmental functioning and performance of these connections, this article’s focus is governance and establishing such connections, given that many of the barriers to integration of urban infrastructures are related to the governance of systems’ change. This requires applying a “learning-based approach to governance” (see Ersoy and Hall, 2020, De Schutter and Lenoble, 2010, Pahl-Wostl, 2009) where participatory procedures support deliberation and mutual learning between individuals and organisations (Voss *et al.*, 2006).

For an analytical framework, we draw from the literature on industrial ecology, financial investment on infrastructure development and management studies. Within the field of industrial ecology increased emphasis has been placed on the institutional dimensions of industrial symbiosis. Analysis is centred on four levels of aggregation: the institutional, the network, the organizational and the individual level (Walls and Paquin, 2015). On the level of industrial park development, there is special attention given to the development of a network of connections, focusing on multiple exchanges between multiple actors, based on the development of industrial parks (Boons *et al.*, 2017). On the level of the organisation, the work of Paquin and Howard-Grenville (2012), on actor strategies to facilitate the development of industrial symbiosis, and especially the work of Wasmer *et al.*, (2014), on why firms engage in environmental collaborations, provide a useful frame for our analysis. Besides the

general storyline of individual firm engagement, authors in both these articles identify factors that play a role in the development of collaborations between different stakeholders resulting in innovative applications of industrial symbiosis. These factors are at the level of the organisation and the level of the partnership or network, and align with the work of Boons and Spekkink (2012) on institutional capabilities, in which the actions of individual actors at the micro level are linked to the ability of actors to solve collective problems at a systems level.

In addition, we draw on the literature on financial investment in infrastructure projects, which is strikingly absent from the industrial symbiosis literature. Unlocking value through industrial symbiosis, however, does require long term negotiations and tangible contractual agreements that specify the conditions, requirements and liabilities associated with a resource exchange between co-located activities and infrastructures (Wang *et al.*, 2017). Relevant theoretical insights are especially concerned with the development of trust as a condition for the long-term collaborations needed for value creation (Ramsheva *et al.* 2019). In the management literature, there has been an increasing interest in the competitive advantages of some organizations collaborating with each other which result in joint value creation that would not be possible otherwise (Dyer *et al.*, 2018, Porter, 2011, Allaoui *et al.*, 2019, Chi *et al.*, 2020). Dyer *et al.* (2018) argue that complementary resources provides ample opportunities for forming alliances even though they bring governance challenges (p. 3159). In the case of the cluster literature, for example, it is essential to identify common interests and a culture of cooperation (Gertler, 1995).

Based on the on-going debate, a conceptual framework has been developed to analyse the cases with a focus on understanding how actors have intervened to create small wins. The small wins approach, a concept originally coined by Weick (1984), is based on the understanding that wicked or complex problems tend to lead to paralysis of actors, amongst others driven by the persistent nature of problems and the risk of failure, or to overestimation by actors that they are able to tame the problem, in spite of its contested character (Termeer and Dewulf, 2019). Small wins points to the importance of an incremental strategy of gradual change, by creating small, often local achievements with lasting impact. Change is key to these small wins: outcomes need to be concrete and visible, results should be jointly acknowledged and valued, and changes are beyond the first order or instrumental level, they need to be of second or third order, evidencing change of goals or institutions (*ibid*).

We will analyse projects that have succeeded to create small wins by unlocking values and creating change at the level of the organization and network. The institutional or macro-level and the micro-level will be disregarded here since they are beyond the scope of the small wins approach; the macro-level being too large scale, and the micro level being too individual. We will use a framework that thus consists of three indicators of small wins:

- *Unlocking values*: Which values compared to more conventional values did the project deliver? The values are defined in comparison to the traditional values of each of the partnering actors in the industrial symbiosis project. How is the contribution to traditional and values reflected in contractual agreements in terms of the allocation of risks and revenues and conflict resolution?
- *Organisational network change*: To what extent has the unlocking of these values required the development of new patterns of interaction and the formulation of shared rules? Actors from different sectors and backgrounds operate according to different rules and will most likely have different perceptions of risks, liabilities and

opportunities. Changed patterns of interaction and the creation of shared rules are indicators of institutionalisation that contribute to the project's long-term sustainability and may even move beyond the project, giving rise to the application of this approach as an organising principle for connecting separate infrastructures in other places.

- *Organisational change*: To what extent has the unlocking of these values required alterations in the partnering organisations? To what extent has the technical symbiosis resulted in organisational symbiosis? How have the organisations adapted to each other?

3. Methodology: cases from the UK and the Netherlands

In this paper we explore four industrial symbiosis urban projects, involving cross-sectoral collaboration, urban infrastructure investments and a linked business case. We use a comparative case study analysis, a suitable method for exploratory research involving multiple variables (Yin, 1994). Two cases are positioned in the UK and two in the Netherlands. Within both countries, urban infrastructure has a different position, which may lead to differences in investment considerations influencing outcomes. In the UK, urban infrastructure is increasingly treated as a financial asset (see RTPI, 2019), whereas in the Netherlands urban infrastructure is considered to be a publicly financed utility¹. Comparing the cases from the two countries will identify differences in the creation of values, and between the different actor strategies used to approach such projects on organizational and on network levels.

It is against the backdrop of these larger scale developments taking place in the UK and the Netherlands that we examine industrial symbiosis projects in existing urban environments. Examining both UK and Dutch case studies provide insights into the transformations at play in various infrastructure domains. They might also contribute to urban infrastructure development strategies with a focus on finance and funding, but perhaps more importantly on creating values that will contribute to enhancing social and economic resilience. Analysing cases from different countries with different institutional settings and developments in urban infrastructure governance contributes to understanding the different forms and directions in which industrial symbiosis might evolve, and the resulting governance challenges in the two countries to guide these developments.

The cases have been selected on the basis of our earlier research experiences: we had access to the data and information on these cases collected in other research contexts. The Dutch cases have been studied as part of a research project on Circular Urban Water Systems, a collaborative initiative of actors in the Dutch water sector². For each of the Dutch cases, 4-6 interviews with key stakeholders have taken place in 2017, in addition to an analysis of documents online available and provided by the interviewees. The UK case studies were identified from the same county, Worcestershire, and were selected from smaller towns and cities rather than from larger cities. Smaller towns and cities have limited resources and need to innovate to meet resource constraints. In addition, the smaller towns and cities have been under-researched compared to larger cities. Both cases involved face-to-face interviews as well as observation of meetings of policy makers and access to minutes of these meetings. In

¹ <https://www.government.nl/topics/business-for-development/improving-the-climate-for-business/infrastructure>

² <https://www.kennisactiewater.nl/> (retrieved April 20, 2020)

this paper, a secondary analysis of the cases has taken place using the framework presented in section 2

The four cases have been selected to facilitate a comparative analysis, but also to highlight infrastructure heterogeneity and industrial symbiosis. The two cases from the UK reflect the development of a new organisational network forms – the merger of two libraries – and operational linkages in which heat produced by one process is used to heat a swimming pool. The library case is more complex as a novel approach to sharing library services including development and operational costs had to be negotiated and agreed. The two cases from the Netherlands represent technological solutions in which waste outputs from one system are converted to useful inputs into another. The first case is similar to the UK swimming pool in which water is heated by excess heat produced by a factory. The second case involves the storing of energy in the form of cooling over a period of time and its application to cooling blood. All cases involve the development of new forms of organisational network and also alterations to day-to-day operations. It is noteworthy that there is no alteration in the experience of service users.

4. Industrial Symbiosis and Infrastructure Interdependencies – Creating Additional Values

The Hive – Combining a Public and University Library

The Hive was the first library in Europe to house both a university book collection and a public lending library replacing the City of Worcester library in The Tything and the University of Worcester's Peirson library. It is a partnership project and service between the University of Worcester and Worcestershire County Council (WCC). The Hive represents an unusual example of industrial symbiosis in which a building is developed and designed to bring together related functions to maximise operational and environmental efficiency. A stand alone public library would not have the economies of scale that were possible by merging the city's library needs with that of the University of Worcester and the County archives resulting in the development of organisational network change and organisational change. There are three value systems behind the Hive. First, was a concern with designing and building a library based on a number of measurable environmental criteria that were defined in the building contract. This included a target figure of 30% recycled content (22% was achieved as 30% was uneconomic), a potable water target of 75% that required reliance on rainwater harvesting and BREEAM excellence. The building was designed with the highest practical level of thermal insulation possible and with an energy consumption of 50% below Building Regulations Part L and with 50% renewable energy. Water is extracted from the River Severn and used for heating and cooling. These measures emerged through a process of competitive dialogue during the tendering process reflecting the interaction between the investment market and the client and more specifically one Worcestershire County Council employee who tried to minimise the environmental impacts of the new library building. The approach was to adopt a total cost approach combining construction costs with operational costs over the estimated life of the building. Second, the benefits of combining three library services (city, university and county archives). The integration of these three types of library services into a single building produced operational and efficiency savings, but also enhanced user experiences.

Third, integrating the public library services with that of the University provided an unusual opportunity to bring the University into the centre of the city and the life of the citizens. The

Hive provides an exhibition space, but also an opportunity for all visitors to the Hive to learn about their local University. One of the most important benefits from combining these three library services was merging their catalogues into a single integrated database. The ownership of the joint collection is still apparent behind the scenes, but for the public both collections have been combined. This required the development of a new Library Management System (LMS). When a user logs on to any of the shared computers in the Hive, the LMS identifies whether they are a student or a member of the public. All material is available to all users, but the LMS recognises that certain texts are of key importance for students. This means that restricted texts can be borrowed by students for 2 hours but can only be consulted on site by members of the public. Students can borrow up to 12 core university texts for two weeks, but members of the public can only borrow them one at a time. The LMS system allows the Hive to identify any gaps in the joint collection and to target acquisitions increasing efficiency. Merging the two collections has also enabled the pooling of staff to occur between the University and the County's library services. This means that the Hive is open from 8.30am to 10pm everyday of the week meaning that access to library services is one of the best in the UK.

Worcestershire Crematorium and Swimming Pool

One town in the United Kingdom developed a rather special solution in 2011 to heating their public swimming pool and sports complex using excess heat produced from an adjacent crematorium. Redditch Borough Council, Worcestershire, developed this approach to heating Abbey Stadium Sports Centre, on the assumption that it would reduce running costs by around £14,500 a year³. The council owned both the crematorium and the sports centre and this innovation required no alteration in the operational activities of the organisations but did require the linking of two buildings and also two different Council service areas. The idea of using the extra heat can be traced back to 1946 when the Worcester plan included a proposal for a covered swimming pool to be heated by waste heat from an adjacent electricity works (Minoprio and Spencely, 1946). This was not built and the electricity works was demolished in the 1970s⁴. However, in 1972 the city's first indoor heated swimming pool was opened, which was heated by waste energy from a sewage works. After its proposal in 2011, the County piloted the idea to heat a public swimming pool by using heat diverted from a crematorium. Cremation of a body is carried out at a temperature ranging between 1400 to 1800 Fahrenheit during which the body has been reduced to its basic elements and dried bone fragments. Although cremation serves as a process for the final disposition of a dead body in a coffin or casket, it is an industrial process which uses an immense amount of energy. In fact, it has been argued that it raises concerns about environmental friendly funerals because when a body is burned, it releases approximately 573 lbs of CO₂ in to the atmosphere and uses about 29 kWh of electricity which would provide sufficient energy to power an average home for two weeks⁵. Instead of losing all that heat (and its accompanying energy), the Council noted that the application of an industrial symbiosis approach to the crematorium would also reduce the city's total CO₂ emissions.

The construction was delayed as new equipment had to be installed at the crematorium to meet new laws regarding the reduction of mercury emissions. At this time, the two cremators,

³ <https://www.express.co.uk/news/uk/225082/Worcestershire-swimming-pool-that-s-heated-by-a-crematorium>

⁴ http://news.bbc.co.uk/local/herefordandworcester/hi/people_and_places/history/newsid_9357000/9357873.stm

⁵ <https://mysendoff.com/2012/01/taking-responsibility-for-our-impact-on-the-earth-even-in-death/>

which had been working for 12 years, and the flue network were also being replaced⁶. This outcome was a reduction in the running costs of the swimming pool and a reduction in the environmental impacts of the Crematorium. Greater alignments between the operational hours of the crematorium and the swimming pool would have increased the effectiveness of this example of industrial symbiosis. In this case organisational change occurred as the Council adopted industrial symbiosis and applied it to two different service areas. However, there is no direct alteration to user experiences. This innovation has encouraged other Councils to consider the application of an industrial symbiosis approach to the operational integration of services areas. Durham Crematorium planned to sell the electricity generated from its furnaces to the national grid⁷. Values were created based around a reduction in CO2 emissions from County activities. There was a time-limited debate in the local and national media that highlighted the novelty and some ethical concerns with heating a swimming pool from the waste heat produced during the cremation process.

Beilen: a dairy-based municipal heat supply (industrial heat supply to swimming pool and school)

In the northern province of Drenthe, in the village of Beilen, part of the municipality of Midden-Drenthe, the DOMO factory, owned by Friesland Campina, one of the world's five largest dairy producers, provides employment and income to villagers and to local dairy farmers. Since 1983 it has provided heat to an adjacent swimming pool. In the early 2000's, both the swimming pool and the nearby elementary school required renovation. The DOMO factory had problems with the discharge of wastewater to surface water, which often exceeded the legal maximum permitted temperature. The municipality, with the support of the provincial authorities, developed a plan to renew the heating infrastructure for the swimming pool but also to extend the connection to a school. These were both publicly owned. Once the hot water is used by the swimming pool and school the water would then be returned to the factory for discharge. For DOMO, cooling water this way was cheaper than renewal of its industrial processes. DOMO was willing to collaborate with the municipality because of the close relationship between the firm and the local community. After the municipality and DOMO agreed to implement this plan installation and operating costs would be paid by the municipality, supported by the province and an available state subsidy. In return, the municipality would receive free heat and would contribute to climate change mitigation goals. DOMO would obtain the cooled water back and would not have to change its production system. For DOMO, the heat delivery was a free way to cool water while contributing to corporate social responsibility and enhancing the firm's relationship with the local community. In 2014 DOMO decided to renew this industrial process. Internal considerations and alterations in the legislation regarding the discharge of heated water led to the firm deciding to invest in a cooling compressor and a heat pump. Even though DOMO no longer depended upon the cooling by the school and swimming pool, it decided to continue providing heat. The heat pump could generate enough heat for the school and swimming pool. 90% of the heat pump's capacity was used for the firm's industrial production processes. DOMO paid for this capital investment and delivered the heat for free to the municipality; the marginal costs consisting of electricity to run the heat pump. Even though the school, with a gas connection, is no longer dependent upon heat delivery from DOMO, it aims to optimize the system to further reduce its carbon footprint. The swimming pool remains fully dependent upon the heat delivery by DOMO for thirty years.

⁶ <http://www.bbc.com/news/uk-england-hereford-worcester-19053184>

⁷ <https://democracy.durham.gov.uk/documents/s29912/240413-CDCJC-Item5-SR-Appx5-Feas-Rpt.pdf>

In this case, values include a reduction in CO₂ and in environmental pollution from heated water. These represent a triple bottom line approach for DOMO as the firm's application of industrial symbiosis produces environmental, social as well as economic returns. These are two additional elements to this case. On the one side, the establishment of a relationship between DOMO and the swimming pool and school developed a new local organizational network. This was more than a network based on social relationships but included an engineered relationship. This is an important duality which appears to have produced a form of path dependency. DOMO's requirement to alter its processes could have led to the termination of the relationship between the school, swimming pool and company. But this was not the case, and DOMO decided to continue to supply free heat. This may reflect a form of organizational change with the firm's relationship with the school and swimming pool becoming an important element of the firm's approach to community engagement and corporate social responsibility. The new arrangement comes with some additional costs to DOMO but a trade-off has been made between these costs and the benefits accruing to the firm from community engagement. This reflects a form of local embeddedness. There are many different forms of embeddedness including emotional that reflects attachment to a place (Salder and Bryson, 2019). In addition, strategic embeddedness occurs when relationships with co-located firms and institutions provides a firm with critical inputs into its operational processes. Another form is coincidental in which relationship form locally, often by chance, that could be substituted by inputs from elsewhere. These are less critical inputs. The case of DOMO reflects a form of emotional embeddedness, but also strategic embeddedness that is transformed into coincidental. Initially, the relationship with the swimming pool played an important strategic role for the company, but the heat pump transformed the relationship between the school, swimming pool and DOMO into a form of coincidental embeddedness.

Amsterdam: in cold blood: cooling donor blood with drinking water

The two key players in this case are Sanquin and Waternet. Sanquin is a not-for-profit organisation responsible for the collection of blood in the Netherlands, and also operates the Amsterdam blood bank. In addition, Sanquin operates internationally to develop medical resources. The cooling of blood is highly energy intensive, requiring large refrigerators. Waternet is Amsterdam's local water company and is the only integrated local water company in the Netherlands, and thus has a unique institutional configuration within the Netherlands. This creation of this public company was prompted by a strategy based on the control of the whole urban water cycle, drinking water supply, sewage collection and treatment and local water quality and storm water management by one organisation. As a result, the regional water board and the municipal department, both democratically elected bodies, decided to set up a joint organisation called Waternet a decade ago. Waternet was established to optimize the water cycle and contribute to public goals of water saving and climate change adaptation. More recently, Waternet is considering opportunities on a more structural scale to produce energy from its assets. The availability of water and water-related infrastructures has encouraged Waternet to develop some innovative projects to explore the opportunities for energy production from its assets. However, a key challenge is the renewal of the city's sewage system. This system is close to the technical end of life and its replacement will be extremely costly and disruptive.

The cooling project with the blood bank is one of Waternet's pilot projects with a focus on investigating the opportunities for energy production from water. The idea is that with heat exchangers and additional piping and storage, the cold from the winter can be stored in a

reservoir and can be used in summer for cooling stored blood. This system only needs limited additional cooling in winter and summer. The expected energy savings are 20,000 GJ annually in the first years, comparable to the electricity used by some 1800 households, and is expected to double to 40,000 GJ savings in the years to follow reducing annual carbon emissions with 1,100 tonnes. The up-front investment costs, 1,8 million Euros, have been primarily funded by Waternet, with the support of a European subsidy, of which a part has been granted to Sanquin to cover the cost of the investment. Waternet is not democratically mandated for investments in the field of energy generation and supply. For this project, Waternet asked special permission and a budget from the Amsterdam city council, which was granted. This represents the development of a new organisational network that ultimately resulted in organisational change. A joint business model proposition was created, with Waternet bearing the initial capital investment, which would be earned back through monthly payments by Sanquin. The monthly costs for Sanquin were modelled on this organisation's regular energy bills and a tariff agreed based on per GJ in addition to a fixed monthly connection charge. This price setting contributed to the project's transparency enabling a realistic test of the business case and contributing to business development and innovation in this field. Waternet and Sanquin have committed themselves to this project by agreeing a 30 year contract, that specifies the monthly connection costs. This agreement would result in the repayment of capital costs over a period of 30 years. Sanquin was able to afford these payments given the reduction in its annual energy bill. At the end of this contract, both parties can agree to stop or continue with the project. In the case of only one of the parties deciding to stop the project, the other party needs to be compensated.

In this case, a formal relationship has been negotiated between a charity and a publicly owned water company. This highlights the emphasis that the Netherlands places on the public ownership of critical local infrastructure. The cooling of blood, through the storage of cooling, provides additional values that are part of a climate change mitigation strategy. In addition, a new local network form has been negotiated, and the terms of a contractual relationship agreed. It is possible to argue that this example represents an alteration in operations rather than a moment of organisational change. This is an important point. Our framework, highlighted the important of organisational network change and organisational change. In addition, it needs to differentiate between strategic versus operational change. Organisational change is a form of strategic change whilst operational alterations may not involve major changes in the relationships between organisations. Thus, industrial symbiosis might result in organisational change or might be targeted at operational alterations. There is a danger in confusing strategy with operations. These are linked processes, but one is about forms of governance – organisational change – and one about production processes.

5. Discussion

The analysis has revealed how cross-sectoral urban infrastructure projects can stimulate change on urban infrastructure governance. Table 1 summarises how the indicators we have used can capture small wins. Developing a holistic approach to the design and management of urban infrastructure can capture values besides costs, profits and risk reduction that can be characterised within a traditional approach. In terms of organisational network change, such a holistic perspective challenges traditional supplier-client relationships between partnering organisations. Last but not least, organisations can reflect on their long-term ambitions and goals which would impact on their institutional structures.

<Please insert Table 1>

For our case studies, Table 2 shows how our indicators can be visualised. Our analysis shows that in some cases, the transformation of local infrastructure has direct and indirect impacts on existing socio-technical and operational configurations, urban actors and their practices. For instance, during the construction of the renewed system in Beilen, it became clear that the heat would have a temperature of 42 instead of the expected 70 degrees Celsius. Meanwhile, the radiators had already been installed in the school as part of a high temperature system. Changing to a low temperature heating system was no longer possible. However, the municipal team, with an installer on board, did not see any difficulty with this and expected that the system would work. Soon after the reopening of the swimming pool and school it turned out that the heat supplied was too cold to heat the swimming pool and school. The swimming pool initially solved this by notifying the public regarding the daily temperature, but the school director decided to send children home after a cold day and temporarily shut the school. The municipality saw no other option than to install a back-up system, thus doubling costs, which was accounted for by adapting the business case of the swimming pool. The return on investment was extended from twenty to thirty years. The school was connected to the gas grid after all; the swimming pool obtained a small gas-fired central heater for the showers and additional heating of the swimming water. Also the DOMO factory had problems with the system. On some days the school and swimming pool did not use enough heat, causing the returned water to be of a too high temperature for discharge. This highlights the importance of considering the technical, operational, organisational and governance aspects of localised forms of industrial symbiosis.

In the case of Amsterdam, the project was delayed due to medical development activities on the US market. The US Food and Drug Administration put any expansion of activities of Sanquin and accompanying cash-flows on hold. To compensate for this uncertainty – Waternet had already started the investments – Sanquin promised to reduce the payback period to five years once the project resumed. However, this turned out to be rather optimistic. Once the project resumed, Sanquin agreed to pay back part of the investment over 15 years, and part over 30 years. The city council approved this agreement. Security of supply was of the utmost importance to the blood bank. However, since Sanquin is the only client, the underground heat and cold storage has enough backup capacity for a few days and repairs based on overtime can be avoided reducing operational running costs. Waternet did not have to make any organisational adjustments to deliver this service. However, expansion of these energy delivery activities by Waternet has required a 24/7 maintenance unit, adding costs to the business case.

In comparison to the Dutch examples, the transformation of local infrastructure has been less problematic in the UK. For Worcestershire Crematorium and Swimming Pool, the main challenge has been the alignment of the opening times of these two facilities. The waste heat producing CO₂ from the crematorium is now used to heat a swimming pool. This reduces operational costs for the swimming pool considerably and also reduces environmental problems related to releasing hot air. Nevertheless, linking the crematorium with the nearby swimming pool led to the media raising ethical considerations. There was opposition from the local community because of this unconventional and potentially unethical way of heating the swimming pool. This type of ethical reaction is something that has not been central to debates on infrastructure interdependencies and the financing of urban infrastructure. In the case of the Hive library, the identification of energy consumption measures and environmental targets emerged through a process of competitive dialogue during the tendering process reflecting the interaction between the investment market and the client. The approach was to adopt a total

cost approach combining construction costs with operational costs over the estimated life of the building. This approach is an unusual example of a university investing in a community setting working in collaboration with a local authority.

<Please insert Table 2>

Our analysis also show that different actor strategies have been used to unlock values, enhance network and affect organisational change in these four case studies. Placing these three dimensions in relation to infrastructure interdependencies can stimulate more interest amongst a range of stakeholders. However, this process also comes with governance challenges. For instance, in the case of the Hive, a continual dialogue has to occur between the University and the City Council. This also involves the allocation for any CO₂ produced by the library. For Worcestershire City Council, the contribution to climate and energy policy goals was important even if two infrastructures were linked under the same ownership. In Beilen, public authorities are in search for contributing to climate and energy policy goals while running the risk of getting engaged in financially disadvantageous and environmentally suboptimal industrial symbiosis projects, which would create a lock-in for future developments. Last but not least, for Amsterdam, the local or decentralised character of decision-making by infrastructure owners might lead to path-dependent developments, with long-term infrastructure investments and technological lock-ins at the urban level.

6. Conclusion

Infrastructure systems are key to enabling economic prosperity, environmental sustainability and social well-being. While improving and maintaining the technical performance of individual infrastructure assets remains essential, the traditional approaches towards financing urban infrastructure is no longer sufficient due to the complexity of physical assets, projects or sectors as well as the number of actors involved in decision-making process. A systemic analysis of the resources the service infrastructure domains provide, as well as the outcomes those services enable, permits critical impacts on people and businesses to be identified who depend on urban infrastructure. To gain the best value from infrastructure, understanding of infrastructure systems and new innovative infrastructure interdependencies needs to continue to evolve. It can then better serve and engage individuals, communities, and businesses, while contributing to effective responses to major societal challenges. While this issue is often discussed in terms of the need for new infrastructure business models, considering approaches based on combining inputs and outputs from co-located infrastructure provides valuable opportunities to create alternative economic and non-economic values. Releasing additional values from infrastructure interdependencies contributes to ensuring that the infrastructure conversation retains the necessary breadth and depth. Thinking in governance terms is one way of raising broader questions concerning the purpose, value and benefit of infrastructure alongside more detailed questions regarding operational delivery and financing.

In this paper, the four case studies have raised dimensions for governing a series of urban infrastructure projects and how a holistic perspective can generate additional non-economic values. They highlight the opportunities for corporate social responsibility and the role that this can play in supporting the provision of local infrastructure. This also raise interesting questions regarding the blurring of the boundaries between providers of similar but different co-located infrastructure services, for example a public library compared to a university library. There is also an important discussion to develop regarding the ways in which conceptualising co-located infrastructure as potentially interdependent leads to alterations in

operations but also to the creation of values with significant societal and environmental benefits. For instance, the case of Beilen originally acted as a small win, but was overhauled by process innovation within the factory based on other considerations (Even though from a community perspective – DOMO being the largest local employer / client of local farmers, it did deliver some value). The anchoring of a joint ambition / goal in the agreement turned out to be a weak point from the start, but it may also show the challenges of integrated urban infrastructures in times of uncertainty – volatile prices, changing environmental regulations, and technological developments.

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