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Governance instruments for optimising source separation in novel urban water systems: the case of cross-connections in urban water systems

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Abstract

Using the three-phase cooperation model and analysing projects based on their cooperation demands in the planning, implementation and operation phases, this article answers three main questions for each of the abovementioned phases: (i) How and between which systems do cross-connections occur? (ii) Which actors are involved in those phases? (iii) Who needs to participate in which type of governance to achieve a better, more structured process of cross-connection control? The article refers to the world's largest novel water system in the Chinese city of Qingdao where a Resource Recovery Centre (RRC) providing the treatment of greywater for domestic and landscape reuse for 12,000 inhabitants has been implemented. A systematic interdisciplinary analysis of cross-connections leads to the conclusion that the approach to source separation needs to be complemented by governance instruments. These governance instruments derived from the actors identified by the cooperation management approach comprise processes of deliberation and communication, qualification and certification, final approval and inspection, as well as learning and evaluation.

Keywords: China; Construction defects; Cross-connections; Governance instruments; Novel urban water systems; Service water; Water reuse

Introduction

Source separation is a main feature of novel urban water systems. Connections can result in the unwanted mixing of flows of different qualities that are managed separately, with mix-ups causing specific risks in the operation of novel systems (and to their widespread implementation in future). Design problems and malfunctions have been documented in other implementations such as Rouse

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Hill (Sydney) and Sydney's Olympic Park (cf. Hambly *et al*., 2010) where plumbing errors resulted in cross-connections during the operation phase. Another example concerns six pilot housing estates in the Netherlands built in the 1990s. In the Dutch case, the government abandoned its plans to reuse grey water on a larger scale due to the health risks detected from cross-connections in the pilot housing estates (cf. Oesterholt *et al*., 2007). In the case of wastewater from separate urban drainage networks, situations can arise in which significantly larger amounts of wastewater are collected and have to be treated. This not only results in less efficiency and a higher consumption of resources for wastewater treatment, but in extreme cases also leads to malfunctions. Operational treatment targets (or even legal effluent restrictions) cannot be met and the designed treatment capacities are exceeded (cf. Friedler *et al*., 2015; Tolksdorf & Cornel, 2017).

Different types of interconnections can occur, both intended and non-intended. Misconnections are defined as the result of deliberate infringements or noncompliance by tenants, investors or their agents (e.g. discharge of drainage water into the piping network of greywater or blackwater by tenants or investors in order to save individual costs). In contrast, cross-connections are not intended but are caused by a lack of due care or insufficient knowledge. This paper does not consider cases of misconnections that might refer to criminal actions and motives, such as the abuse of the system for site drainage or even sabotage. Cross-connections in dual water supplies, in particular, need to be avoided since a mix-up of drinking water and service water could lead to unacceptable health risks.

A review of scientific publications in the field has revealed that the occurrence of cross-connections has hitherto been treated as a niche topic. Although indications of them (and sometimes warnings) are relatively frequent, there is still a lack of systematic analysis of the issue or suggestions for solutions beyond technical monitoring methods (except in the USA; see Pontius & Evans, 2008). In scientific literature, cross-connections have hardly been analysed at all.

Irrespective of the technical progress made in detecting cross-connections, there has barely been any discussion about the procedural and institutional approaches that could contribute to prevent these incidents through specifically designed governance, monitoring and management processes based on an evaluation of the sources of misconnections and cross-connections using an ideal project development model. Therefore, the following key questions need to be addressed: (i) How and between which compartments of the novel systems do cross-connections occur?[1] (ii) Which actors contribute to misconnections and cross-connections and which actors should be involved in contributing to their prevention? (iii) Who needs to participate in which measures of governance to achieve a more effectively institutionalised and hence more structured process of cross-connection control?

Methods, conceptual framework and material

Cooperation management approach

Like other technological innovations, novel urban water systems require changes to be made both to established operating routines and to the requirements made on its different (partial) operators, people in the connected buildings, and those involved with public sewers and water treatment in resource recovery

[1] Cross-connections are not weightened according to their impact on public health although strongly contributing to pressures to adapt the novel water system's design.

centres (RRC). The reconfiguration (and transformation) of water infrastructure systems can be supported by specific procedures that enable coordinated modification of routines and requirements.

Adequate organisation for the necessary coordination and cooperation between different actors can be supported by means of cooperation management (cf. Schramm *et al*., 2017). The aim of this is to identify optimal constellations of important actors in the novel urban water system as well as the transition to future institutional arrangements, with coordination requirements appropriate to the system. Cooperation management conceived as a means of supporting innovations can be carried out by a single key player (e.g. the innovation leader) as well as in a collaborative way by several actors (cf. Winker *et al*., 2017). When planning cooperation management, it is helpful to initially map the various actors, tasks, responsibilities and interests, and to define their relationships and interactions. Using this map as a foundation, different and more adequate options for coordinating and structuring cooperation processes can be generated, adapted to the new urban water systems as a second step. Finally, the most feasible variant(s) can be selected (cf. Schramm *et al*., 2017).

The coordination that needs to take place and the actors who need to be involved vary depending on the state of the innovation process. For the introduction of novel water infrastructures in urban areas, it makes sense to differentiate between the phases of planning, implementation, operation and assessment at the end of a life cycle (cf. Schramm *et al*., 2017). The first of these phases includes both the decision to introduce a novel urban water system and the local planning process in the area where the system is to be implemented. When it comes to the construction of new urban districts (possibly also in the case of an area conversion), formal planning procedures are in place that are legally structured. The second phase not only concerns the specific design of the settlement and detailed planning (including of infrastructures), but also its underground and overground construction (including completion of the buildings' interiors). In addition, the operating phase must be taken into account in which the buildings and the associated infrastructure are used and operated. For example, the urban development administration is a central actor in the planning phase, but in the subsequent phases it tends to be marginalised, while the residents are initially considered at the outset, but only become a key actor during the third phase (cf. Schramm *et al*., 2017).

Approaches to a governance of socio-technical systems

As any source separation leads to a more complex water infrastructure with separated sewer and dual supply systems, complementary organisational and procedural innovations are extremely relevant for the improvement of novel urban water systems (cf. Moore *et al*., 2014). Governance in a socio-technical and social-ecological context needs to involve a wider range of actors than established processes that are based on inflexible formal delegation chains in public administration (see Strøm, 2000). In line with the study by Hajer and Wagenaar on deliberative policy analysis, governance is defined as the analysis of formal and informal everyday interactions between individuals and organisations (cf. Hajer & Wagenaar, 2003). These include processes of individual and collective action as well as social learning. Specifically applied governance instruments can contribute to a reduction in the probability of the faulty design and construction of interdependent infrastructures such as novel urban water systems. Considerable literature on governance in environmental policy, therefore, addresses complexity in the three dimensions of uncertainty, interdependency and fragmentation (cf. Booher & Innes, 2010; Head, 2010). These dimensions can be interpreted as the social burdens relevant for governance approaches to innovative systems, such as the reuse of greywater.

Although the dimensions of complexity and the problem descriptions of governance of complex socio-technical and socio-ecological issues are relatively clearly articulated, the suggested governance instruments are very diverse in terms of the roles of actors and the processes to be designed. With regard to the actors, links between planners, construction companies and civil society need to be established in order to avoid cross-connections and thus gain acceptance for greywater reuse. In the particular case of an innovation, it is hypothesised that neutral facilitators or intermediary actors such as advisors play a key role in the uptake of an innovation (cf. Booher & Innes, 2010). Furthermore, the effectiveness of governance approaches based on social networks demand change agents who are defined as individuals or organisations willing to use their resources for innovation now in order to profit in future and secure the enterprise's future capacity to act (cf. Dodgson *et al*., 2008; Moore *et al*., 2014). In the case of novel urban water systems, actors' activities are rarely limited to one administrative level, interest or peer group, branch or customer. The change agent has to develop the capacity to address different scales and organisational structures. Strengthening coalitions in favour of the innovation as well as an analysis of potential gatekeepers directly accounts for the fragmentation of interests and norms (cf. Dodgson *et al*., 2008; Daniell *et al*., 2014). The developed governance approaches need to respond to this social reality through a multi-staged process design, with early phased stakeholder participation integrating local knowledge and defining shared aims (cf. Fung, 2006; Newig & Koontz, 2013).

Deliberative formats promote communication between all the parties involved and thus enable and require governance based on self-organisation (cf. Booher & Innes, 2010; Moore *et al*., 2014), which on the one hand sets the stage for mutual trust and on the other ensures variability with respect to case-specific solutions (cf. Hajer & Wagenaar, 2003; Head, 2010). An institutional economic governance perspective would further add to the relationship between principals and agents in mechanisms of adverse selection and moral hazard (cf. Strøm, 2000). As a preventive approach to cross-connections, adverse selection is more closely linked to the authors' understanding of governance than the mechanisms to prevent moral hazard through a command and control policy. This article focuses on the roles of actors and instruments that combine traditional adverse selection through certification and licensing, with the bottom-up logic of deliberation and feedback loops.

China, in particular, has acquired considerable experience of restructuring processes since its transition to a market economy. This knowledge can be applied when it comes to the process design and its improvement, as in the case of Qingdao discussed here (cf. Daniell *et al*., 2014).

Case, material and systematic approach

The fast-growing port city of Qingdao has suffered from water shortages for a considerable time, and the scarcity of water resources has become one of the most important factors restricting the city's development (cf. Tolksdorf *et al*., 2016). In Qingdao, the implementation of the SEMIZENTRAL approach has been developed under the general management of the Chair of Wastewater Technology at the Technical University Darmstadt, in close cooperation with numerous German partners from industry as well as scientific partners from Germany and China. Launched in 2014, this implementation is currently the world's largest novel urban water system. About 12,000 population equivalents are connected to a system that collects blackwater, rainwater and greywater flows separately. In the relevant RRC, water is processed for subsequent reuse for irrigation and domestic applications to reduce drinking water usage by about 30% (cf. Tolksdorf *et al*., 2016). Furthermore, the sludge from blackwater and greywater treatment is co-digested with organic material to generate biogas. The biogas is then reused to generate electricity and supply the entire system's electricity needs. At the same time, the generated heat can be used to run the sludge module. Ideally, the entire system will ultimately achieve energy sufficiency (cf. Tolksdorf *et al.*, 2016).

The World Horticultural Exhibition in Qingdao in 2014 provided an opportunity to build a semi-centralised water infrastructure for a newly built city district with residential buildings, several hotels and the offices of the World Horticultural Exhibition, which introduced the source separation system. During the construction and running-in phase, the Qingdao government enabled the establishment of a publicly funded legally private project developer, which assumed responsibility for investment in and the trial run of the greywater system, while the running-in operation for the blackwater system was the responsibility of the RRC's subsequent operator, the Qingdao Water Group. The scientific monitoring of the implementation was supported by the German part of the research network funded by Germany's Federal Ministry of Education and Research (BMBF).

Measurements of the inflow to the RRC (cf. Tolksdorf & Cornel, 2017), random sampling in the catchment area, construction plan analysis and technical inspections of the existing blackwater and greywater sewers and connected buildings in Qingdao, together with expert interviews, formed the basis for an interdisciplinary desktop investigation of cross-connections. Initially, an inspection was carried out for the catchment area of the RRC in Qingdao, followed by fault analysis in the public networks and buildings, thus identifying interconnections.

The technical error analysis led to the conclusion that cross-connections may occur at multiple levels of multiple ownership:

- in the RRC itself
- in the public networks (under the streets)
- in the built areas (houses and surrounding land).

In addition to the technical error analysis, an attempt was made to investigate the causes of errors using social scientific methods and to identify measures to prevent unwanted connections. Most of the measures examined to prevent undesirable mixing of flows in the catchment area were identified using the cooperation management approach (Schramm *et al.*, 2017). With respect to the various actors and their relationships this meant on the one hand to examine their roles, understandings and interests and on the other hand, was aimed at the identification of currently deficient social interactions that could be improved by intermediation and expertise. To the existing knowledge about the actors and their case-specific problem definitions, governance perspectives were added to develop recommendations for cross-connection control (cf. Schramm *et al.*, submitted).

Results

Planning

As in planning phases in western industrial countries, the Ministry of Housing and Urban-Rural Development (MOHURD) defines standards, such as the one for miscellaneous urban reuse of wastewater (cf. Ministry of Construction, 2003). Although MOHURD demands wastewater reclamation and reuse on a national scale, standards are part of interdepartmental coordination with other ministries such as the Ministries of Environmental Protection, Agriculture and Health (cf. Lyu *et al.*, 2016).

MOHURD is represented in each local government by the City Authority, which organises comprehensive planning in the departments responsible for urban environment and sanitation, municipal management, public utilities management, urban water supply management, landscaping management and environmental protection (cf. Figure 1). Additionally, local Development and Reform Commissions

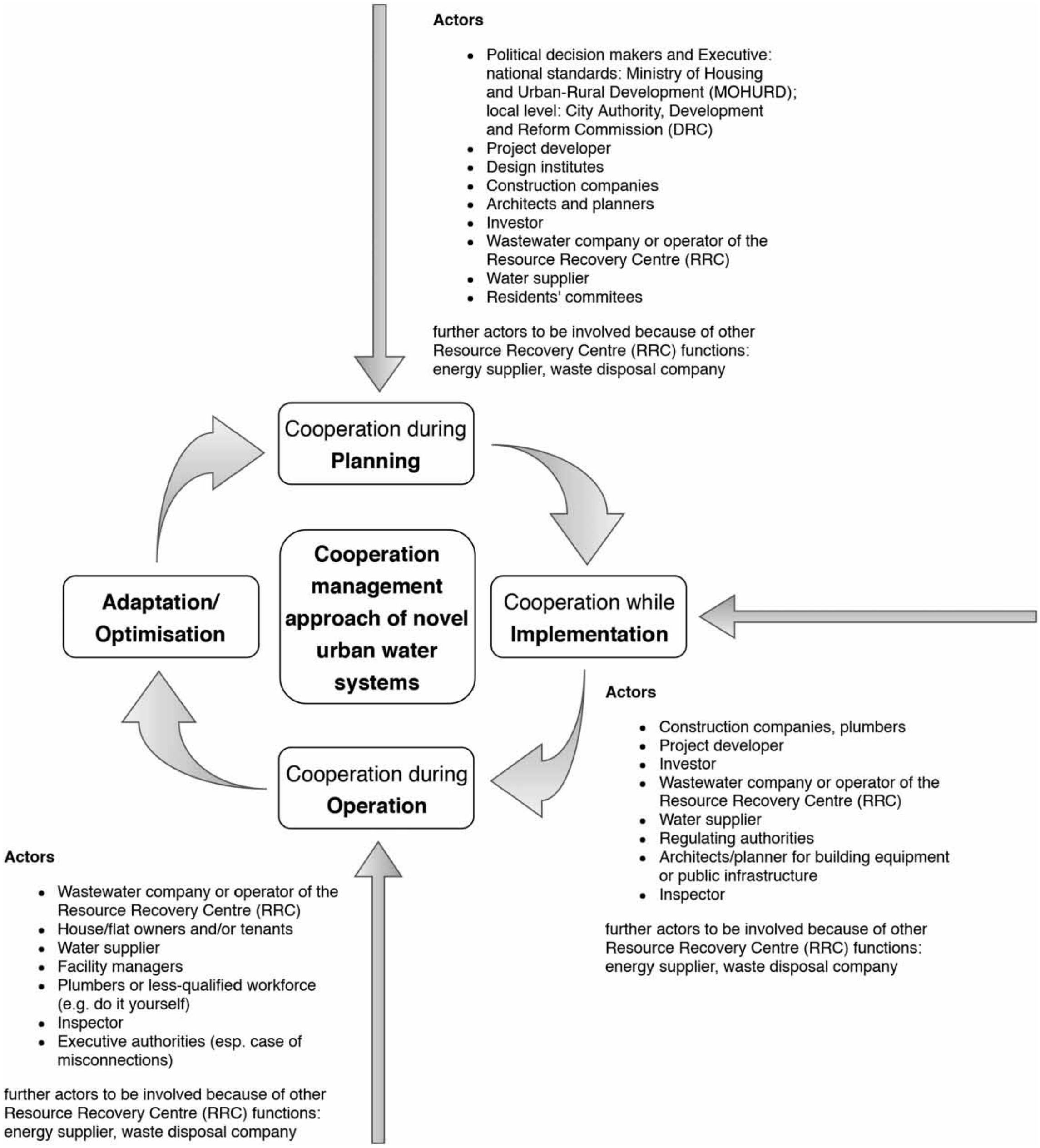

Fig. 1. Cooperation management approach: Actors needed for adequate planning, implementation and operation – the case of a novel urban water system, the Resource Recovery Centre (RRC), in the City of Qingdao, China.

(DRC) have two roles in the planning process: first, as the local planning authority, it provides funding for municipal construction projects (cf. Figure 1) and second, the DRC is a direct gatekeeper in the project's approval process supervising the departments of the City Authority. In a multi-level setting, the DRCs have to balance budgets between centralised plans and regionally developed plans (cf. Heilmann & Melton, 2013). In cases of projects that have public funding, the approval procedure is structured in three phases: (i) a project proposal, (ii) a feasibility approval and, finally, (iii) a preliminary draft. The local DRCs approve projects based on integrated special plans with quotas for wastewater recovery in urban areas and environmental impact assessments that are part of the feasibility checks during the project's approval (cf. He *et al*., 2011; Chang *et al*., 2013).

With cross-connections, this complex system of deliberation may have resulted in diverging definitions of greywater. The German project partners in their feasibility study defined greywater as including kitchen water since that is widely understood by German engineers. Due to a high load of fat and food waste in Chinese kitchen water, this flow is usually part of the Chinese definition of blackwater (cf. Zhu *et al*., 2018). While SEMIZENTRAL initially intended kitchen water to be treated as greywater, the concept that was implemented subsequently focused exclusively on a greywater definition that included wastewater from showers and body care. This change in concept presumably led to the kitchens being connected to greywater pipes in one of the major hotels in the catchment area.

From this point on, private investors are involved and pass through the same process as the publicly built infrastructure. In the case of SEMIZENTRAL, the publicly funded legally private project developer had to hand over the DRC-approved preliminary draft to the Residents' Committee. The project developer then appoints design institutes (cf. Figure 1) to support the process. In some cases, design institutes are established on behalf of state actors, while others are private entities with or without an origin in universities. Private investors should be free to choose their design institutes. According to Article 3 of the Bidding Law of the People's Republic of China (1999), public funding has certain restrictions concerning the design institute's qualification. Consequently, private and public investors might be confronted with inconsistent advice from design institutes because of the design institutes' different backgrounds and diverging criteria behind their selection. The post-DRC approval part is also the phase in which the WHE Group initiated the timetable for the project's implementation.

With respect to cross-connections, which according to the definition in this paper are unintended, time planning is a critical juncture when switching from the planning phase to the implementation phase (cf. Zou *et al*., 2007, 3.3). The installation of a complex system that incorporates three different sewer networks (rain/stormwater, greywater and blackwater) and a dual supply system (drinking water and process water) needs to be accurate. A realistic timetable can only be developed in cooperation with the experience of the construction sector (cf. Figure 1). Being part of a policy based on plans and quotas, it would be appropriate to define a second pillar of qualitative aspects as an incentive for enterprises to invest in staff training (see Implementation). Defined work packages in the call for tenders, such as constructing the pipeline/sewer networks or as working as inspectors of connection qualities in the networks (for details see Implementation), may then only be implemented by qualified organisations. With certification by chambers of commerce or design institutes, this would point to a governance instrument for public and private planning actors alike. Having more objective knowledge about a company's references around water engineering and water reuse experience, the issue of adverse selection is reduced and a contribution possibly made to the prevention of cross-connections (cf. problem description, Wang, 2014). The second advantage of the certification governance instrument would be that design institutes then have greater motivation to engage in questions of water reuse. In the Chinese construction sector, certifications are already well established for the construction of larger building complexes[2] (cf. Zhang *et al*., 2013).

However, the certification of planners and construction companies cannot prevent misguided incentives in terms of the balancing act between tough, quantity-based plans and the need for a response to quality standards for environmental and resource protection. One example of the negative consequences of this is the emergence of 'ghost towns' (cf. Chang *et al*., 2013; Heilmann & Melton, 2013). These housing areas are often conceptualised without there being any demand for them because revenues of the municipality largely depend on the sale of land rights for a limited period (cf. Wang, 2014). In Bijia A and C, there has been a delay in residents moving in, as in other Chinese ghost towns. One more reason was that the resettlers were not allowed to remove into the area until the end of the exhibition. In the case of novel urban water systems, ghost towns challenge the technical solutions to water shortages in the Qingdao region and suggest links to governance issues.

With regard to the planning of novel urban water systems in China, the design institutes in cooperation with private project developers, city authorities and the planning bureau are the most important change agents providing independent advice, ensuring consistent definitions and establishing contacts with qualified enterprises in the construction sector. Where different design institutes are commissioned with the task by private and public planning actors, it would be appropriate for the design institutes to have informal links through communication and knowledge exchange.

The interim conclusion for governance instruments aimed at an improved implementation of novel urban water systems drawn from the case of the Semizentral research project in Qingdao and existing literature of planning processes in China suggests that more consideration needs to be given to definitions of terms such as greywater and project developers need to develop realistic timetables, with certified organisations and design institutes acting as advisors. Public actors need to address misguided incentives and enable ties to be strengthened between the planning and the construction phase through the certification of construction companies by design institutes.

Implementation

In the case of the development of new areas, the water infrastructure system, housing and other buildings will be built in this phase. There is considerable potential for critical design elements like bridges, intersections and dead ends to contribute to cross-connections, based on experiences in Tianjin (Chen *et al*., 2017).

Interconnections can either be attributed to communication errors in the previous phase (e.g. misunderstandings regarding the discharge of kitchen wastewater, as occurred in a hotel in Qingdao) or to the fact that a land user misconnects the estate's drainage to one of the sewer systems. Fundamentally there are two reasons for the occurrence of unintended cross-connections during the implementation phase: (i) design plans are produced according to routines that do not take into account the special features of novel urban water systems and (ii) routines established for the construction of conventional infrastructure systems are applied that do not take into account the special features of source-separated systems and a dual water supply (e.g. misinterpretation by or ignorance of construction workers).

[2] Currently certification is dependent on the number of construction managers, the construction costs, the number of storeys and the projected number of square metres – see Zhang *et al*. (2013).

A solid knowledge base for the structuring of connections in novel urban water systems needs to be developed. For novel systems, most of the specific technical norms and standards have yet to be defined. This applies to the collection, reuse and treatment of source-separated wastewater flows as well as for dual water supplies. Consequently, system leaders must set out their own rules and communicate them in such a way that planning and construction are carried out accordingly. Standard-setting institutions, design institutes and qualifying bodies can support this process of deliberation about rules and norms by joining voluntary and issue-specific discussions and workshops that are also meant to forge new alliances between the actors involved. Whether the time and effort required for these alliances are worthwhile or sufficient for defining and communicating the standards still needs to be evaluated.

In the case of the People's Republic of China, peculiarities in the construction process can exacerbate the occurrence of cross-connections. Time pressures in the construction work (with unrealistic deadlines) often result in sloppiness and improper execution of construction processes. Time pressure and a lack of skills among managers and (migrant) workers alike often cause construction defects. There is less of a focus on managers' social competences and soft skills in China's management education discourse. In particular, experienced managers in the construction sector emphasise cost- and time-related risks much more than environmental risks (e.g. water pollution) (cf. Zou *et al.*, 2007). Zhang *et al.* (2013) measured a correlation between the organisational culture, its style and structure, and the way projects are performed. Beyond the emphasis in management education on values diverging from cooperation and nature conservation, as in most other countries of the world, there is a lack of dual training for the workforce (both in the workplace and in a vocational school). Most people in the plumbing and construction trades are solely trained on the job. As with migrant workers, poor pay leads to a lack of continuity and considerable mobility in the construction industry (cf. Heilmann & Melton, 2013). Low wages often lead to a brain drain of personnel skilled in European-style capacity-building measures. When the workforce is subcontracted, the contractor loses control of workers' skills (cf. Zou *et al.*, 2007). In these circumstances, proper construction documentation is practically impossible. As buildings are durable goods, construction documentation as a complement to the original plans is hugely important for future users of the buildings.

In order to ensure the detection of cross-connections in novel urban water systems, the construction company certified by the design institutes in the planning phase may function as inspectors (cf. Figure 1) who accompany the implementation process and check probable points of cross-connections, such as bridges and intersections during spot checks. It may, therefore, be useful to design inspection flaps or shafts for inspection purposes. To prevent moral hazards, a certified construction company may not inspect its own work. Inspection by an independent certified company has the advantage of establishing a control mechanism for the case of subcontracting and an inadequately skilled workforce. The business model of inspection attracts construction companies, particularly when the inspection is part of the construction documentation. Another important motivation is the mechanism of control then established through competition. One solution for the inspection is a check carried out by a competitor, who should be motivated to detect cross-connections and misconnections. An alternative to the motivation of competition could be that some of the certificated construction companies stop doing the operational side of the business and specialise in being part of a new inspection business model.

As a further governance instrument, the certification of construction companies is tied to confirmation that their staff have been trained. For the training measures, the design institutes, which are often close to universities, work with MOHURD to develop construction and operating materials, which are tailored to the needs of different stakeholders to close the skills gap at different levels. The most relevant stakeholder groups are the managers of project developers, the managers and workers in construction companies, the staff of specialist inspectors and employees of the RRC (cf. Figure 1).

Operation

The start of the operation phase means a shift in responsibility for the novel urban water system. Project developers and construction companies hand the newly installed infrastructure over to the operator/s of the networks and the RRC and to the tenants or future landlords of the buildings. The inspection process, which has to be coordinated during the implementation phase, should take place in the crossover between the implementation and the operation phase in order to create awareness, ownership and trust in the new technical approach. Therefore, a systematic inspection of the novel urban water systems, including the connections inside the house, domestic piping and the connections inside the RRC, is necessary from the outset. The contracted construction company remains responsible for the connection pipes and the domestic network until the inspection results show that the system has been built in accordance with the relevant technical regulations and that inspection shafts or dampers are present at the main transfer points. Using these shafts or dampers, the inspector takes random samples to verify the correct status. Furthermore, correct installation of non-return valves and calibrated water meters is verified.

To complement the above-mentioned procedural and social aspects, other technical approaches to cross-connections have to be integrated in effective governance instruments. In terms of the detection of cross-connections, the 'blue water' inspection, which is compulsory in Germany, is one monitoring approach that is available (cf. Senatsverwaltung Stadtentwicklung, 2007). At the start of the operating phase of novel urban water systems, there needs to be a systematic and holistic inspection of the connections in the water supply sector and in the RRC. Before commissioning, the additional supply network should be checked in future to rule out cross-connections with the drinking water network. The compulsory approach to this in Germany is to briefly dye process water blue with food colouring (indigo carmine).

During the operating phase, maintenance work, in particular, due to malfunctions of the networks as well as an enlargement of the novel system (expansion to other districts), entails the risk of new interconnections in the street networks (see Operation). Other circumstances that can lead to alterations in domestic installations are a change in a flat's tenants (cf. Figure 1) due to generation effects, or a fundamental need for the flats to be modernised (e.g. the addition of an extra bathroom). In such cases, it can be expected that this work will be carried out by the occupants or with the help of unskilled friends or neighbours. The task of the independent inspection in the operation phase is to ensure that amendments do not violate technical standards and that changes to the system design are properly documented. Intrinsically, tenants have a self-interest in maintaining these standards because a rental agreement in the People's Republic is invalid if there is any violation of construction regulations. As the apartments in Qingdao are handed over to the tenants on the basis of a temporal property right assigned to them and any children for up to seventy years[3], it has to be ensured that knowledge of the system's existence and its basic functions are passed from one generation to the next.

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[3] The duration of temporal property rights depends on the usage of the buildings. Usually, industrial and commercial buildings are restricted to a shorter period in time than apartments. The ways in which residents who have been compensated with flats for leaving their traditional houses in the old village of Bijia perceive the reuse of water in general, and the role of the RRC, in particular, are documented in Birzle-Harder and Götz (2016).

In every house connected to dual networks, a building and operation manual designed for tradesmen and laypeople, developed by the design institute in cooperation with the water utility or RRC operator taking ownership of the novel urban water system, should be available and familiar to facility managers. They probably require a professional to explain this information and possibly also instruct the staff of the RRC to prevent cross-connections in public installations and within the RRC. Using the manual, which for example decodes the permanent marks of the different supply and sewer pipes, this trainer raises awareness to ensure that there is no confusion between the pipes either in the installation or in the documentation (for other aspects of good management, see Schramm *et al.*, submitted).

For effective governance of cross-connection checks during the operation phase, the suggested procedure has to be monitored for its labour intensiveness, especially with respect to the division of costs between the operating water supply company and the private temporal owner (see the case of small towns in the US reported by Pontius & Evans, 2008). If the cost-by-cause principle is applied, there would be a burden for the tenants to entrust an inspection company with approving the change in the design of the water systems in the apartment. Routine or random tests financed by the RRC operator could prevent a moral hazard, but would lead to additional costs in the operation of the novel urban water system. Another governance instrument to enforce a willingness to pay for an inspector is the establishment of fines by the city authority when amendments by the tenant are not yet documented by an inspector. To prevent market failure, it might be appropriate to establish a fee schedule for the services provided by inspectors.

Buildings reaching the end of their life cycle tend to drop out of the supply and demand sides of the novel urban water system. Consequently, the RRC needs to be kept informed and involved in the planning processes of the City Authority in order to ensure that replacement buildings are connected to the novel water system. Its incentive to engage in planning phases of new districts is also that the novel water systems could spread to the surrounding region so that it then has the advantage of being an innovation leader.

Discussion and recommendations

The use of the cooperation management approach (cf. Schramm *et al.*, 2017) as a systematic tool to deconstruct the causes of cross-connections, identify the actors to be involved and develop appropriate governance instruments to prevent cross-connections in novel urban water systems in China, in general, and in the case of SEMIZENTRAL in Qingdao, in particular, has highlighted that cross-connections are a problem caused by issues in the planning, implementation and operation phases. Compared to the construction of a conventional infrastructure, the construction of an RRC and of networks and buildings with an additional service water supply and source-separated sewer systems requires the involvement of several additional actors. It has proven very fruitful to enrich the existing cooperation management approach with governance approaches focusing on actors and their roles in deliberation and learning processes. However, additional research about informal interactions and the change agent as a neutral facilitator in other cases of novel urban water systems would help clarify the third research question about an improved institutionalised method for dealing with cross-connections. In particular, there could be further research into the three dimensions of complexity – (1) diverging problem descriptions, in the present case system descriptions, (2) uncertainty and (3) interdependency (cf. Head, 2010) – to highlight and structure the motivations behind the governance instruments discussed.

During deliberation processes in the planning phase, the perspectives of the RRC's operator need to be taken into account as well as those of certified plumbers and construction companies. As hypothesised in the section on approaches to governance, deliberation processes need to start as early as possible to ensure that special features, such as the dual supply of service and drinking water and the source separation of greywater and blackwater, are familiar. They need to be understood and implemented by central actors such as the system leader and operator, the design institute, the City Authority and the construction enterprises selected in competitive tenders who are all in agreement (cf. Schramm *et al.*, submitted). This is especially relevant for projects in which parts are funded by both public and private investors. Closer coordination is necessary between public planning processes for the public distribution and collection networks, and the private planning bureaus designing the buildings and the RRC, due to the more complex and still innovative system characteristics. For both, it is important to obtain ongoing and consistent qualified advice from design institutes, which should be selected based on common agreed criteria. Given these preconditions, design institutes could adopt the role of an important intermediary actor. Beyond definitions and design aspects, deliberative processes could be used to establish a proper time schedule and the creation of ownership and mutual trust.

The character and success of the deliberation phase are heavily determined by the number of specially qualified and certified actors involved, as well as their skills to create incentives for system leaders to engage in the project. Knowledge generation and distribution as well as capacity and awareness building can be achieved through self-organised learning processes in the construction and plumbing sector. The processes to select design institutes, construction companies and plumbers could be implemented to prevent adverse selection. These rely on objective skills for the construction of novel urban water systems through the certification of independent expert organisations. Skills and quality control are particularly critical in the implementation phase. Suitable materials intended for various actors such as plumbers, foremen as intermediary actors providing training for unskilled workers on the job, construction company managers or inspectors commissioned for final approval and documentation need to be developed (cf. Schramm *et al.*, submitted).

Based on a gap identified in the analysis of cooperation management, it could be argued that an independent actor, the inspector, should be responsible for conducting and documenting the 'blue water' tests on behalf of the RRC's operator. The operator is intrinsically interested in collecting and treating the greywater (or blackwater) and redistributing the service water produced in pipes and sewers without cross-connections. If the operator is not prepared to pay for cross-connection controls, the economic incentive to invest in novel urban water systems may diminish. Going beyond the short-term costs of the investment, adequate tariff models need to be developed for the long term.

With respect to maintenance work, it is extremely important that there is a manual that complements the documentation on site. It should include a short system description, information about existing inspection flaps, the permanent marks used for the pipes in the building and a list of inspectors. That method of documentation offers the advantage of new users of the buildings, new facility managers or new generations[4] moving into and redesigning the apartments using on-site information for awareness building and training. A further suggestion is to use the expertise of the inspector and the 'blue water' test once again in the operation phase. The recommended solution for a governance instrument to prevent cross-connections due to design changes has to comprise three strands. The first is based on voluntary signalling to the inspector

[4] This is particularly relevant in the case of Qingdao because most residents who received compensation for leaving their former village for the new housing estates Bijia A-C have already retired (cf. Birzle-Harder & Götz, 2016).

that a change in the design has taken place inside the apartment. In the second strand, random monitoring (e.g. with sodium bisulfite, cf. Friedler *et al*., 2015) commissioned by the RRC ensures that a voluntary approach is preferred, because in the case of cross-connections or intended misconnections, the polluter is punished by a fine set out in the third strand. Comparable governance instruments have already been used on public transport to address the issue of people travelling for free ('free-rider problem'). For the in-house installation, the facility manager (cf. Figure 1) is another important actor during the operation phase.

Since dual water systems are innovative and currently exist in niches, the missing piece in the jigsaw of governance instruments is learning and evaluation. Therefore, a culture of feedback within actors' groups and in inter-group communication between intermediary actors such as design institutes or inspectors, RRC operators, certified plumbing and construction companies, investors, system leaders and state actors such as the DRC and City Authorities is a necessary precondition. Given the lack of party competition in China, learning and evaluation of governance instruments in a political sense remain limited to executives and structures within the Communist Party of China, which are not considered in this paper.

Finally it is believed that effective integration and consistency between the governance instruments developed comprising (1) deliberation and communication, (2) qualification and certification, (3) final approval, inspection and documentation and (4) learning and evaluation need to complement the transformation of the water infrastructure towards resource recovery and water reuse in urban areas (cf. Figure 2).

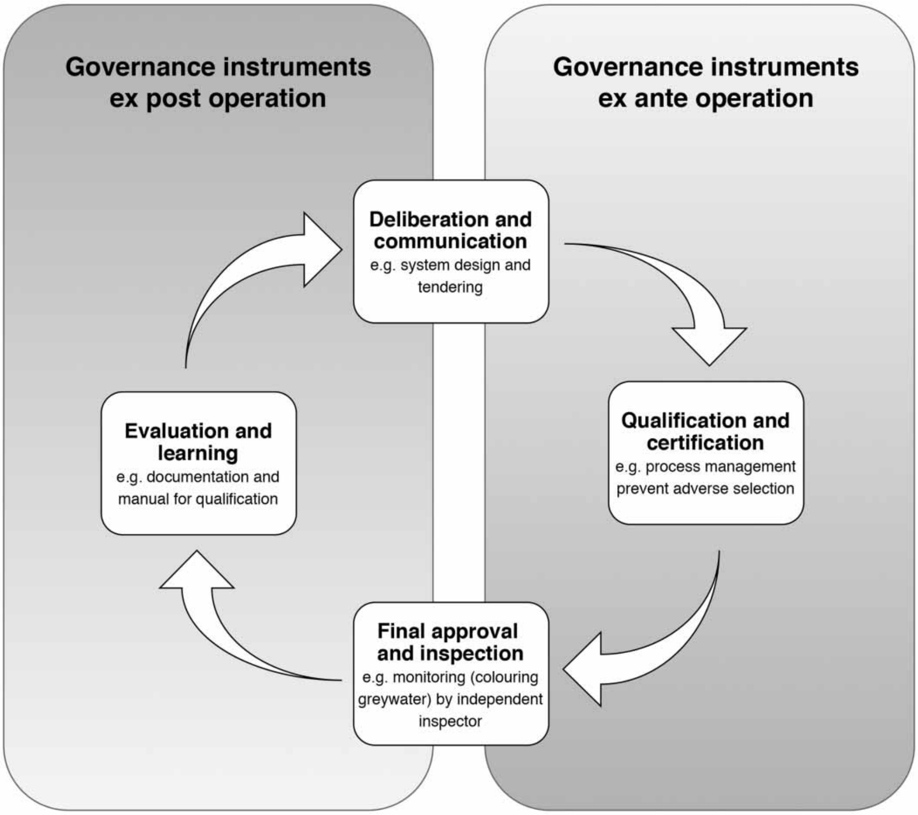

Fig. 2. *Ex ante* and *ex post* governance instruments to address cross-connections in novel urban water systems based on the application of the cooperation management approach and empirical evidence in the case of the RRC in Qingdao, China.

These empirical findings have shown that cross-connections can occur in all phases of the cooperation management approach. Therefore, the approach suggested here emphasises governance instruments that address cross-connections *before* they arise. In such proceedings, the precautionary principle is taken into account. While *ex ante* instruments such as deliberation, communication, qualification and certification are highly important in the planning and construction phases, *ex post* instruments have been developed to establish ways of controlling the (more complex) water infrastructure. Improvements in the documentation of novel urban water systems for the operation phase contribute to learning and evaluation, which again affects the *ex ante* instrument of deliberation and communication in subsequent planning phases. By combining technical and design approaches, such as the ‘blue water’ monitoring, inspection flaps or colour codes for the pipes installed with the above-mentioned governance and management instruments to prevent adverse selection, newly independent and specified actors such as the inspector, deliberation and qualification, it can be concluded that ensuing cross-connections should not hamper the development of novel urban water systems in future.

Concluding remarks

In the case of SEMIZENTRAL, causes of cross-connections have been analysed in the three phases of the cooperation management approach. To (re-)structure the debate on the challenges presented by interconnections in novel urban water systems, the article differentiates in terminology between unintended cross-connections and deliberate misconnections and examines governance approaches to prevent the former. The structure of the case has made it clear that cross-connections can occur in the planning, implementation and the operation phases in the RRC, public networks and built areas. Different responsibilities and institutional and organisational conditions influence the probability of cross-connections. By integrating the review-generated approaches to the governance of socio-technical systems and the actor perspective of the cooperation management approach, and confronting this framework with the complexity of the specific case, it has been possible to suggest governance instruments that establish the precautionary principle in each phase of cooperation management.

During the planning phase, in particular, deliberation about definitions of greywater for example and an early involvement of qualified and perhaps certified construction companies and advisors such as design institutes are crucial, for example, for time planning and awareness building (the role of calls for tenders is discussed in Schramm *et al.*, submitted). In the absence of international standards for the construction of novel urban water systems, good business practice has to be ensured, especially with regard to the training of the workforce, including managers and foremen. Qualification has to become compulsory for certification to indicate competence. The shift from the implementation phase to the operation phase is characterised by a newly established actor, the inspector, who is responsible for the ‘blue water’ monitoring to confirm the correct construction and enable proper operation. In the event of amendments during the operation phase, the article suggests that an inspection is again carried out. Referring to the cost-by-cause principle, the inspector is paid by the system’s operator. Changes during the operation phase need to be documented, contributing to evaluation and learning.

In summary, cross-connections in novel urban water systems can be prevented through an interplay of technical progress in detecting cross-connections and governance instruments such as deliberation and communication, qualification and certification, final approval and inspection, as well as learning and evaluation. In further research, these case-inspired governance instruments should, in particular, be applied to other cases of cross-connections or construction defects and in general to other questions of complex socio-technical systems.

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