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A data management framework for strategic urban planning using blue-green infrastructure

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ABSTRACT

Spatial planning of Blue-Green Infrastructure (BGI) should ideally be based on well-evaluated and context specific solutions. One important obstacle to reach this goal relates to adequate provisioning of data to ensure good governance of BGI, i.e., appropriate planning, design, construction, and maintenance. This study explores the gap between data availability and implementation of BGI in urban planning authorities in Sweden. A multi method approach including brainstorming, semi-structured interviews with urban planners and experts on BGI and Geographical Information System (GIS), and validating workshops were performed to develop a framework for structured and user-friendly data collection and use. Identified challenges concern data availability, data management, and GIS knowledge. There is a need to improve the organisation of data management and the skills of trans-disciplinary cooperation to better understand and interpret different types of data. Moreover, different strategic goals require different data to ensure efficient planning of BGI. This calls for closer interactions between development of strategic political goals and data collection. The data management framework consists of three parts: A) Ideal structure of data management in relation to planning process, data infrastructure and organisational structure, and B) A generic list of data needed, and C) The development of structures for data gathering and access. We conclude that it is essential to develop pan-municipal data management systems that bridge sectors and disciplines to ensure efficient management of the urban environment, and which is able to support the involvement of citizens to collect and access relevant data. The framework can assist in such development.

1. Introduction

Urbanisation is accelerating at the global scale (CBD, 2012). While urban expansion onto surrounding land is one trajectory, especially common in the global south (Bren d'Amour et al., 2017), urban densification is a strategy aiming to reduce urban sprawl and increase population density for efficient public transport and energy use (Grimm et al., 2008; Hassan and Lee, 2015). However, densification may lead to reduction in urban green spaces and spaces for surface waters (Haaland & van den Bosch, 2015). Such development could lead to lack of freshwater, increased air pollution, increasing noise, elevated urban temperature levels, lack of areas for recreation, less surface to detain runoff, and loss of biodiversity as potential consequences (Grimm et al., 2008; Stott et al., 2015). In addition, climate change will exacerbate several of the negative consequences of urbanisation, such as elevated temperatures under heat spells and increased risk of flooding from strong rainfall events (Grimm et al., 2008; Semadeni-Davies et al., 2008). Consequently, both under urban expansion and densification, there is a strong need for solid strategies to preserve, build, develop and increase the quantity (area) and quality of urban green and blue spaces (vegetation and surface water) to deliver multiple benefits (ecosystem services, ES) to urbanites, i.e. be multifunctional (Pauleit et al., 2011; Hansen and Pauleit, 2014; Sörensen and Mobini, 2017).

Researchers and public organization at multiple administrative levels have since the 1970's launched several concepts to describe and aid planning and implementation of green and blue structures in urban and rural areas: Low Impact Development (LID), Sustainable Urban Drainage Systems (SUDS) (Stahre, 2008, Hoang and Fenner, 2016), Nature-Based Solution (NBS) (EC, 2015), and Green Infrastructure (GI) (Fletcher et al., 2015). One of the aims of these concepts has been to upgrade green space to a coherent planning entity and incorporate aspects of ecological sustainability (including biodiversity conservation) and well-being of urbanites (Tzoulas et al., 2007; Ahern, 2013; Hansen and Pauleit, 2014). All the concepts require work beyond administrative

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'silos' and across disciplines and sectors, as well as a systematic involvement of stakeholders and citizens (e.g. Brown et al., 2009; Ahern et al., 2014; Hansen and Pauleit, 2014; Wihlborg et al., 2019). In recent years, NBS has been put forward within the European Union, as a measure to increase innovation and development of multifunctional solutions inspired, supported by, or copied from nature (EC, 2015). The close connection between GI, NBS and ES has been identified by Hanson et al. (2020).

The concepts do, however, relate differently to urban vs. rural areas, terrestrial structures vs. water, and large vs. small spatial scales. This makes recycling of ideas complex and to some extent even confusing. In this study we focus on urban planning as a way to manage the urban environment and therefore use the term Blue-Green Infrastructure (BGI), as this concept emphasises the importance of connected blue and green structures in the city. The term 'infrastructure' also indicates that surface water, green spaces and stormwater management are of the same importance in the urban environment as other infrastructures (Lennon, 2015). The addition of 'blue' to the GI-concept is common and highlights the importance of water in planning and management of green structures. In this study, we use NBS when we talk about specific solutions as a part of the BGI.

Geographical Information Systems (GIS) are key tools in spatial planning to support urban environmental management (Yeh, 2005), and can be integrated in decision support systems (DSS) (Zerger and Wealands, 2004). DSS systems are efficient for data retrieval, query, and mapping (Yeh, 2005) and allow spatial data to be managed, visualised, analysed, and used for modelling to serve spatial planning (*ibid.*). There are, however, several types of difficulties related to gathering and using adequate and appropriate data for BGI planning in cities, related to economic, social, and environmental technical factors. They span from lack of information about the extent of existing BGI, costs of maintenance and citizens' perceptions and preferred solutions, to technical difficulties. The latter can e.g. be database structure, format of available GIS data, e.g. patchy data provision based on lack of data, lack of coordination between data collecting authorities at different spatial and temporal scales, as well as lack of knowledge of using the systems (Hansen and Pauleit, 2014; Ahern et al., 2014).

Previous research on how to circumvent these difficulties has mainly focused on either technical aspects of data management (e.g. Carrera, 2004), specific challenges such as flood risk management (Zerger and Wealands, 2004), or data sharing between authorities and the public (Mansourian et al., 2006). Methods or tools have been proposed, e.g. to develop GIS-based decision support systems (DSS) (Zerger and Wealands, 2004), or to use spatial data infrastructures (SDI) for sharing geographic data and metadata among stakeholders (Mansourian et al., 2006). Also data collection through community mapping, Volunteered Geographic Information (VGI), has been widely discussed (Budhathoki, 2010; Capineri et al., 2016). Previous frameworks thus mainly focus on technical solutions to well-defined problems (e.g. cyclone induced inundation), or data access and sharing of data *per se*.

Here, we take a broader view on the persisting information gaps regarding data availability for adequate planning of BGI and include data management for improved BGI through the whole spatial planning process. We do so by focusing on the municipal level of spatial planning in order to identify information barriers between expressed data needs, data collection, and data use. With this information we develop a framework to assist strategic spatial planners overcome information gaps related to data management to facilitate the inclusion of high quality and context relevant BGI in urban planning.

2. Physical planning in Sweden

Physical planning includes deciding how land and water areas are to be used (Planning and Building Act 2010:900) which sets the frame for all aspects of environmental management. In physical planning, different public interests are weighed against each other in an open and democratic process, taking into account the rights of individuals and the environment. In Sweden, the municipalities have the main responsibility for the physical planning. Municipal authorities thus have an overarching duty to provide good living conditions for its human inhabitants, and simultaneously provide ecologically sustainable cities and habitat for biodiversity, in line with global conventions and national regulation and policy. To do so, it is essential to coordinate the implementation of new BGI into the built environment and improve existing ones. This requires strategies that combine maintenance of existing BGI with strategic placement and the development of adequate quality of new BGI, both in the existing urban space and in new urban developments. The type of solution to be introduced will depend on the main purpose of the BGI (e.g. water retention, biodiversity or recreation), in combination with additional local demands. A challenge here is that administrative borders often do not coincide with spatial or temporal scales necessary for adequate maintenance and governance of ecosystems (Borgström et al., 2006; Faehnle et al., 2015). For example, municipalities or separate water utility companies are responsible for urban drainage, but neither of these can govern what is built on private land in detail. The Swedish Environmental Protection Agency (national level) and the County Administrative Boards (regional level) are responsible for green infrastructure strategies in general, spanning both rural and urban areas (Ministry of Environment, 2014) while the National Board of Housing, Building and Planning (Boverket) is responsible for guidelines regarding urban green infrastructure, and municipalities are responsible for the concrete spatial planning at local level.

Pursuant to the Planning and Building Act, the Swedish planning system, consists of a comprehensive plan, covering the whole municipality, area regulations, covering neighbourhoods or parts of a city, and the detailed development plans, covering a plot or a group of plots. The latter are the only ones that are legally binding (Swedish National Board of Housing, Building and Planning, 2010a) (Fig. 1). The detailed plan defines what can be built and what should be left as "open" green or blue structures. The building permit is closely linked to the detailed plan. The last stage is implementation. As detailed plans are largely focused on the built structures, any space for potential BGI has to be clearly identified in the building permit or in processes linked to the building process such as different types of greening measures (Belčáková et al., 2019; Park and Guldmann, 2020). In addition, regional assessments are developed to facilitate coordination of cross-municipal issues that requires resources and abilities that individual municipalities have difficulty mobilising, such as infrastructure, climate change adaptation and regional housing supply.

3. Methods

The proposed framework was developed to overcome information gaps related to data management to facilitate the inclusion of high quality and context relevant BGI in urban planning. It has been developed through four consecutive, empirical steps:

Step 1. Brainstorming among the authors, with the aim to identify barriers influencing the flow of information. The authors represent different disciplinary backgrounds and approaches to BGI and its implementation: from knowledge of urban water management to biodiversity and ecosystem services, and from theory and policy to practice. A few solutions were selected as cases, in order to create a foundation for the authors' discussions (Table S1, Supplemental material). The selection of solutions aimed to illustrate a wide variety of function and type of NBS. The discussions resulted in a list of potential barriers for data management in relation to BGI, an inventory of available data, and a draft framework. In this case, we combined our three separate disciplinary backgrounds. As a part of the brainstorming a general list of available and necessary data was identified.

Step 2. Interviews with selected municipal officials and practitioners from dealing with different aspects of implementing and developing

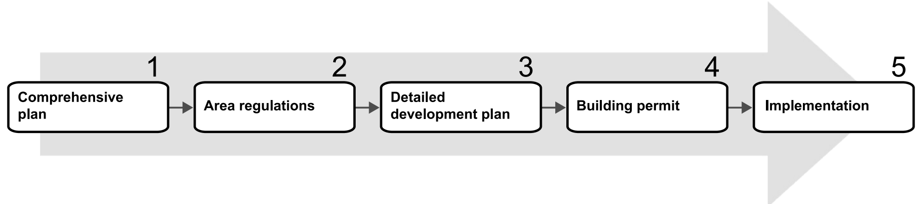

Fig. 1. The Swedish planning system.

BGI. Interviews were performed to complement the list of barriers identified in Step 1. The interviews were semi-structured (Bryman and Bell, 2015), focusing on identifying data or information perceived as missing to meet urban challenges and plan for future distribution and placement of BGI. The draft framework from step one and the six resulting questions identified through the brainstorming served as a basis for the questions to the interviewees. As the interviewees had different backgrounds and experiences related to BGI implementation including the roles of collectors, users, managers, analysts of data. Consequently, the questions and follow up questions varied. Six practitioners were interviewed (Table 1). Recordings and detailed notes were taken during interviews and recordings were transcribed. Results were analysed through thematization of the answers—an approach commonly used in qualitative text analysis (de Sousa et al., 2018; Krawatzek, 2018; Northcutt and McCoy, 2004).

Step 3. Validation of the framework was done through a workshop with 11 stakeholders, five from Swedish and four from Danish municipalities and water utility companies, one representative from a consultancy firm and one representative from a construction firm. The meeting was arranged around two cases targeting different spatial scales of the planning process, where blue-green solutions were suggested to be introduced in the urban space. For each case, different aspect of the framework was discussed: When the framework would be more helpful in relation to the planning process was discussed in relation to Case 1. Data needs and technical and organisational aspects of communication was discussed in relation to Case 2.

Step 4. Triangulation of collected data (Mathison, 1988); Data from brainstorming, interviews, and the workshop were combined to the final framework to facilitate urban planners to grasp the complex set of issues related to data use and management central to a sustainable inclusion of BGI in urban areas.

4. Results

4.1. Results Step 1: brainstorming

The following barriers were identified during the brainstorming sessions among the authors conducted in autumn 2016 and spring 2017.

Table 1
Interviewed practitioners' position and educational background.

Interview	Position	Educational background
1	City of Malmö, Planning Office, Planning department	Landscape Architecture
1	City of Malmö, Planning Office, Strategy Department	Ecology
2	Planning engineer, VA Syd (water utility company)	Civil Engineering
2	City of Malmö, Streets and Parks Department	Civil Engineering
3	Researcher with GIS expertise at CEC, Lund University	PhD in Applied Biochemistry
3	Responsible for GIS in two municipalities (Tomelilla and Simrishamn)	Architecture

4.1.1. Multiple needs of data

Several types of data are necessary, e.g. to inform actions to reduce noise, control pollution, limit lack of green spaces for recreation, reduce exacerbated temperatures and stormwater runoff, and increase infiltration and evapotranspiration. There is a need for data to produce maps on availability, lack of and need for several ES, as well as to provide information on what functions and services BGI can deliver. A list of NBS was developed and discussed, clarifying the diverse needs associated with different NBS, like placement (street, roof, park, garden, square, etc.), function (hydrological, biological, aesthetic, social, pedagogical, etc.), maintenance, ownership, and spatial scale of implementation (Table S1, Supplemental material). These different needs lead to multiple data requirements when planning, implementing and maintaining the solutions.

4.1.2. Lack of data

Some data was identified as missing due to difficulties related to data collection. For instance, underground infrastructures are difficult to investigate, including their maintenance needs. Data on spatial distribution of species in urban habitats are costly to acquire and update. Data collection can also be affected by ownership structures. For example, green roofs built by the city councils are more likely to be registered compared to privately constructed roofs.

Inventories of existing biological and ecological values are often made based on existing knowledge rather than actual needs of information. For example, the Swedish Species Information Centre's crowdsourcing leads to more reports on rare species close to where interested biologists live and a lack of information in other areas. A SIS standard for biodiversity surveys exist since 2014 and is starting to be implemented at the municipal level (SIS/TK 555 Naturvärdesinventering).

4.1.3. Problems related to data management

We identified several problems related to data management, from technical issues such as incompatibility between database structures, to problems related to human resources. The latter includes low priority for certain municipal assignments, scant knowledge of available data, as well as competition, prestige, and difficulties to cooperate between departments, as well as leadership related issues. In addition, collection and processing of data to assess the development and function of BGI are divided between several national, regional, and local authorities. Data is collected in relation to the legal and administrative responsibility of these authorities. As the purpose of collecting and assessing data differs between authorities as a consequence the collected data seldom result in a comprehensive basis for planning BGI; neither is it comprehensive in spatial cover, content or quality.

4.1.4. Raised questions

The questions raised during the first brainstorm sessions, together with the draft framework, were used to guide the semi structured interviews in Step 2. The following questions were identified.

- Which data exist and at which scale?
- What kinds of data are lacking?
- Is the data format convenient or not, when cooperating with other professions in the planning process?

- Are authorities that work at different spatial scales aware of the need to pool data to improve evaluation and planning of BGI at the local scale?
- Is there data for costs of maintenance of future and existing BGI?
- Is there data about citizens' perceptions and preferred use of BGI?

4.1.5. Present situation and data need

A list of available and currently used data was collected as a part of the brainstorming (Table S2, Supplemental material). The list includes data at different planning stages and organisational levels, provided by various authorities and organisations. From the list, the following categories of spatial data needed in the planning process of BGI were developed and later included as Part B of the framework. The categories are ensuring that all kinds of needed data are included in the data management discussions.

- Cadastral (e.g. property ownership, land cover)
- Technical (e.g. pipes, cables)
- Geological (e.g. soil layers, stability)
- Biological (e.g. citizen observations of species, important habitats)
- Environmental (e.g. environmental monitoring, polluted soil and groundwater)
- Risks (e.g. flood claims, flood hazard mapping, environmentally hazardous business)
- Social (e.g. socio-economy, historical buildings)
- Administrative (e.g. protected areas, municipal maps for planning)
- Meteorological (e.g. temperature, precipitation, humidity)

This spatial data further needs to be complemented with data related to, e.g., economy and maintenance.

4.2. Results Step 2: interviews with municipal officials and practitioners

The interview results are presented and discussed below under six themes. These themes slightly differ from those identified in Step 1. The results are summarised in Table 2.

4.2.1. Lack of data

In two of the interviews, lack of GIS data related to ES such as pollination and tree shade, and mapping of biotopes, including the marine environment, was mentioned (Interview 1, 3, see Table 1). The general lack of 'green' data for private land was also mentioned (i.e. lack of surveys of green cover and biodiversity). One of the interviewees mentioned that there is a tree database for public land in Malmö but not for private land, whereas the pluvial flood management plan concerns the whole city. Therefore, it becomes difficult to assess the real lack of green space for stormwater management (1).

For stormwater management, it was mentioned that flood hazard maps are not updated in accordance with the development of the city, e.g. deep excavation holes may be included in flood simulations, but are later filled and built on. Even if data quality is improving, the resolution is still low and data update processes are perceived as too slow (2).

It was argued that the quality of data for species occurrences in the Swedish Species Observation System is uneven. To correctly interpret this data, it is important to have knowledge of the structure and purpose of data collection, i.e. knowledge of metadata (1).

It was also mentioned that the City of Malmö is currently improving the so-called Malmö City Atlas, so that employees will have individual access to common GIS layers. In the future, the atlas will include data from the Swedish Species Observation System (1).

4.2.2. Data access and rights

In interviews 1 and 2, the lack of access to inundation data from insurance companies was mentioned as a problem. However, it was also mentioned that insurance companies are working to facilitate access to such data and the possibility to combine insurance data and data from the water utility company's own flood claims to enable calculation of future expected flood damage costs (2). It was argued that metadata related to different flood hazard modelling scenarios is not stored systematically so that only the modeller can properly access this data and the underlying scenarios (2).

It was mentioned that municipal maps of blue structures are difficult to use for strategic planning at the municipal level because the Planning Office Strategy Department lacks access to certain GIS layers from the Streets and Parks Department (within the same municipality) (1, 3). It was also argued that strategic service providers (e.g. energy suppliers, fire and rescue services) claim to have control over their infrastructure and environmental risks related to them, while the municipality does not know on what information these assessments are based (2).

Another problem related to data access is that data is physically scattered. For example, while data on the sewer system covers the whole municipality, it is spread over different databases and formats, including digital maps, scanned documents and paper copies (1). In relation to the pluvial flood management plan it was argued that one simulation result (the flood hazard risk map for a so called hundred-year-rain) is available on a shared platform, while other simulation results only exist on the computers of the modelling consultants (2). It was also mentioned that an evaluation of added 'green' values, including several ES, was made for the pluvial flood management plan but did not enter the final report and is therefore not available to the municipality (2).

One of the interviewees, with experiences from data management in different municipalities, argued that data access is especially difficult in

Table 2
Results from interviews under six themes.

Lack of data	Data access and rights	Lack of knowledge	Tools that are not adapted to user's needs	Organisation of data management	Strategic data use
• Lack data related to ES • Lack "green" data on private land • Maps not updated as the city is changed • Too low resolution • Uneven data quality	• No access to data from several external data owners • No systematic storage of metadata limits access to data • No access to certain GIS layers • Physically scattered data • Evaluation of ES not available to municipality • Data access sometimes limited due to culture within the organisation	• Know either CAD or GIS, not both • Smaller municipalities have lower level of knowledge • Bigger problem than lack of data • Threshold to use GIS • Even skilled users feel they lack knowledge about possibilities in GIS • Little knowledge among leaders leads to few courses for staff	• High cost, while the system is not adapted to the need • ArcGIS has an oligopoly in Sweden • Hard to change software • Lack access and routines to correct data • Specific features missing, like quick analyses of flood risk • Need lists of open access data	• Too many plans and programmes to consider • Some plans and programmes only available as PDF documents • GIS competence often sorted under City Survey, far from budget work, and therefore not prioritised • Important to migrate existing data into a single system • Initiatives to improve data management • Good if open source code was used more	• Too much information to grasp • Still needs more data, but with guidelines on how to use them • Impossible to priorities everything, despite politicians' wish • Possible to be strategic if you are prepared early in the planning process

municipalities where the officials in charge are afraid to make mistakes, and therefore restrict access to the data (3).

4.2.3. Lack of knowledge

Many municipal officials use either GIS or CAD-based planning platforms, but very rarely both (3). Planners typically use CAD, with only restricted knowledge of GIS (2). Small municipalities generally do not use any of these platforms, but if they use GIS it enters at the end of the planning process for map production (3). This situation is mainly due to lack of local GIS knowledge rather than lack of data, as a lot of data is freely available to the municipalities through the Swedish Geodata collaboration (3). Using GIS is a matter of practice: if you do not work in a GIS environment regularly, there is a threshold to use this type of programme (2). Even officials that use software like ArcGIS (Esri) on regular basis are rarely aware of many of the possibilities of the software. There is thus a need for introduction to GIS, e.g. for middle management positions, to make them aware of the importance of GIS competence among staff (3).

4.2.4. Tools that are not adapted to users' needs

The high costs of ArcGIS were identified as a problem (USD 3500–6000 for a licence and ca USD 100 for maintenance per year). The system is not perceived to be adapted to municipal needs, and therefore not worth the cost. There is a sort of oligopoly of ArcGIS in Sweden where three companies deliver services, and municipalities are restricted to the structure they choose to buy from the start (3).

In interview 2, several wishes for tool developments were expressed. Practitioners maintaining stormwater drainage systems lack access or routines to add new data when they find faulty or missing data (1, 2). Needs for specific tools were also mentioned, for instance a system where contrasting rainfall scenarios could be compared in real time. Today it takes two weeks to run a model for one scenario and this requires a consultant (2). In the detailed planning stage, it would be valuable to easily assess how much water an area undergoing planning receives and how much it drains to other areas (2). It is however difficult to develop tools that can handle all needs (3). An initial step is to provide open access data (3). A dream would be to have lists of open data, including metadata, with different security levels depending on the type of data (3).

4.2.5. Organisation of data management

It was mentioned that there are too many plans and programmes to consider when developing BGI (2). The fact that these plans are often only available as PDF documents makes it difficult to compile information during the planning process (2).

The GIS infrastructure is organised very differently in different municipalities. In Malmö, one official at each department is responsible for GIS, but the departments do not work together. In Helsingborg municipality, there is instead one GIS unit serving the other departments. Moreover, GIS competence is often sorted under the City Survey Department, situated under the planning unit, far from the budget work. As data availability is of strategic importance, data collection and storage strategies should be organised from a more strategic position to increase its status and priority, similar to IT issues that in general are organised under the leading functions (3).

It was argued that the only solution to the lack of GIS data is to collaborate and migrate the existing data into one single municipal-wide system. It is a one-time-only job, but it is very important to do it correctly. Lack of progress in GIS data management is in several municipalities probably due to a combination of lack of knowledge and economic resources (3). There are several on-going initiatives to improve data organisation and ensure its availability, for example the Swedish Association of Local Authorities and Regions and Sweden's innovation agency, Vinnova, currently cooperate to make planning more digital. Data is increasingly open access, e.g., data from the cadastral and land registration authority is now free for municipalities (3). Another example mentioned was the current cooperation around the tool 'Ekogeokalkyl', led by the Swedish Geotechnical Institute, which will include benefits from green space and ES in urban areas. It will be open for everyone working in ArcGIS/ArcScene (2).

To create a structure for data flow, it is, according to one of the interviewees, important to handle the three pillars of information handling: storage of data, analysis and visualisation, and data maintenance. These may require different software but should preferably be based on open source code (3).

4.2.6. Strategic data use

In two of the interviews, 'too much information' was mentioned as problem (1, 2). It was argued that there is a need of more, but not too much, data, as well as guidelines to know which data to focus on. For example, in the neighbourhood Söderkulla in Malmö, in total 14 separate flood models have been run and the multitude of information is difficult to handle (2).

Another issue is that politicians want to be good at everything and consider everything. In contrast, as a municipal official, you have to be clear about what you have prioritised and know that not everything can be prioritised (2).

In interview 1, it was argued that strategic data is indeed available through the Malmö City Atlas, databases about areas of national interest (Riksintresse), and the Swedish Species Observation System. This data can be used to prioritise what to protect and what action to take, and it is possible to be strategic if you are prepared early on in the planning process. The interviewee gave an example of a park and a pond in two newly developed areas where this information had been successfully used (1).

4.3. Results Step 3: validating framework through a stakeholder workshop

Some of the major findings from the workshop are that the framework both identified several problems and helped to identify solutions to them. The problems raised relate to the need to identify structures to involve all citizens, and the importance of creating structures for evaluation of long-term effects of introducing of blue-green solutions as a way to motivate politicians but also to ensure that the implemented BGI achieve the intended goals. It was discussed that the framework should be closely connected to the municipalities' environmental or sustainability goals to become efficient. It was also noted that maintenance is essential to consider in relation to the improvement of blue-green infrastructure and blue-green solutions, as well as the importance of communicating end results to politicians and citizens. Solutions mentioned were the need to create new organisational structures that are able to handle the necessary data, as well as the need to increase capacity of municipal employees to manage and use both existing and new data.

4.4. Results Step 4: triangulation of data from brainstorming, interviews, and stakeholder workshop to develop a final version of framework

Through the three empirical steps presented above, we identified issues relevant for strategic use of data to aid the development of BGI. We developed the following framework to support data use in planning, implementation, and maintenance of BGI, which consists of three parts: A) Ideal structure of data management in relation to the planning process, data infrastructure and organisational structure, and B) A generic list of data needed, and C) The development of structures for data gathering and access. Part A and Part B show different aspects of data management for strategic planning of BGI, where a graphical overview (Fig. 2) covering Part A has been developed to facilitate discussions on data management within and between organisations working with BGI in the urban environment, typically in a certain city. The graphical overview includes five main steps (box 2–6 in Fig. 2): from obtaining data to the actual delivery of ES from BGI. These main steps are based on

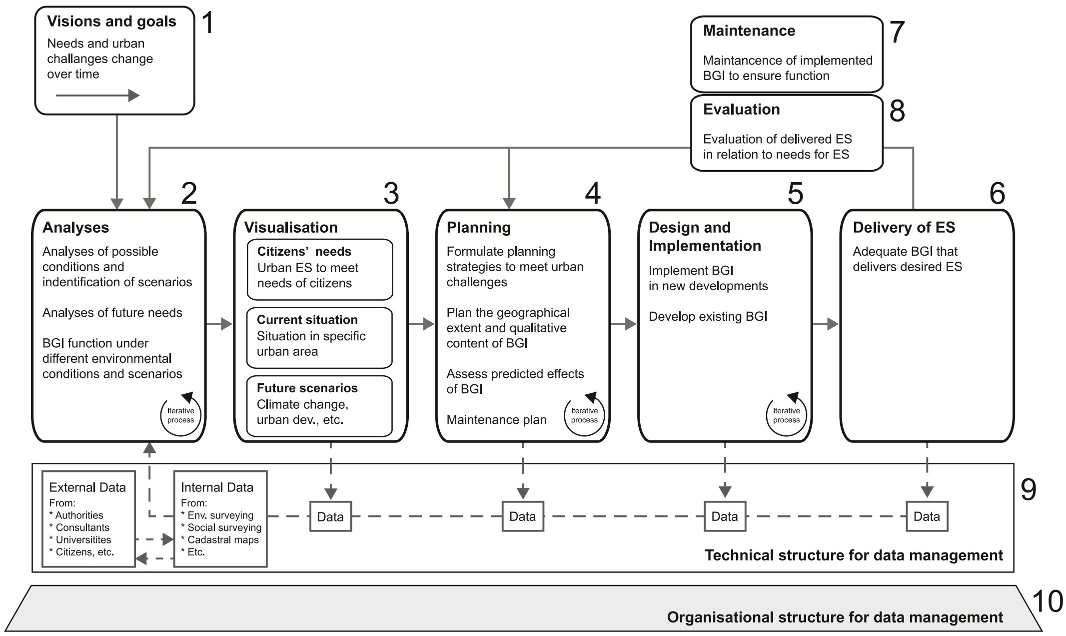

Fig. 2. Framework for improved information flows in urban planning of blue-green infrastructure (BGI) and their delivered ecosystem services (ES). Graphical overview to be used in Part A: Ideal structure of data management in relation to planning process, data infrastructure and organisational structure.

a suitable organisational and technical structure as well as the involved actors' knowledge (box 9 & 10). Also maintenance and evaluation of existing BGI are included (box 7 & 8), as well as visions and goals (box 1). In Part B, data need is discussed. To support the discussion, the list under 'Present situation and data need' (see Results Step 1: Brainstorming) could be used ensuring that all kinds of needed data are included. The use of part A and B leads to the third part, C, in which decisions are taken regarding data gathering, access, management, and organisation in a specific case. The following manual should be used to guide involved staff through the parts and steps of the framework:

Use Part A and the overview in Fig. 2 in order to:

1. Give common strategic objectives for BGI data management
2. Identify gaps in the current data management procedure
3. Discuss how well the technical and organisational structure works currently and how they could be improved in the future
4. Nurture discussion on data management

Use Part B and the list under 'Present situation and data need' (see Results Step 1: Brainstorming) in order to:

1. Identify data needed for strategic planning of BGI
2. Identify gaps in the current data

Based on the discussion related to Part A and B, the next step (Part C) is to:

1. Identify who should have access to which data
2. Identify who should gather data needed and from where
3. Decide how the technical and organisational structure should work in the future
4. Give an overview in order for each partner to identify their role:
   a. As planner of BGI
   b. As data supplier and/or user

In the following paragraphs, the graphical overview for Part A of the framework (Fig. 2) is explained in detail.

As a basis for the work with BGI in urban planning lays political visions, environmental goals, and current legal standards defined to meet present urban challenges (Fig. 2, box 1). It is essential to keep track of changes in data needs based on these requirements over time. Both data structures and data collection processes should be updated regularly to ensure they are useful to fulfil the needs.

Box 2 to 6 includes the main planning steps from data analysis to implementation of BGI and its deliver of ES. In box 2, data is used for analyses of possible conditions for BGI and identification of future scenarios for the urban space, for analyses of future needs, and for analyses of BGI function under different environmental conditions and scenarios. Data collected or produced both within the organisation and data accessible from other organisations should be available. It is important to note that if collected data is not stored in a proper way, access to it may in reality be limited.

In box 3, data and analyses are visualised, e.g. information on citizens' needs, the current situation of BGI and related assets in the urban environment, and future scenarios such as predicted climate change and urban development. This requires data visualisation at a scale useful for spatial planning, but also visualisation that can inform smaller, local projects. For urban planners, engineers, etc. visualisation is a crucial step, as data presented in a convenient and well-structured way is essential for their work. A good and readily accessible visualisation of the data also saves time.

In box 4, planning strategies are formulated to meet urban challenges. Such strategies must include a plan for the geographical extent of the BGI, as well as a plan for the qualitative content. During the planning step, predicted effects of the BGI on targeted urban ES, including co-benefits and trade-offs, should be assessed. The results of strategies and assessments are presented as reports, strategy documents, or as a part of comprehensive plans, while detailed plans (legally binding building plans) often concern smaller areas. To ensure proper long-term functionality, all planning of BGI must include a maintenance plan.

Box 5, implementation, includes the process from planning and design to construction of BGI. Both implementation in new developments and maintenance and development of existing BGI should be in line with strategic plans to ensure high quality of the solutions. Some data is produced during this step, especially during the design phase. This data is often produced in a different format (e.g. in CAD) but should be transformed to GIS for inclusion in future planning. All data produced in the planning process, especially related to box 4 & 5, should be available for future planning.

Box 6 shows the main goal, delivery of desired ES by BGI. While no data is automatically generated during this step, collection of data from the implemented solutions are important for future planning. Box 7 shows maintenance of implemented BGI, which is essential to proper functionality (and aesthetics) of the implemented solutions. A well-structured and continuous evaluation of implemented structures is essential to assess their success (box 8). Such evaluations may be conducted by the municipality or by external actors, for instance through a scientific evaluation of the delivered ES in box 6 related to the identified needs in box 3.

The data management in spatial planning of BGI should be based on suitable organisational and technical structure, including appropriate knowledge of included actors. By organisational structure (box 10) we mean how officials exchange data and knowledge, meet and interact, and how responsibilities regarding data management is organised. By technical structure (box 9) we mean the tools and solutions used for management of data during all steps in the spatial planning process, including data collection, storage, and maintenance. Staff with adequate knowledge is necessary to ensure high-quality results, e.g. engineers who to construct database structures and planners/designers to make visualisations. Appropriate data (box 9) to support the development of new BGI, or to maintain current ones, is essential to ensure a strategic development that benefits both people and nature itself. It is therefore essential that this step includes links to broader municipal goals to ensure relevant data collection. It is equally important that actors involved in municipal development (box 10) are aware of available data. Moreover, as urban areas change quickly, data maintenance is essential to ensure its relevance and quality. Box 9 therefore includes both data maintenance in a more technical sense, and information on how data has been collected (metadata).

5. Discussion

Blue-green infrastructure incorporates ambitions that require work beyond administrative and disciplinary 'silos' and a systematic involvement of relevant stakeholders, including citizens. Based on such perspectives, this study has aimed to better understand the information gaps and develop a framework that can support adequate planning of BGI at the municipal level. We initially identified barriers to information flow and created a draft framework (Step 1), then used interviews and a workshop (Step 2 and 3) to improve both the understanding of barriers and the framework. In the following sections we discuss identified barriers in relation to scientific literature and suggest how the framework could be used in strategic work to implement long-term sustainable urban BGI.

Themes identified in Step 1 and 2 differ slightly. *Multiple needs of data* (Step 1) were not directly mentioned in Step 2 but served as a background for the discussions. *Lack of data* (Step 1 and 2) and *data access and rights* (Step 2) are closely related and are therefore discussed together under *data availability*. The same goes for *problems related to data management* (Step 1), which is closely related to *tools that are not adapted to users' needs* (Step 2), *organisation of data management* (Step 2), and *strategic use of data* (Step 2). These are discussed together under *data management*. *Lack of knowledge* was only mentioned in Step 2 and is discussed separately.

5.1. Data availability

Major issues related to availability of data for strategic development of BGI are; lack of data on quality of BGI, patchiness of existing data, and the continuous physical change of the urban matrix. In the interviews, it was argued that different actors produce and have access to different sets of data and that access is related to security of sensitive information and privacy issues. One of the interviewees emphasised that open data, with different access depending on security level, is much needed in order to overcome data access problems. Additionally, it is important that this data is not only available, but also re-useable (Benitez-Paez et al., 2018), which should include that data reuse should be promoted, re-users' needs should be identified, metadata should be user-focused, and the terms of use should be easy to read. Ethical aspects of data access are increasingly mentioned in the literature (Yeh, 2005; Newman, 2010; Schweitzer and Afzalan, 2017), raising concerns of access between municipal departments, municipality, and private actors, as well as between these actors and citizens. The latter issue is raised as a consequence of the new General Data Protection Regulation of the European Union. At the same time, more and more research indicates that improved access to data, for instance hazard model outputs, can stimulate dialogue between different stakeholders, like modellers, risk managers, and urban policy makers (Zerger and Wealands, 2004). However, a major concern is that increased use of informatics may widen the gaps in power and political voice between experts and non-experts (Viitanen and Kingston, 2014; Grindrod, 2016). With the development of smart green cities, where information systems are out-sourced, ethical assessments and consideration of consequences of data collection systems will grow in importance. It will also be essential for municipalities to consider how to store model simulations and scenario structures in a transparent way, as an increasing amount of in particular water related data is produced by external consultants. For public decision-makers, especially in small municipalities with few employees, it may be difficult to keep up with the development of specific models and to interpret what the produced data actually means and at what scale it is relevant.

At a more general level, it may even be difficult to discern what type of model or consultancy advice should be procured, as illustrated by a review of decision support tools for informed decisions on urban water management (Lerer et al., 2015). The reviewed tools were categorised in three groups, i.e. 'How Much'-tools, 'Where'-tools, and 'Which'-tools. None of the reviewed tools addresses all aspects relevant to water management and they were influenced by the local context of where they were developed (*ibid.*), making it difficult to overview and choose between the tools for non-experts.

It is noteworthy that data on people's perception of green spaces, human well-being, economic benefits of BGI, and the cost of development and maintenance were not mentioned in the interviews. This may reflect the selected interviewees, but if related to the identified list of data in step one (Table S2, Supplemental material) this type of data is often lacking. Similar results have been found in a study mapping research priorities for green and public urban space in the UK (Bell et al., 2007), where health and well-being had weak scientific, and hence data, support.

The challenges identified above need to be solved to reduce risk of unsystematic data use due to lack of coordination of existing data (Bell et al., 2007) to aid development of multifunctional BGI. Similar observations have been made about data for climate adaptation in urban planning, especially when conflicting interests appear towards the end of the planning process (Eliasson, 2000). Our workshops confirmed that the proposed framework both can help to identify what is currently not working or lacking, as well as develop ideas on how such issues can be solved. In that sense, the framework serves a double function.

5.2. Data management

Municipalities organise their data storage in different ways, also indicated by Hansen and Pauleit (2014). Some municipalities have a central unit for data storage and management, whereas others have a more decentralised organisation. To ensure a holistic approach, the development of a system where data storage and management supporting strategic urban development are a part of a centrally organised municipal service, is one way forward. It could be beneficial to connect GIS experts to the IT unit, often located higher in the municipal hierarchy. When developing such structures, it is essential to develop solid data categorisation systems to ensure that data can be found and maintained when needed. It is also important to save and store model scenarios in a structured and accessible way also for non-GIS experts. For example, a spatial data infrastructure (SDI) could be employed to assign different writing and reading access for different officials and reading access for the public (Mansourian et al., 2006).

Combining an SDI with web-based solutions make data and information on a detailed level available to responsible parties, while the public can access up-to-date information. SDI makes it possible for GIS datasets to be used by others than the data-providing organisation, and for purposes other than they were originally meant for. By database writing permissions set by the responsible data holder, stakeholders can contribute data to datasets in the SDI. Both Malmö and Helsingborg, two of the cases in this study, use SDI to share information with the public, e.g. noise assessments, planned bike lanes, schools and areas for recreation. Community mapping allows the public to contribute with data to a common database. While often claimed to be motivated by altruism, Budhathoki (2010) shows that one of the most common motivations, besides the individual's local knowledge and eager to correct blank or erroneous data, is monetary. In Sweden, community mapping is e.g. used to collect observations of species from the public via the Swedish Species Observation System (Artportalen), led by the Swedish Species Information Centre and the Swedish University of Agricultural Sciences. The information is used in planning of BGI.

Moreover, it was argued by several of the interviewees that there is too much data or that the politicians want to do 'everything', which makes strategic use of data difficult. This finding can be interpreted in several ways: the data handling systems are not good enough, or the goals of the BGI are not clear enough. The first issue has been discussed above. As for the second issue, it seems essential, as an integral part of planning documents, to define or decide for what or for whom BGI is developed, and to clarify the goal(s) of each feature, both smaller and larger solutions. Several municipalities have initiated the development of such an assessment (Hansen and Pauleit, 2014), which could be used as inspiration for how to organise similar work in Swedish municipalities.

Moreover, the building and construction sector is increasingly using collaborative IT systems such as Building Information Modelling (BIM), integrating several expert areas into one IT structure (Dossick and Neff, 2011). Recent research has shown the ability of these systems to work as digital boundary objects (Alin et al., 2013), but this potential is strongly linked to how users perceive the organisation, form and content of the system (Poirier et al., 2017). This links to our findings, that data organisation plays a central role in the success of the integration of new IT to support decision-making. Spatial planning could be supported by similar tools, allowing both experts on different aspects of urban development and citizens to create a collaborative space to learn from each other. Hopkins et al. (2005) developed a planning data model (PDM) that enable urban development decision makers to view planning as a process where the specific plans provide useful and useable information. There are also other potential data sources that could be explored such as the inclusion of citizens' perception via mobile phone data (Reades et al., 2007).

The workshops confirmed that the framework is a good way to obtain an overview of the different data needs in the municipality, but also to identify where the provision is particularly strong or weak.

5.3. Lack of knowledge

Lack of GIS knowledge is related to problems and perspectives of other sectors and disciplines, data management and data use. The difficulty for different disciplines to understand each other, and the negative consequences related to practical and scientific development, is not a new discussion (Hultberg et al., 1998). Concerning data management, Yeh (2005) concluded that the main constraints for the use of GIS in urban planning are not technical, but linked to the availability of data, staffing and need for reorganisation. This is confirmed by our findings. An example of lack of knowledge of perspectives and techniques used by different expert groups in the urban planning process is illustrated by the identified mismatch between non-GIS-supported data, GIS data, and visualisation of urban visions and designs. For architects, visualisation is an important tool to convey ideas, but these ideas need to be connected to municipal plans, as well as to data supporting the understanding of context specific parameters relevant for a continued provision of high-quality green spaces. Consequently, some kind of translation structure is needed between data and visualisations and from visualisations to data, to aid communication across disciplines and between actors. There is also a need to move between a larger strategic spatial scale and the level where specific solutions are implemented. The interviews showed that the GIS skills are too weak to support such a conversion. Häggquist and Nilsson (2017) examined officials' use of geographical information in Swedish municipalities and found that perceived usefulness, educational efforts, work tasks and gender affected the rate of use. This may be important to consider when aiming to increase the digitalisation of society. The workshop also identified lack of knowledge about different data sets and sectors when utilising the proposed framework as a basis for discussions on implementation of blue-green solutions.

5.4. Proposed framework

In this study, we have found that the sector division of responsibilities (blue respectively green and grey), influence the main focus of the municipal officials and thereby also the perceived data needs, despite common goals, visions, and urban challenges at the city scale. Hence it is not only their different responsibilities, but also conceptual focus that influence the data they perceive is needed. The study showed that the data collected and used is not always in sync with the data needed and that data is produced in most planning steps. Much of this data is rarely spread or used outside the source of collection. One reason is probably lack of routines to convert data from, e.g., CAD to GIS, but also the culture within the organisation might hinder data sharing. Feedback of data between different planning steps is crucial for effective management of BGI.

As a solution to these problems, we propose a framework to help strategic spatial planners overcome information gaps and facilitate the inclusion of high quality and context relevant BGI. The developed framework could serve as a basis to create a new data management culture and identifying gaps in data availability, acknowledging the need of different kinds of data to ensure holistic, strategic planning of urban BGI. The framework can be used to identify challenges specific to individual municipalities, and to strengthen and develop a clearer structure for how different sectorial practices and their interrelated disciplines can collaborate. It has to be recognized that the A, B and C processes will be different depending where in the planning process the framework is used: on a more overarching level, or at the detailed plan level (see Fig. 1). However, the discussions in the workshops, focusing on cases on different spatial scales, show that the framework can be useful for structuring work and data flow at different scales.

We believe that using the framework to identify gaps in data availability could provide local politicians with useful information on the benefits and costs of BGI. Including BGI benefits at an early stage of the planning process could support assessments of the impact of proposed urban developments and improve understanding of how to meet defined environmental and sustainable development goals. This could avoid unnecessary costs later in the planning process. A sound knowledge of the potential of green spaces to deliver ES is needed to fully exploit the opportunities (Lennon, 2015). This supports a governance approach where data collection and management can ensure that BGI become comparable to other urban infrastructures such as roads, electricity grid, traditional pipe bound sewage and stormwater systems (Carrera, 2004). Comprehensive data collection and management could facilitate systematic assessment of the ES needed and produced in urban blue-green spaces. Based on such knowledge, the links to guidelines and goals on BGI implementation could be updated and improved. Knowledge of ES should also serve as a basis for assessments of synergies and trade-offs between different functions.

On a more concrete level, the framework can be used to discuss the questions that have emerged as essential for a good BGI management: Who knows what, and who can contribute with what information? How can data be transferred between departments and individuals? How can missing links be identified and closed? What and where are the weakest links in the chain of information? The framework can also be used to discuss who should do what in each step. Who can create a good database structure? What tools and solutions should be used? What is the best organisational structure? Who is the expert on data collection, data management, and different kinds of analyses? Who can ensure that data produced during planning, implementation and maintenance of BGI are converted to the right format, stored and used in future data analyses? Who can visualise the data in a user-friendly way and to convey goals and requirements from a diverse user group? Are there any skill or knowledge gaps among involved actors that must be handled? Such questions were raised by the participants during the workshop.

This study has focused on Swedish municipalities, which due to the Swedish municipal planning monopoly are independent in their role to promote urban development. This may influence our results, as each municipality is free to organise its work in its own way, creating different structures for promoting development of BGI. Despite this possibly different role of Swedish municipalities compared to elsewhere, we believe that there are clear similarities due to the common environmental challenges faced by urban areas worldwide, as well as the common challenges and possibilities of multiple information systems.

6. Conclusions

Our findings indicate that it is essential to develop a data management system that is pan-municipal, bridging sectors and disciplines, and can be used to involve citizens as sources of data. Urban environmental management, managed though spatial planning, must be based on adequate data for all aspects related to BGI. Digitalisation of information is developing fast, which opens for integrated decision platforms. Through for example the Geodata collaboration, Swedish municipalities can use common sets of GIS data. But, as noted in the interviews, there is a lack of knowledge of how to use this technology, and several datasets are missing and such a lack needs to be improved.

As a step for further research, we suggest that our framework is tested in a set of real cases, which, in addition to assessing the framework in itself may identify additional barriers and provide input on how to organise data collection, management and use. In addition, there is a need for further knowledge on the need for data at different spatial and temporal scales, to better understand multifunctionality at different spatial scales to be able to investigate how multifunctionality within the BGI can be distributed in space and time. This may help to identify priorities for enhancement of necessary ecosystem services and biodiversity conservation.

Authors' contributions

All authors conceived the ideas and developed the framework in an iterative process; ASP and JS developed the graphical representation of the framework; All authors conducted the interviews and analysed the results; JS and JAO conducted the workshop and analysed the results; JS led the writing of the manuscript; All authors contributed critically to the drafts and gave final approval for publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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