The Nature of Innovation for Urban Sustainability

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Abstract

Urban nature-based solutions (NBS) are novel interventions that mobilize nature to address pressing societal challenges in cities. These include, but are not limited to, climate change adaptation and mitigation, health and well-being, biodiversity enhancement and economic development. Because of these benefits, NBS are increasingly seen as promising to contribute to grand societal challenges in urban contexts. Yet, currently their application is limited and their wider upscaling is necessary. However, limited knowledge is available on the range of factors that are critical to consider in innovating with and scaling up NBS.

This working paper explores the factors at play in innovating with NBS through a systematic literature review. NBS encompass components such as green roofs, green infrastructure, urban forestry and sustainable urban drainage systems. NBS have been studied from a range of disciplinary perspectives. In a 6-step approach, relevant literature in fields such as socio-technical transition studies, environmental governance and urban scholarship has been explored to identify factors enabling or constraining innovation for urban sustainability. A total of 75 publications with strong relevance to the topic have been identified, of which 39 publications have been read, coded and analysed in more detail.

The working paper identifies the following groups of variables relevant to innovating with NBS: cognitive factors, agency, discourses and vision for the future, strategic plans, legislation and regulation, institutional set-up and governance structures, collaboration, learning, resources and the local geographical context. We note that this list resulted from an inductive data-driven approach rather than a deductive, theory-driven approach. Likely many of the factors identified are mutually related and embedded in wider urban and sectoral systems. As such, this working papers ends with the suggestion that further theoretical work is necessary to relate the findings to relevant, but more generic theoretical frameworks in the field of urban innovation.

1 Introduction

Nature-based solutions (NBS) in cities are physical interventions based on natural resources and processes. Examples include green roofs and city parks that limit heat stress while contributing to everyday life, city lagoons that store water and permeable surfaces and create havens for biodiversity, vegetation and rain gardens which intercept storm water while also creating space for urban food growing activities (NATURVATION, 2016). They are increasingly advocated as alternatives for grey solutions such as sewage systems and have the potential to limit impacts of climate change, enhance biodiversity and improve environmental quality while contributing to economic development and social well-being (NATURVATION, 2016).

NBS such as green roofs, rain gardens, Sustainable Urban Drainage Systems (SUDS) or permeable surfaces can be considered as alternative and sometimes n interventions in an urban context. In order to learn from other

innovative urban interventions in terms of 'what works', i.e. what factors enable of facilitate the uptake of NBS interventions, this working paper conducts a literature review in order to identify factors enabling or limiting innovation for urban sustainability in an urban context. This includes the role of governance arrangements, and factors that together make up such an arrangement, including discourses, institutional context, coalitions and resources (van Tatenhove et al. 2000), as well as a wider set of contextual conditions (e.g., new technologies, geographical context, power dynamics).

The planning of this literature review was done in close collaboration with the Universitat Autonoma de Barcelona (UAB). They focus specifically on the cultural values and politics of nature-based solutions (NBS), describing different ideal-types of governance arrangements for the implementation and continuity of green interventions. In addition, they cover normative governance evaluations of NBS. Although there is some overlap in scope and therefore relevant papers, we took care in keeping this to a minimum by bilaterally discussing the literature sampling methods used for our reviews and scrutinizing the final selection of papers for both reviews. As a result, the both groups produced working papers that are complementary. In addition, we have also had a bilateral discussion on the scope of the literature review with our colleagues from the Sustainable Finance Lab at Utrecht University. As a result, our review does not cover in much detail sustainable business and finance models.

2 Method

UU-Copernicus (UU-Cop) collaborated with UAB in order to develop a similar reviewing methodology. This was done in order to enable merging both reviews into a single review document or paper if desired. We engaged in the exchange of ideas and feedback via Skype and/or email on several occasions, and both roughly followed the following procedure for preparing the working paper, which are further elaborated below:

Step 1: Develop a list of relevant key words
Step 2: Search for relevant references
Step 3: Select papers for further analysis
Step 4: Analytical mapping of papers
Step 5: Extracting key-insights
Step 6: Prepare the final working paper

2.1 Develop a list of relevant key words

The first step was to develop a relevant list of key-words that we used for extracting a long list of relevant papers in Scopus. We developed two lists of key words: one related to urban innovation and one related to

urban politics and governance. The lists of key words were developed in an iterative way and with input from all relevant local researchers at UAB and UU-Cop, and informed by concepts used in a number of key papers in our fields. Feedback was also sought from Durham University. We agreed that for both UU-Cop and UAB, relevant papers would need to touch upon innovative or multifunctional 'green' interventions in urban contexts. Hence, both reviews shared two categories of key words:

- *Contextual constraint:* "urban" OR "city"
- *(Type of) 'green'/sustainable intervention:* "nature-based solution" OR "nature-based infrastructure" OR "engineering with nature" OR "ecological engineering" OR "catchment systems engineering" OR "green infrastructure" OR "blue infrastructure" OR "green wall" OR "green roof" OR "bioswale" OR "sustainable urban drainage system" OR "urban farm" OR "community garden" OR "multifunctional green space"

A third category of key words was defined for each of the two reviews to reflect the disparity in thematic focus between the two reviews. For this review on urban innovation for urban sustainability, the third category of keywords comprised keywords relevant to innovation mechanisms:

- *(Type of) innovation mechanism:* innovat* OR upscal* OR transition OR transformation OR experimentation
- The exact search protocols were defined, and lists of key words further developed, in the next step of the process.

2.2 Search for relevant references

In the second step, we proceeded by performing search queries in Scopus. To ensure research quality, we only included peer-reviewed journal publications. We initially ran searches with different combinations of keyword categories in order to check whether the total number of returned papers was manageable and overall content sufficiently matched the thematic focus of the review. UU-Cop eventually opted for a three-tier search strategy with different combinations of the three categories of keywords presented above. This sampling strategy was sufficiently lenient to identify papers on e.g. urban sustainability that were not specific to green interventions, while still being sufficiently restrictive to filter out papers that touched on e.g. innovation without making any link to sustainability or the city. The search strategy could be summarized as follows:

Search 1: Urban AND green intervention

Search 2: Urban AND innovation

Search 3: Green intervention AND innovation

Search 2 returned a very high number of hits with 1000s of papers. Therefore, an additional keyword category – *Sustainability* – was added to be used in conjunction with the two categories in search 2 (*Sustainability:* "sustainable development" OR "sustainability" OR "climate change" OR "water management"). The revised three-tier strategy – resulting in 1,550 unique hits – is presented below:

Search 1: Urban AND green intervention

Search 2: Urban AND innovation AND sustainability

Search 3: Green intervention AND innovation

2.3 Selection of papers for further analysis

In the next step, the lists of papers were brought down to a total of c. 25 papers with highest relevance. In a first step we brought down the number of papers to c. 200 titles based on relevance of paper titles, and considering citation count together with year of publication. We excluded all papers from before 2014 with 3 or fewer citations. Titles were scored by three reviewers for their relevance with regard to the review theme of "factors/mechanisms that drive innovation for urban sustainability, and their applicability to the domain of NBS" on a three-point scale.

After bringing down the total to c. 200 papers by selecting those papers with highest combined scores, one reviewer studied all abstracts. Based on this, a selection of c. 75 papers with strong relevance for the key topic was made. This was reduced to 39 papers for review after four different reviewers indicated their preferred selection of papers. The final list of references for UU-Cop can be found in Appendix A.

2.4 Analytical mapping of papers

In a first step, UAB and UU-Cop created a table to extract relevant information from the papers for both teams (Table 1). Initially, paper excerpts were copied into a Word document, to be coded and summarized later on.

Table 1. Initial table for data collection agreed by the UAB and UU-Cop teams

Article	Claims, conclusions about relevant constructs: Drivers	Claims, conclusions about relevant constructs: Barriers	How are nature and/or nature-based-solutions and other relevant terms conceptualized/ understood, if at all?	Definitions of relevant terms	When is an intervention identified as a success, or a failure? Under what criteria, if so (e.g. economic growth, social	Are there relevant examples of NBS in the paper (described as case studies)?

					inclusiveness, ecological sustainability)	

2.5 Extracting key insights

In a next step, the extracts captured within the two "claims and conclusions" columns were independently coded in nVivo by two researchers. After carrying out a sample of the total data, they reviewed each other's work and met to discuss the preliminary categories. Based on this discussion, categories were refined and a final list prepared, which is presented in table format within the Results section below. Due to time constraints, we included 28 out of 39 papers selected in this review. They were selected in descending order based on the combined score of the three reviewers (see Section 2.3).

3 Conceptualisations of NBS

3.1 Nature and nature-based solutions conceptualised

The review of nature-based solutions and cognate concepts revealed a variety of approaches to conceptualizing NBS and related concepts. We highlight some of the key features below.

Urban nature-based solutions and similar concepts such as **urban green infrastructure** are often described as approaches aimed at promoting **sustainable urban development**. This is a type of development that provides social, economic and environmental benefits simultaneously and continues doing so over a long time horizon (Bayulken & Huisingh, 2015; McCormick et al., 2013; Vandergert et al., 2015). NBS are thus **multifunctional** interventions that consider natural as well as cultural **ecosystem services**, while also stimulating the green economy by being efficient and cost-effective, and advancing social equity (Horwood, 2011; Kabisch et al., 2016; Munoz-Erickson et al., 2016). Therefore, NBS contribute to urban **resilience**; the ability of a city to recover and/or adapt to shocks such as flooding or economic crises (Vandergert, Collier, Kampelmann, & Newport, 2015). Doing so, they can be applied to deal with modern-day urban challenges around topics such as health and well-being, food security, urban drainage, water retention, changing temperatures and air quality (Kabisch et al., 2016). While NBS are often about **innovative** development (Kabisch et al., 2016), they can also be concerned with promoting sustainable production and consumption (Brown, Farrelly, & Loorbach, 2013). As such they can play a role in long-term societal and technological change as part of a wider **sustainability transition** (Munoz-Erickson et al., 2016).

According to the European Commission, NBS are interventions that are "inspired by, supported by or copied from nature" (European Commission, 2015). This implies that NBS interventions *per definition* entail **human-modified** nature or built structure inspired by ecological processes or adopting ecological principles

(Matthews, Lo, & Byrne, 2015). Included are attempts at **physical greening, ecological engineering** and **ecosystem-based adaptation**. Physical greening is about "the increase of vegetated and natural systems" (Young et al., 2014, p.2580). Ecological engineering is concerned with the creation of engineered systems that mimic natural processes (e.g., modeling wind turbines based on the fins of Humpback whales to reduce drag), and the ecological enhancement of built structure to provide improved habitat for species (e.g., adding artificial rock pools to seawalls to support starfish, Naylor, Coombes, Venn, Roast, & Thompson, 2012). The European Commission, however, has explicitly excluded such bio-mimicry from their NBS definition (European Commission, 2015). Ecosystem-based adaptation refers to innovative planning or governance approaches that stimulate improved delivery of ecosystem services in order to increase resilience to climate change and disruptive societal processes (Wamsler, 2015a). As ecosystem services are often the result of complex socio-ecological systems, **adaptive governance** and **adaptive co-management** – polycentric systems with governance responsibility diffused to multiple scales – are key to promoting urban resilience (Vandergert et al., 2015; Wamsler, 2015b). This also needs to be flexible to "the geographically distinct urban landscapes, community identities, and specific practices of active citizen groups across the city" (i.e. **mosaic governance**) (Buijs et al., 2016).

3.2 The conceptual underpinnings of the literature

Within this review, we went beyond studying literature from a single field of study. Rather, we selected papers based on topical relevance. As a result of this, many of the papers in this review focus on papers examining the development or implementation of specific types of (instruments for delivering) NBS interventions. The types of interventions in our study were high quality urban green spaces, eco-towns, green roofs, sustainable urban drainage systems, urban green infrastructure, community gardens). They make use of theory in socio-ecological governance, urban (green space) governance, adaptive governance and experimentation, institutional theory and urban studies. Very few papers focused on system-wide transitions of socio-technical regimes and the role of grassroot niches, for example using the Multi-Level Perspective, although a few examples of papers with such theoretical focus were part of this study (e.g., Brown et al., 2013; Murphy, 2015). Perhaps of this rather strong focus on individual interventions, most studies were focused on the planning and development stage. Some also focused on the uptake stage but very few on the long-term maintenance and production stage. It is therefore difficult to reach any conclusions about what happens following the innovation (e.g., whether interventions are scaled up).

4 Drivers and barriers of NBS

4.1 Performance indicators for successful innovation

Before discussing drivers and barriers of NBS in detail, we first need to clarify the dependent variable. This serves to help the reader understand what factors contribute to urban innovation for sustainability (e.g., quantity of NBS interventions, longevity, innovativeness) were considered in the literature that we are describing in Section 3.3.

We explored the question of what qualifies as performance by looking at references of performance indicators in the literature and clustering those. An obvious success indicator is the actual implementation of NBS intervention in cities (Dupras et al. 2015). What matters is not just if NBS are implemented, but also to what extent. For instance, Mees et al. (2015) looked at the surface area of green roofs as a function of population size and available roof space. Others have stressed the importance of quality and 'smart' allocation; the dense city of Singapore has well-distributed small-scale green spaces across the city contributing to a 'green' image (Haaland & van den Bosch 2015). Implementation can also be looked at from a temporal perspective: long-term survival (Ghose & Pettygrove 2014), long-term support (Bayulken & Huisingh 2015) and broadly shared support due to a change in values and visions (Munoz-Erickson et al. 2016) are all regarded as success factors. The success of NBS innovations can also be judged based on the degree to which it contributes to goal achievement (Bayulken & Huisingh 2015). A wide range of indicators can be developed and utilized to assess performance against goals. This includes indicators for environmental performance (incl. disservices), health and well-being, citizen involvement, adaptive capacity (e.g., stormwater retention), active transport and social interaction as well as public attitudes (Kabisch et al. 2016; Tillie & van der Heijden 2015). When the NBS concerns a demonstration project, transferability could serve as an additional indicator (Kabisch et al. 2016). The successfulness of NBS innovation can also be considered from a normative perspective by studying the distribution of NBS across the city and reflect upon its contribution to social coherence and racial/social justice (Haaland & van den Bosch 2015; Treemore-Spears et al. 2016).

4.2 Factors influencing innovation for urban sustainability

This section, which provides the core of our review, systematically organizes all factors influencing innovation for urban sustainability. We present a table with an overview of all variables (Table 2), which is followed by a more detailed discussion. We note here that this table and the following discussion do not go into detailed discussion of each of the particular mechanisms and how they may shape (or prevent) NBS innovation. Rather this literature review has aimed to provide a comprehensive overview to identify a broad range of factors currently known in the literature, rather than to discuss a limited number of factors in more detail. Nevertheless, most discussions – without claiming to be exhaustive - do highlight several key mechanisms

found in the literature. We also note that these factors have been grouped on the basis of an iterative process in which 2 reviewers made initial groupings, discussed these collectively, and went back the original literature in case of ambiguities. Further work is necessary to identify how and which this categorisation relates to (potential different) underlying epistemological and ontological logics across multiple disciplines and theoretical frameworks.

Table 2. Overview of factors influencing innovation for urban sustainability

Variable	Subfactor	Description	Example extract
Cognitive factors	*Awareness*	Awareness by decision-makers and users of the role NBS interventions could play as a solution to complex problems. e.g. holistic thinking (in organisations), the role of "NBS advocates" and (formal) knowledge brokers, changing perspectives	As urban forests' benefits become more widely understood, federal, state, and local funding tools conventionally reserved for traditional infrastructure are becoming increasingly available. (R. F. Young, 2011, p. 379)
	Uncertainty	Limited clarity about right course of action influencing decision-making regarding NBS	Green Infrastructure is considered a risky end use for local governments to commit to when compared with traditional land uses such as residential or commercial re- developments where the projects can be vetted and measured by a return on investment (ROI) calculation in dollars (Chaffin et al., 2016, p. 438).
	Sense of urgency	A new problem presents itself or is perceived to be increasingly urgent as a result of pulses, which prompts the exploration of new solutions (if solution-focused, it is part of *discourse* factor)	Examples of pulses include a severe storm, a crash in financial markets, massive foreclosure and home abandonment, or a devastating riot. Such disturbances often reveal underlying stressors associated with persistent presses on a sys- tem, such as climate change, sea level rise, long- term unemployment, rising costs of living, or a decline in environmental quality (Munoz-Erickson et al., 2016, p. 5).
	Flexibility	Individuals or organizations showing openness to external	Successful implementation of AM requires an inclusive group of

		input or circumstances using a 'learning-by-doing' approach	stakeholders to negotiate goals and objectives upfront, and at the same time agree upon intervention points to renegotiate (or change) those goals and objectives if either 1) monitoring reveals new information; or 2) institutional constraints of the stakeholders change (Chaffin et al., 2016, p. 439)
Agency	*Leadership and power*	People and organizations taking up leading roles, taking charge of the process. E.g. champions, mayoral leadership, frontrunners etc.	Political power is a key force shaping social settings within which GI can advance (R. Young et al., 2014, p. 2575).
	Commitment	Long-term devotion to processes of change. Could be by individuals or groups (community groups, municipalities, a company's CEO, …)	The importance of sustained public sector commitment is underscored by the experience of respondents in Houston, Albuquerque, Sacramento, and Salt Lake County (R. F. Young, 2011, p. 378).
Discourses and future visions		Collective worldviews (e.g., sustainable development, biodiversity, governance) influencing the interpretation of a problem or a course of action (e.g. urban greening)	First, both cities are well known for their favourable green political climate, which stimulates the adoption of sustainable solutions by residents (Mees, Driessen, Runhaar, & Stamatelos, 2015, p. 819).
Strategic plans, legislation, regulation and policies		Formal documents outlining a development trajectory, projections of ideal futures. Also planning regulations and legislation relevant to NBS pathways	Rule of law is a third consideration, which has some bearing in three of the cities in initiating policy. National/federal Acts place duties of care for flood management on the local authorities of Basel, London and Rotterdam (so this is a case of mandated responsibility), and hence they might be held liable for flood damages and forced to provide compensation (Mees et al., 2015, p. 810).
Institutional set-up and governance structures		Diffusion of responsibilities and power between decision-making units at micro (intra-institutional), meso (at city or regional level) and macro level	One of the barriers to the implementation of SUDS in Dar es Salaam may be the institutional set-up for managing storm water and flood risk. There seems to be a

		(at national or transnational level)	certain level of institutional fragmentation and overlap in the responsibility for storm-water drainage and solid-waste disposal services. The interviewees tell of a frustrating lack of coordination within the municipalities' departments, between the three municipalities, the city administration and the various government ministries (Mguni, Herslund, & Jensen, 2015, p. 137)
Collaboration	*Networks, partnerships and social interaction*	Formal and informal coalitions between individuals, collectives or organizations, and attempts at strengthening these	As evidenced by the organizations at the project phase, single regulatory directions that rely on traditional views of the vertical power of the state for mobilizing change are now based on unfounded assumptions of the capacity of state agencies to direct change, and, therefore, unlikely in isolation to enable transformative and sustain- able change. Hence, based on the research insights, this philosophy should be based on mobilizing horizontal power that facilitates organizational and cross-sectoral interaction in pursuit of enabling governance of the urban water environment (Brown, 2008, p. 232).
	Participation	Citizen participation and engagement in plan development or NBS maintenance, including consultation, co-governance and community action	Because programs start at the individual and neighbourhood level, are supported by city and state resources, and are guided by a philosophy of empowerment and community development, these programs help resolve social justice issues while promoting sustainability (Treemore-Spears et al., 2016, p. 95).
Learning	*Education and training*	Actors and organizations engaging in a process of active	To exert the necessary influence on the regime, bridging organizations should first focus on generating

		learning, with a view on increasing resources	understanding, collating evidence and nurturing relationships, then build confidence amongst practitioners, up-skill and train a broad range of actors within the sector, then focus pressure towards generating policy shifts (Brown et al., 2013, p. 716)
	Experimentation	Testing or piloting projects or forms of governance aimed at change/innovation	Experimentation with different solutions and approaches is a key to generate sufficient variety in problem-solving capacities (McCormick, Anderberg, Coenen, & Neij, 2013, p. 6)
	Research	Knowledge partners/ institutions contributing to the knowledge base (on topics such as climate change) by systematic studies	Ecological enhancements designed for engineering works should seek to address two issues. Firstly, to meet the legislative, policy or non-legislative targets relevant to the particular scheme and location in question and, secondly, to design enhancements so that they are scientifically robust enough (with suitable replication for example) to be used as case studies for future designs (Naylor et al., 2012, p. 44)
	Monitoring and evaluation	Keeping track of (changes to) the process and assessing outputs, outcomes and impacts	Establishing key principles and evaluations for sustainable urban transformation and tracking progress towards goals is a foundation for effective strategies and actions (McCormick et al., 2013, p. 7)
Resources	*Materials, tools and technology*	Computer, physical and engineered tools that are used towards innovating practice	The north-west is one of several partners involved with the development of a GI toolbox, along with several other regions and national organisations (Wilmers 2009). This toolbox approach is designed to equip GI practitioners with a way in which to justify GI projects based on their monetised value. As will be seen later, this approach can be contextualised

			within the trajectory of developments focusing on an economic approach to green space through GI (Horwood, 2011, p. 966)
	Knowledge and human capital	Relevant knowledge, skills, abilities, relevant experience of individuals, collectives or populations	Greater availability of performance data, tailored to individual markets and climates would help reduce these misconceptions about green roofs (Hendricks & Calkins, 2006, p. 18)
	Financial factors	Funding, incentives, cash flows, market demand etc.	It was also clear that external resource opportunities through state government grants have been used by the more entrepreneurial organizations for attracting internal attention and resources (Brown, 2008, p. 230)
Local geographical context	*Built environment and urban amenities*	Characteristics of certain places, tied/bound to that space. (e.g., to built environment, environmental qualities, demographics)	Low rise buildings usually have large area of vacant roof, high accessibility thus more feasible to adopt extensive green roof systems (Zhang, Shen, Tam, & Lee, 2012, p. 318)
	Environmental qualities and climate	Local flora and fauna, presence of water and vegetated areas, type of soil, etc., as well as the influence of local weather climate and climate change	The Hurricane Sandy floods had significant ecological impact, driving the acceptance of GI as part of NYC's infrastructure planning (R. Young et al., 2014, p. 2578)
	Societal processes	Societal processes affecting local populations. E.g. urbanisation, unemployment, urban agglomeration dynamics	Auckland's social drivers include population growth, Auckland's contribution to New Zealand's economy, external and newly developed internal legislation, and the regional economic importance of Auckland's natural environment (local recreation and tourism) (R. Young et al., 2014, p. 2580).
	Local culture and image	Cultural or individual preferences and norms (e.g., regarding aesthetics or lifestyles), or regional role of city (e.g., as trading centre or	While one could argue that the aesthetics of green roof technology are better than the traditional alternatives, the look of green roofs is a departure from the norm and respondents generally did not

		creative hub) influencing NBS pathways	recognize the aesthetic benefits (Hendricks & Calkins, 2006, p. 16)
	Land or property ownership	Ownership of the land (e.g., public or private)	Participation in decision-making would help address the potential barrier of ownership, especially where SUDS elements are to be implemented on individually owned plots of land or buildings (Mguni et al., 2015, p. 130).

4.2.1 Cognitive factors

The support and implementation for ecosystem-based adaptation or innovation for urban sustainability depends on the willingness of people and organizations as a whole to engage in sustainable development and adaptive governance or co-management. Attitudes, appraisals and assessments about the right course of action are to a large extent influenced by ideas about "how to do something or how to interpret or understand the world" (Murphy 2015, p.78). Therefore, many of the factors outlined in this review are aimed at influencing one of the four cognitive factors described below as these are seen to change behaviour supporting or undermining the roll-out of NBS-interventions. We identified several cognitive factors based on the literature, but often the exact cognitions required to make a step-change in innovation remain hidden and can therefore be considered a 'black box'. For example, the role of networks and partnerships was emphasized in many papers, yet the purpose of these in promoting learning, leading to improved awareness, was not always made explicit.

Awareness

Several papers describe the important role of awareness. This has two main components: 1) awareness of the problem (e.g., climate change impacts; McCormick et al. 2013) and 2) awareness of the benefits provided by possible solutions (Young 2011). The studied literature touches more on awareness of the benefits than on awareness of the problems. Lack of awareness can pertain to a particular domain (e.g., environmental benefits or financial payback; Hendricks & Calkins 2006) or may apply across several domains. Increased awareness of benefits may facilitate support, acceptance and demand for NBS amongst the public, private and third sectors as well as the general public (Naylor et al. 2012; Young 2011; Zhang et al. 2012).

Several mechanisms for awareness building are described. These include early adopters demonstrating the benefits of an intervention (Hendricks & Calkins 2006), and related to that, exposure to 'green' solutions (Tian et al. 2012), and experts sharing information on (optimizing) the technology (Mees et al. 2015). City advocacy (e.g., by creating "cutting-edge" demonstration projects) can play a role in promoting such opportunities for information sharing (Hendricks & Calkins 2006), while the media is also an important knowledge provider (Zhang et al. 2012). Rather than sharing information in a single format, it is more effective to make use of knowledge brokers who help stakeholders to understand the value of NBS interventions (in meeting duties and targets) from their own perspective (Naylor et al. 2012). Another route is through new research demonstrating the performance of NBS interventions through systematic assessments (Kabisch et al. 2016).
Tools can be applied to study awareness through the lens of others. For example, consultation forums may serve to come to a shared understanding of a problem or an effective solution (Dupras et al. 2015). By checking expectations in this way, and making adjustments to better align these, the uptake of new interventions can be improved (Wolfram 2015).

Uncertainty

In some ways, the concept of uncertainty is the opposite of awareness. However, lack of awareness of problems or the potential of NBS in addressing these is not necessarily always leading to uncertainty. Rather, uncertainty usually surfaces when a certain degree of awareness has already been achieved; and is therefore often acting as a barrier between awareness and NBS support. We identified several factors contributing to uncertainty around implementing NBS. First of all, there can be a perceived risk of investing in NBS due to these interventions adding a layer of complexity to conventional development, the lack of experience by most developers, safety and reliability questions and concerns about incompatibility with existing built structures (Hendricks & Calkins 2006). As a result of these uncertainties, the financial risk of green innovations – especially their maintenance – is often overestimated, which makes it difficult to find investors and would-be adopters (Bayulken & Huisingh 2015; Chaffin et al. 2016). Secondly, there are many question marks around

the effectiveness of NBS. This is mainly because they are deliberately designed to have social and environmental qualities in addition to their economic merits. These aspects are difficult to quantify, especially cultural ecosystem services such as environmental education and services pointing to the intrinsic value of nature (e.g., spirituality function; Chaffin et al. 2016; Kabisch et al. 2016). Besides, such wider benefits are not typically considered in the decision-making frameworks of profit-oriented enterprises (Horwood 2011).

Interventions to overcome uncertainty include learning from early adopters operating within the same domain (e.g., housing development; Hendricks & Calkins 2006) and diffusion of information through peer networks (Chaffin et al. 2016). The success of such approaches is crucially dependent on experimentation and multidisciplinary data collection (ibid.); frontrunners could play a role in this. In addition, there is a need for quantitative indicators or metrics to monitor the effectiveness of NBS (Kabisch et al. 2016) and quantify economic benefits (Horwood 2011), which would improve the accuracy of NBS cost-benefit analyses in the private sector (ibid.). Industry can also play an active role in taking away uncertainty, especially around cost, by engaging in active partnership working with users in product development, providing information on the performance of the intervention, providing a product warranty, creating a quality standard and investing in on-going innovation of products to improve performance standards (Mees et al. 2015).

Sense of urgency

Disturbing events (i.e. pulses), such as an economic crises and cycles of drought or storms, are known to draw the attention of system actors to approaches that increase resilience and therefore can act as turning points enabling a transition to sustainable urban development (Munoz-Erickson et al. 2016). A sense of urgency can also come about because of new intelligence or changing discourses (e.g., regarding the pros and cons of coal as energy resource), resulting in changed perceptions of risk (Rohracher & Späth 2014). A potential barrier emerges when pulses are not perceived as serious threats for human and/or environmental health (Chaffin et al. 2016) or when other issues are perceived as more pressing (Wamsler 2015). The level of perceived threat can be constrained by a range of factors, including: fragmentation in decision-making units, limited coordination between units operating at different spatial levels, and a suboptimal science-practice interface (McCormick et al. 2013).

Flexibility

Openness of individuals and institutions to new information, and the ability to flexibly respond to this, is an important aspect of adaptive governance. Such flexibility promotes effective responding to changing circumstances or intelligence, and is especially important in partnership working where the role of stakeholders may change over time (Chaffin et al. 2016). Institutional flexibility and nimbleness are conducive

to new governance arrangements involving non-governmental stakeholders and facilitates system transformation as innovative niches are supported to expand (Munoz-Erickson et al. 2016).

4.2.2 Agency

By agency we refer to the roles of actors and institutions in addressing urban challenges with NBS interventions. Cognitive factors play an important role in driving agency. Yet, agency is also driven by more subjective considerations including "individualized objectives, goals, motivations, egos, rights, choices, and perceived capacities for action" (Murphy 2015, p.78). For example, developers are unlikely to take a leading role in adopting NBS if they do not feel responsible for delivering environmental and social benefits (Hendricks & Calkins 2006). Agents of change, often referred to as "champions", often play a key role in systemic change, or transitions. They have the ability to bring people together in creating a common vision, act as knowledge brokers and thus contribute to overcoming epistemological dissimilarities, protecting the common good, and learning-by-doing (Brown et al. 2013). They tend to have a disposition at being both personal and cooperative (ibid.). As a result, they can greatly contribute to promoting buy-in into an idea by a range of partners and attracting (different types of) funding (Vandergert et al. 2015). Agency can be expressed and supported in different ways, as we will illustrate below.

Leadership and power

Institutions can use their power to influence the development and uptake of NBS interventions. Regional and local authorities, for example, are mandated to control the planning process and have control over environmental policies and regulation (Young et al. 2014). In some cases, mayors have shown clear leadership in urban sustainability transformations (ibid.). They also have an operational unit and manage land directly, while they may also directly influence what private actors are doing through public-private partnerships (Bayulken & Huisingh 2015). Authorities, given their strategic overview, also have a role to play in coordinating local level efforts through community governance (Brown 2008; Mguni et al. 2015). That is, one local flooding intervention is not going to stop the problem of urban flooding. Moving beyond authorities, institutions can express leadership in NBS development in a multitude of ways. Firstly, they can initiate or endorse demonstration projects (Bayulken & Huisingh 2015; Zhang et al. 2012). They can also support individuals and new initiatives to develop transformative leadership, or institutional or civic entrepreneurship, skills through training and up-skilling (Brown et al. 2013; Wolfram 2015). Other strategies include promoting state-of-the-art research, information sharing, product innovation, shadow advocacy and lobbying (Brown et al. 2013; Mees et al. 2015). For example, extensive lobbying resulted in green infrastructure being put on an equal footing with transport, water, power and waste infrastructures in the Regional Strategy of north-west England (Horwood 2011).

Leadership and power is supported by seniority (Brown et al. 2013), and related to that centrality of position in networks, which is an important predictor of "building organizational capacity and political clout" (Ghose & Pettygrove 2014, p.96). Another important predictor is available finances such as subsidies (Vandergert et al. 2015). Factors undermining leadership include fragmentation (Munoz-Erickson et al. 2016); unequal power relations limiting some from accessing resources (Ghose & Pettygrove 2014; Young et al. 2014); and networks that stifle creativity and initiative (Ghose & Pettygrove 2014).

Commitment

Simply doing the regulatory minimum that is required of you as an individual or organization tends to lead to low sustainability performance (Brown 2008). This also applies to authorities; political will is crucial to instigate change, such as the implementation of green belt plans (Dupras et al. 2015). Conversely, investing time and energy in activities such as joining adaptation-related networks, communicating about sustainability through social media and writing funding bids for relevant projects have been described as drivers for sustainability transformation (Naylor et al. 2012; Wamsler 2015; Young 2011). True commitment is implicit in long-term, as opposed to piecemeal, support for change (Brown et al. 2013). This can be reflected in agency-wide policies, such as interdepartmental sustainability committees and dedicated resources for sustainability-related projects (Brown 2008). Commitment can also manifest itself in institutions actively supporting multi-stakeholder participation and local initiatives (Bayulken & Huisingh 2015; Dupras et al. 2015).

4.2.3 Discourses and future visions

Discourses such as 'green city', 'eco city' and 'innovative city' are collective worldviews that can profoundly influence the interest in, and uptake of, NBS interventions (e.g., Mees et al. 2015). Discourses can shift as a result of information provision, disturbing events and activism, creating a "social momentum for change" (Rohracher & Späth 2014, p.1425). Discourses translate in norms for action and therefore can inspire the development of (long-term) future visions (Young 2011). These visions and the accompanying goals and objectives, provide another, more indirect, route to behavioural change (Bayulken & Huisingh 2015; Young et al. 2014). They do so by drawing attention to particular research findings and experiments, and prompting the introduction of alternative governance structures and availability of resources such as administrative tools (Brown et al. 2013).

Concerning visions, the studied literature describes several pathways to success. First of all, a vision needs to be broadly shared, and is ideally prepared in consultation with stakeholders from a range of different (professional) groups (Chaffin et al. 2016; Mguni et al. 2015; Young 2011). Collaborative networks or communities of practice therefore play a key role (Kabisch et al. 2016), and so does leadership (e.g., by the

mayor) (Young et al. 2014). When engaging in collaborative visioning, it is important to start by setting clear goals and objectives accompanied by an action plan and a common set of definitions in order to facilitate concerted action and, ultimately, goal achievement (Bayulken & Huisingh 2015; Vandergert et al. 2015). In order to facilitate broad support in modern-day society characterized by neoliberal ideology (Munoz-Erickson et al. 2016), visions greatly benefit from providing an economic as opposed to an exclusively ecological rationale (Matthews et al. 2015). This was also observed by Horwood (2011), who found that framing green infrastructure as an "enabler" as opposed to a "barrier" to growth had been key to policy uptake in north-west England. The case for NBS as an enabler can be made in several ways depending on local context. In areas in which climate change plays a potentially disruptive role, for example, the connection between urban greening and resilience could be stressed, while in post-industrial cities focusing on the role of NBS in urban reinvention and innovation may prove to be a more effective case (Treemore-Spears et al. 2016). Civic support can be harnessed by stressing contributions to environmental and social equity, sustainable lifestyles and quality of life (McCormick et al. 2013; Vandergert et al. 2015).

Visions require long-term support in order to truly change the direction into which a system is moving (Young 2011). Therefore, the impact of visions is threatened by powerful actors changing their motives and beliefs; for example, as a result of shifts in the political landscape (Vandergert et al. 2015). The ideology of neoliberalism, although not necessarily always in conflict (see above), can also throw up barriers. For example, state retrenchment from sectors including energy and public transport has reduced political influence and increased the complexity of the governance system (Dupras et al. 2015; Rohracher & Späth 2014). The multitude of actors complicates the process of agreeing and sustaining a common vision; epistemological dissimilarity between stakeholders is a significant hurdle to transition (Mguni et al. 2015). Neoliberalism may also prompt authorities to divest in urban greening as they increasingly rely on income from property tax and land sales for property development (Dupras et al. 2015).

4.2.4 Strategic plans, legislation, regulation and policies

A large number of studied papers pointed to the key role of policies and regulations in realizing sustainable development and delivering NBS. For example, McCormick et al. (2013, p.1) write that "governance and planning were identified as critical to bringing about sustainable urban transformation". Next, we outline lessons learnt regarding how to optimize this impact. We roughly distinguish between legislation and regulation, on the one hand, and strategic plans and policies on the other hand.

Different types of regulation can be effective in promoting sustainable development. Firstly, high-tier levels of government can impose duties of care on local authorities, for example for flood management (Mees et al.

2015). Planning authorities, on their turn, can apply environmental regulation and zoning to influence the behaviour of landowners and private developers (Young et al. 2014). They can also introduce building regulation, such as the compulsory inclusion of green roofs in new developments in Basel and Stuttgart (Mees et al. 2015) or the stormwater management regulation imposed on developers in Auckland (Young et al. 2014). Authorities should also consider applying quality rather than just quantity criteria in judging new developments (Haaland & van den Bosch 2015). Sometimes lifting regulations in certain areas rather than imposing new regulation should be considered as to increase the success rate of particular developments (Naylor et al. 2012), for example those including NBS interventions. Finally, authorities and institutions can also impose environmental levies (Brown 2008).

Strategic plans and policies (e.g., development plans) benefit from a holistic perspective, incorporating the entire (city) region (Haaland & van den Bosch 2015), a full-system perspective by considering all aspects of urban planning in one document (Bayulken & Huisingh 2015; Young et al. 2014) and including a long-term vision (Haaland & van den Bosch 2015), which we have discussed in Section 4.3.3. Ideally they are translated into management, business and public engagement plans at the local level (Young 2011); the latter not just for consultation but also to promote active engagement in plan implementation (Bayulken & Huisingh 2015). It may be beneficial to develop individual plans and/or policies for the implementation of specific high priority NBS interventions, such as sustainable urban drainage systems or green roofs (Mees et al. 2015; Mguni et al. 2015). Plans and policies need to go hand-in-hand with financial incentives as this mix has been found to provide a particularly effective route to gaining broad policy support (Mees et al. 2015). Temporary measures as well as activities providing medium- and long-term benefits should be considered for funding in order to facilitate a transition (Treemore-Spears et al. 2016). Policies also become more effective when they incorporate feedback from consulted stakeholders and citizens (ibid.), and plan developers used a data-driven approach (Young 2011). Finally, a small number of barriers could be identified from the studied literature. Firstly, the impact of policies and regulation can be diminished by insufficient enforcement (Haaland & van den Bosch 2015; Zhang et al. 2012). Secondly, sectoral opposition (e.g., finance sector) to plans may harm their effective implementation (Dupras et al. 2015). And third, sometimes strategies for sustainable development themselves are perceived as a barrier, for instance hindering economic development (Young et al., 2014).

4.2.5 Institutional set-up and governance structures

The ability of single actors or networks to enact interventions aimed at sustainable change is influenced by institutional structures[1]. Brown (2008, p. 230) states that "the intra-organizational operating context was the key factor for determining the level of success" in the implementation of sustainable interventions. Urban sustainability interventions could benefit from institutional thickness, e.g. a dense network of institutions and intermediaries that is present in urban areas (Wolfram, 2015), or stronger institutional structures (such as formal organisational structures and laws) (Mguni et al., 2015). Murphy (2015, p. 79) notes that while structural factors such as "rules, norms, roles, expectations, hierarchies, and regulations" shape transformations, these structural factors are linked to subjective or cognitive factors that shape the agency of actors. Both types of factors co-determine and co-constitute each other and cannot easily be separated (Murphy, 2015).

Several authors refer to the importance of internal management structures in building institutional capacity. Brown (2008), for example, refers to the importance of an interdepartmental policy community and a departmental management system, with each of these units having sufficient resources. Administrative and organisational capacity, which can ensue from involving a balanced variety of actors, are mentioned by Chaffin et al. (2016) and Ghose and Pettygrove (2014) as elements of institutional capacity. Brown (2008) identify three domains of institutional capacity building: human resource development, intra and inter-organizational strengthening, and institutional reform.

Different governance features contribute to the implementation of green urban interventions. For a sustainable city, four governance features are essential according to Munoz-Erickson et al. (2016): holistic, decentralized solutions as an alternative to traditional top-down decision-making; integrated, networked management as to eradicate agency boundaries (i.e. jurisdictional fragmentation); involving actors beyond the traditional governance structures; and knowledge systems spanning multiple disciplinary and policy sectors. Another feature is clarity on responsibilities between (governing) departments. This increases the efficiency of implementing interventions (Kabisch et al., 2016; Tian et al., 2012; Wamsler, 2015). In the study by Mguni et al. (2015) institutional fragmentation and overlap in responsibilities were observed to be a barrier to effective implementation of nature-based solutions. Young et al. (2014) point to the benefits of a strong mayor-oriented set-up, as this mayor can than act as a leader towards change.

[1] There is certain overlap between references made to relations between stakeholders and to governance structures. Types, characteristics and benefits of governance relations are touched upon into more detail under the heading 'Networks and partnerships'. Institutional and governance structures are discussed in this paragraph.

In addition, a discrepancy in the spatial level at which policies are formulated (the national scale) and implemented (the local scale), can provide organizational difficulties and result in an "ongoing debate assessing the value of such policy" (Young et al., 2014, p. 2574). For instance, in New Zealand local government bodies did not regard sustainability issues to be their mandate (Young et al., 2014).

Castán Broto & Bulkeley (2013) note the increased blurring of authority with the emergence of a variety of partnerships and non-governmental actors active in transitions towards sustainability. Charging one entity with the task of taking care of green infrastructure positively influences the capacity to change current systems (Haaland & van den Bosch, 2015). In the study by Chaffin et al (2016), the absence of a specific stormwater entity made changing the existing infrastructure difficult. Holistic thinking, both in theory and practice, helps to ensure new developments are more sustainable and less dictated by short-term economic motives (Bayulken & Huisingh, 2015).

On the basis of the reviewed literature, some drivers of a beneficial institutional set-up can be identified, mainly concerning collaboration and innovation in governance models. McCormick et al. (2013) state that conventional governance approaches do not suffice in the face of sustainability chances. As already noted under 'Networks and partnerships', collaborative governance can create beneficial institutional mechanisms that overcome jurisdictional fragmentation and enable sustainability transformations (Munoz-Erickson et al., 2016). Institutional reform should be informed by new organizational practices and advocacy for change by individual actors (Brown et al. 2013). Institutional and organizational innovations may result in pressures on existing regimes (Rohracher & Späth, 2014). Engaging in place-based experiments can (re)shape governance relations (Wolfram, 2015). However, local buy-in alone appears to be insufficient into overcoming certain institutional barriers, such as the distribution of resources, path dependency and uneven power balance (Vandergert et al., 2015).

Beneficial institutional structures can support community efforts. These cannot hold out for long without a firm institutional set-up and infrastructure (Mguni et al., 2015). In additional, a certain structure can induce buy-in of important stakeholders in transitions. Polycentric institutions that operate at different scales (government and spatial) create connections across these scales. It is this multi-scalar institutional dimension that has ensured buy-in of the different stakeholders in a study by Vandergert et al. (2015). However, Murphy (2015) and Young et al. (2014) indicate that existing institutional structures can also prove to be a barrier to change, making shifts towards alternative regimes difficult.

4.2.6 Networks and partnerships

To advance sustainable urban transformation processes, the inclusion of a variety of partners is needed as well as collaboration between them (Castán Broto & Bulkeley, 2013; Kabisch et al., 2016; McCormick et al., 2013; Treemore-Spears et al., 2016; Wolfram, 2015). Transformative and sustainable change can be established by "mobilizing horizontal power that facilitates organizational and cross-sectoral interaction" instead of trusting on (the more traditional) vertical power of the state (Brown, 2008, p. 232). Integrated management and planning practices that favour networked approaches, inclusion of multiple stakeholders and public-private partnerships, and transdisciplinary knowledge systems are among the key governance features of a sustainable city (Munoz-Erickson et al., 2016).

Fragmentation in urban planning and practice, limited coordination between different administrative levels and a gap between science and practice have led to a lack of awareness and therefore of powerful initiatives that advance sustainable transformation (Hendricks & Calkins, 2006; McCormick et al., 2013). Networks and partnerships come in different shapes and sizes. Brown et al. (2013) make a distinction between formal and informal collaboration, and indicate that while informal collaboration did occur, formal collaborations proved to be much more instrumental in the transition of Melbourne's stormwater management. An often mentioned and influential form of collaboration to spur on sustainability transition are public-private partnerships (Bayulken & Huisingh, 2015; Munoz-Erickson et al., 2016; Young, 2011).

As stated earlier, the inclusion of a broad variety of stakeholders in the design and development of urban developments (such as the implementation of eco-towns) is beneficial (Bayulken & Huisingh, 2015). Actively selecting and empowering stakeholders increases the chances of long-term support for urban development (Bayulken & Huisingh, 2015). Strong stakeholders – actors that local governments have to interact with such as housing associations, developers or investors – can provide barriers to urban development (Kabisch et al., 2016). Brown et al. (2013, p. 715) noticed a change in the quality of actor-networks during the different phases of a transition process. First, only engineers were involved. This then expanded to include other scientific fields, "ultimately becoming an interdisciplinary practice network". In the acceleration phase, the "more institutional-implementation type actors" joined, such as practitioners, and later economists and planners.

Bridging organisations help to boost stakeholder participation, exchange of information between stakeholders and alliance-building among key actors (Bayulken & Huisingh, 2015; Brown et al., 2013). In the study by Brown et al (2013), formal bridging organisations were able to formalise niche-regime relations, provide a common platform for ideas and consensus and establish a broad sphere of influence for policy and practice. During the transition process, they had multiple influences: defining research agendas and providing reliable scientific

evidence (eg. by launching experiments and pilot projects, but also through cooperative research centres), shifting policy directions and encouraging knowledge sharing and the education of industry partners (Brown et al., 2013). In regard to the above, Brown et al. (2013: 715) draw attention to the importance of relations between bridging organisations, as "no one bridging organisation is sufficient to influence a transition alone". Individual intermediaries, such as mediators, knowledge brokers or institutional entrepreneurs, also hold considerable power in transformation processes, connecting citizens to non-profit organisation, local government or funding (Ghose & Pettygrove, 2014; Wolfram, 2015) and ensuring buy-in, funding and the meeting of policy and practice needs (Naylor et al., 2012; Vandergert et al., 2015).

Several conditions for sustaining successful networks and partnerships are defined. Openness, transparency and legitimacy ensure good governance practices of partnering between different stakeholders (Kabisch et al., 2016). Legitimization and trust building enable relational proximity, "a circumstance where mutual understandings or a common "gaze" (inter-subjectivity) emerges regarding what constitutes success, sustainability, innovation, etc.", which in turn makes alignment of niche and regime dynamics possible (Murphy, 2015, p. 79). In establishing effective stakeholder relations, the development of 'soft skills' (such as conflict management or confidence building) of both stakeholders and intermediaries is needed (Wolfram, 2015). Successful partnerships are defined by sustained and deliberate actions that "meet people where they are", stakeholder representation and buy-in and timely feedback (Treemore-Spears et al., 2016, p. 93). Brown et al. (2013) underline the importance of actor-networks being adaptable throughout the process. Strategies of issue identification, policy and practice diffusion, shadow advocacy and lobbying and increasingly targeted and sophisticated up-skilling of stakeholders were all observed, but during different phases of the transition.

Local authorities' control over the design and development processes has brought about successful public-private partnerships (Bayulken & Huisingh, 2015). Other success factors include the level of expertise of stakeholders, negotiation skills and knowledge of local authorities, and the local governments' capacity to set standards and monitor the process (Bayulken & Huisingh, 2015). An understanding of local governance structures can support advocates of green infrastructure to make more effective coalitions (Young et al., 2014).

Another important relation for advancing green interventions is that between science and private actors. Sharing knowledge throughout urban sustainability projects strengthens science-industry partnerships (Brown et al., 2013). Greater interaction between science and industry, in turn, stimulates co-creation and the dissemination of knowledge and leads to more useful results of innovation activities (Hendricks & Calkins, 2006; McCormick et al., 2013).

Some barriers to effective collaboration emerge from the literature as well. In ecosystem-based adaptation, as studied by Wamsler (2015), space restrictions and varying interests and concerns of stakeholders have resulted in a lack of cooperative arrangements. Other barriers to effective partnerships are uneven leadership and power relations, which discourage institutional integration (Munoz-Erickson et al., 2016), cultural differences between actors involved (Chaffin et al., 2016), or sectoral silos in city departments, which relates to institutional set-up (Kabisch et al., 2016). Collaborative challenges may also arise due to different stakeholders operating at different timescales (Naylor et al., 2012).

Working in partnerships or sustaining networks has several benefits. Prioritizing network-building and the quality and scope of relations within an extended stakeholder network both foster commitment, which in turn determines the success of implementing (nature-based) solutions (Brown, 2008). In urban settings, spatial features and infrastructures often cross jurisdictional lines. Here, networking in hybrid or collaborative governance arrangement can be useful in overcoming fragmentation (Munoz-Erickson et al., 2016). Collaborative governance structures can also help to build trust and result in shared management approach, leading to more sustainable outcomes (Munoz-Erickson et al., 2016). Transdisciplinary approaches boost the implementation sustainability interventions, as decision-making can then be based on collaboration, negotiation of different viewpoints and mutual learning (Mguni et al., 2015). Castán Broto and Bulkeley (2013) found that city membership of an inter-city network promotes experimentation in urban climate governance. Other positive aspects associated with intercity relations are the capacity of cities for to have a global influence in transformative change, and the possibility for experiment leaders to learn from each other through these networks (McCormick et al., 2013). Transnational linkages and multi-scalar configuration can positively influence transition processes if they facilitate the anchoring and absorption of sustainable innovations into existing structures (Murphy, 2015). Consensus between regions or nations on priorities in terms of sustainability positively affect progress made in these regions (Bayulken & Huisingh, 2015). Networks do not only hold benefits, however: Ghose and Pettygrove (2014) give an example of informal networks of residents opposing the implementation of community gardens (as they associated these with crime and a decrease in property values).

4.2.7 Participation

The condition of participation as defined for this review sometimes partly overlaps with that of networks and partnerships. Long-standing participation of citizens or civil society groups in projects aimed at improving sustainable urban development may form into partnerships and networks. Different papers highlight the importance of city-citizen collaborations and co-creating local policy and practice (Wamsler, 2015). Some also

mention the participation of a variety of stakeholders may lead to greater successes (Bayulken & Huisingh, 2015). For this literature review we have defined participation as civic participation and engagement and empowerment of citizens and residents, which is discussed in this paragraph. Partnerships and networks are defined as more formal structures that include a variety of actors with different roles, such as private developers, urban planners or knowledge institutes, for instance. This category is discussed elsewhere.

Active involvement and empowerment of civil society is an essential condition for sustainable urban development (Wolfram, 2015). Important, influential characteristics of participatory governance are a democratic approach, transparency and inclusion (Bayulken & Huisingh, 2015). An influential form of public participation is participation at the local, community scale (as opposed to city or nation-wide, for instance) (Bayulken & Huisingh, 2015; R. F. Young, 2011). Inviting the community to participate both pre- and post-planning results in the most sustainable solutions (Treemore-Spears et al., 2016). Participation provides public support for new interventions (Treemore-Spears et al., 2016). Facilitating participation right from the start of any project helps secure the acceptance of innovative systems and technologies (Bayulken & Huisingh, 2015). Chaffin et al. (2016) state that community (ie. neighbourhood or district-level) engagement is not always sufficient; engagement at the household-level might be necessary in the case of green infrastructure implementation. It is essential to get residents of the area in which projects are planned on board (Bulkeley et al., 2016; Young et al., 2014). Local residents can play a powerful, informal role in planning for sustainable development (Haaland & van den Bosch, 2015). The lack of participation by private local landowners, for instance, can limit the development of green infrastructures (R. Young et al., 2014).

Community participation may not only lead to more sustainable interventions, but also to more equity, helping to resolve issues of social justice through empowerment of local actors (Treemore-Spears et al., 2016). Wolfram (2015, p. 3) states that “given their orientation at social needs instead of particular technologies or markets, grass- roots tend to create innovations that address several socio- technical systems simultaneously (e.g. combining community gardens, rainwater harvesting and consumer cooperatives)”. Another benefit of participation is that it can help “break the cycle of planning fatigue” of the community, by developing both short- and longer term solutions (Treemore-Spears et al., 2016). On a broader scale, support from and pressures from civil society can also provide leverage in sustainability transformation (Rohracher & Späth, 2014; Young, 2011).

Many of the other (sub)categories outlined in this review instigate or facilitate public participation. For instance, strong commitment of local and national authorities facilitates higher rates of public participation (Bayulken & Huisingh, 2015). Bayulken and Huising (2015) also indicate legally appointed bodies can be

essential for catalysing citizen participation. Allowing for sufficient time and flexibility in planning to include engagement (Naylor, Coombes, Venn, Roast, & Thompson, 2012; Wolfram, 2015) is beneficial. In addition, individuals or groups at the community level that can take leadership adds to the likeliness of successful outcomes of nature-based developments (Ghose & Pettygrove, 2014). "Strong, democratic local leadership" in combination with public finance and participation can also attract private investment, which is often needed for urban (re)development (Bayulken & Huisingh, 2015). Resources, such as space for local initiatives to develop (Tillie & van der Heijden, 2015; Wolfram, 2015), material (tools) and funding (Wolfram, 2015) are also needed to induce active involvement of citizens and civil society groups. Another influential category is that of learning; when residents learn about benefits or possibilities, they often become more supportive of urban development towards sustainability (Haaland & van den Bosch, 2015; Tian, Jim, & Tao, 2012; Tillie & van der Heijden, 2015; Treemore-Spears et al., 2016), or conserving green areas and biodiversity (Tillie & van der Heijden, 2015). Uninformed residents may oppose sustainability projects due to uncertainty of effects (Tillie & van der Heijden, 2015). This learning can take place though education, mentoring and training (Wolfram, 2015). Conversely, participation can also inform learning. Projects can benefit from working closely with local actors to understand local (environmental) conditions and practices (Naylor et al., 2012; Treemore-Spears et al., 2016).

4.2.8 Learning

Learning emerged from the literature review as an important factor – a driver mainly – of nature-based or sustainable urban development. Different categories were distinguished: Education and training; Experimenting; Research; and Monitoring & evaluation. Chaffin et al. (2016) emphasize the need for new provisions for learning and experimenting in order to build capacity to integrate nature-based solutions into existing urban systems. If information or knowledge arrives too late, it influences community engagement negatively (Tillie & van der Heijden, 2015).

Wolfram (2015) states that learning should be experiential (second-order learning), and highlights the role of intermediaries in facilitating this type of learning. Learning from previous experience is useful for cities in advancing sustainability transformations (Wamsler, 2015). In carrying out new projects, knowledge of best practices elsewhere can be beneficial (Dupras et al., 2015). A lack of investment can result in a lack of experience in sustainability development (R. F. Young, 2011). Establishing "platforms for documenting processes, key decisions, mistakes and unexpected results in urban sustainability projects" also facilitates learning (McCormick et al., p. 6), or consultation forums to assess stakeholders' views (Dupras et al., 2015).

Education and training

Education and training are most often named as an important driver of community engagement and participation (Tillie & van der Heijden, 2015; Young et al., 2014) or understanding and awareness of the benefits of sustainable alternatives to existing infrastructures (Hendricks & Calkins, 2006; R. F. Young, 2011). Preceding regulation by educative programs helps "break down resistance" from residents, according to Mees et al. (2015, p. 816). Career development and job training programs are identified as beneficial factors in adopting sustainable interventions (Treemore-Spears et al., 2016). Non-profit organisations and training programmes that empower citizens by education are also noted to play a role (Treemore-Spears et al., 2016; Wolfram, 2015). In terms of knowledge diffusion, Zhang et al. (2012) identify a lack of promotion by the government and local communities among public and private sectors as the most significant barrier to nature-based solutions development.

Research

Science-based ecological enhancements can make these into cases for future reference, thereby potentially advancing the process of sustainable development (Naylor et al., 2012). Furthermore, scientific knowledge and research data represent an important foundation for urban planning (Treemore-Spears et al., 2016) and inform stakeholders of potential benefits of sustainable alternatives (Young, 2011). Research into citizens' needs may result in more variety in the design and management of sustainability projects, which is needed to suit differentiated local preferences (Tillie & van der Heijden, 2015). Knowledge of environmental qualities, such as biodiversity or socio-ecological dynamics, informs the prioritisation of conservation targets (Dupras et al., 2015). The growth of research fields (in this case: ecosystem services valuation) can also be a driver of changes in development approaches (Dupras et al., 2015).

Research agendas and experimentation projects are influenced by leading stakeholders ('frontrunners´ or 'champions') and their networks (Brown et al., 2013). Naylor et al. (2012) emphasize the need for interdisciplinary research and knowledge development in collaboration with end-users. Knowledge actors, such as scientific bridging organisations, were identified as drivers of innovation diffusion during transitions (Brown et al., 2013). Research leaders can also play a role by sharing their (interim) findings with other stakeholders during the process. This enables participation, knowledge sharing and science-industry partnerships and generates (local) investment in research activities (Brown et al., 2013). The frequent gap between research and practice is seen as a barrier to development (McCormick et al., 2013).

Experimentation

Experimentation, learning-by-doing or focus projects are an important source of (social) learning and may influence the shape, direction and speed of sustainability transitions (Brown et al., 2013). Experiments give the opportunity to test innovations (Naylor et al., 2012; Treemore-Spears et al., 2016). This testing can help to overcome concerns and maintain engagement (Naylor et al., 2012; Young, 2011). Experimentation can target different governance aspects , including financial incentives and assessments (Young, 2011) and deployment of community labour (Young et al., 2014). Experiments can lead to new institutional structures and tools (Brown et al., 2013), and have the potential to change values, identities and governance relations (Wolfram, 2015). Successfully implemented innovative legislation and standards can be used as examples for others to learn from and shape local discourses (Rohracher & Späth, 2014). Experimenting can also generate variety in possible solutions (McCormick et al., 2013). McCormick et al (2013) note that experiments can also serve to exchange knowledge on a global scale, furthering diffusion of knowledge on sustainability innovations.

Monitoring & evaluation

Monitoring and evaluation to check upon progress upon delivering goals was often named as a factor positively affecting durable change set in motion by sustainability projects (Bayulken & Huisingh, 2015; Naylor et al., 2012; Treemore-Spears et al., 2016). It contributes to scientific knowledge and evidence of success (Naylor et al., 2012), enables comparisons between the benefits of different approaches (Treemore-Spears et al., 2016) and forms the foundation of effective strategies (Dupras, Drouin, André, & Gonzalez, 2015; McCormick et al., 2013; Naylor et al., 2012). Weak or neglected monitoring undermines stakeholders' commitment to projects (Zhang et al., 2012) and makes comparison difficult (Bayulken & Huisingh, 2015).

4.2.9 Resources

We have defined three main types of resources based on the literature review: Knowledge and human capital; Financial resources; and Materials and technologies. The 'knowledge and human capital' resource is closely linked to the category of Learning. We made a distinction here between knowledge present in the current system (such as experts, or human capital), which we list as a resource, and active knowledge gathering during the process of sustainability transformation or sustainable urban development projects, labelled 'learning'.

Knowledge and human capital

Data, including real-time and big data (Munoz-Erickson et al., 2016), is often named as a valuable resource in urban sustainability efforts. Knowledge of ecological qualities (including biodiversity) of the territory is necessary when implementing green infrastructures (Dupras et al., 2015), as is knowledge on presently existing green spaces (Haaland & van den Bosch, 2015). Knowledge and data can also provide barriers to

development, however, when different stakeholders rely on different sources of information to inform their actions (Munoz-Erickson et al., 2016). A lack of access to information on new possibilities (in building construction) is noted to be a barrier to development (Hendricks & Calkins, 2006).

Expert knowledge and assistance is often needed in implementing and maintaining innovative technologies or systems, for instance roof systems (Hendricks & Calkins, 2006). Individual experts, such as technology advocates (Hendricks & Calkins, 2006), can be influential in promoting sustainable innovations. Currently, both scientists and managers lack in-depth understanding of how nature-based solutions affect urban ecosystems (Chaffin et al., 2016). Zhang et al (2012) indicate a lack of professional experts as one of the causes for low take up of green roof systems by residents in Hong Kong.

Expertise does not necessarily have to be present within organisations implementing innovative technologies, particularly when it can be acquired from external organisations (Brown, 2008). Networking can provide access to the necessary knowledge or data (Munoz-Erickson et al., 2016; Wolfram, 2015). Drawing on local expertise can also make the implementation of sustainability projects more effective, as it gives insight into how innovative approaches may be embedded in their working practices (Naylor et al., 2012; Treemore-Spears et al., 2016). Universities and technology transfer programs can provide grip for pioneering actors in sustainable interventions (Hendricks & Calkins, 2006).

Knowledge can be valorized through platforms or (NBS) ambassadors, in turn facilitating community building around sustainable urban development issues (Kabisch et al., 2016). A key governance feature for sustainable urban development are integrative knowledge systems, spanning multiple disciplines (Munoz-Erickson et al., 2016). The knowledge broker, serving as an intermediary between knowledge producers and users, may be beneficial when there are multiple disciplines involved. These can lay the foundations of fruitful partnerships (Naylor et al., 2012).

Financial factors

Funding is often named as essential for sustainability interventions to succeed (Naylor et al., 2012; Wamsler, 2015; Wolfram, 2015; Young, 2011; Zhang et al., 2012). A “sound financial planning” for the entire development duration is beneficial (Bayulken & Huisingh, 2015, p. 158). Chaffin et al (2016) state new funding models support the multiple goals green infrastructures can achieve. When it comes to nature-based interventions, institutionalizing spending on green interventions in the budget benefits green infrastructure planning, as well as access to traditional financing mechanisms, states Young (2011). More diversified funding sources also positively influence sustainability initiatives (Young, 2011).

Economic incentives, such as grant programs and subsidies or regulations and taxes can be an important source of income for initiatives promoting sustainability (Bayulken & Huisingh, 2015; Mees et al., 2015; Young et al., 2014; Zhang et al., 2012). These can help build support for new regulations (e.g. mandatory interventions) (Mees et al., 2015) and improve the uptake of innovative sustainability interventions (Rohracher & Späth, 2014; Young, 2011). Brown (2008) found that state government grants were used by some organizations to raise internal prioritisation of environmental goals. Sometimes financial incentives can provide a barrier to effective implementation of more sustainable alternatives. Dupras et al. (2015) give the example of municipal tax returns that rely on urban growth, providing a disincentive to the protection and enhancement of natural areas.

Funding can be acquired in multiple ways. Institutional entrepreneurs or project leaders can drive increased funding of sustainability interventions (Vandergert et al., 2015). In addition, building networks can help acquire more funding or enlarge the capacity to attract funding (Ghose & Pettygrove, 2014). Regulations, as well as societal or environmental events (e.g. hurricanes), can also drive financial commitments of public bodies (Young et al., 2014). Bayulken and Huising (2015) found that combining public funding and public participation supported attracting private investment (in the form of loans through adopting public-private partnerships), which was instrumental in urban regeneration developments. The combination of environmental regulation with mayoral leadership in New York has created public markets for the diffusion of green interventions, state Young et al. (2014). Private demand for nature-based interventions can also be boosted by demonstrating the benefits (Zhang et al., 2012). Young et al. (2014) signal that where green infrastructure is implemented in private developments, property prices include the green infrastructure costs and these are thus passed on directly to buyers.

Uncertainty of both non-profit and private financial commitments prevent public-private partnerships' effectiveness in supporting the implementation of nature-based solutions (Young, 2011). Ensuring commitment of local and central governments can minimize financial risks, originating for instance from changes in leadership, political climate or main stakeholders (Bayulken & Huisingh, 2015). (Perceived) increase of maintenance costs also provide a barrier for private parties and individuals implementing nature-based solutions (Hendricks & Calkins, 2006; Zhang et al., 2012). Power differences between stakeholders due to their financial capacities is another important barrier to development. Vandergert et al. (2015) give the example of small-scale farms' bargaining power and capacity to handle price competitions versus that of conventional food retailers in developing sustainable alternatives.

Materials, tools and technology

In addition to knowledge and financial resources, material or technologic resources can prove to be beneficial in diffusing innovative sustainability interventions (Wolfram, 2015). Munoz-Erickson et al. (2016) note that technological structures can create path dependency, thereby shaping urban (sustainability) development.

4.2.10 Local geographical context

Many of the reviewed articles pay attention to features influencing (NBS) innovation mechanics that are tied to an area, or place-bound. As Murphy (2015) states: "As urban and political geographers have shown, place – broadly considered here as a geographical phenomenon constituted along three dimensions: locale, location, and the senses or affects individuals associate with it (Agnew, 1987) – can have a significant influence on urban-regional or community development processes." In addition, it is important to pay attention to spatial variation in drivers and character of the development of nature-based interventions (Young et al., 2014). Based on the reviewed articles, several categories of such features could be distinguished: The built environment and urban amenities; Environmental qualities and climate; Societal processes; Local culture and image; and Land or property ownership.

Path dependency is a feature linking different elements in the categories set out in this paragraph. Path dependency is noted as influential factor multiple times. Regional assets with historical importance may shape development (Vandergert et al., 2015). The obduracy of the built environment – built structures and infrastructures that are difficult to change – also forms path dependency of innovation trajectories (Chaffin et al., 2016; Munoz-Erickson et al., 2016). Moreover, existing urban infrastructure "serves specific constituencies and interests connected to specific property and appropriation regimes", thereby influencing further developments (Young et al., 2014, p. 2581).

The availability of space regarded to be a necessity for civil society actors to meet and get actively involved in co-creating solutions (Wolfram, 2015). Treemore-Spears et al. (2016) note that the availability of space in the vicinity of affordable housing can create options for communally developed land to ensure food security and adaptation to climate change. Space can become a barrier when it is limited: urban compactness and density of (other) infrastructures restrict the implementation of green interventions (Haaland & Van den Bosch, 2015; Tian et al., 2012; Wamsler, 2015). More generally, a city's size and its associated resources are influential "at all levels of mainstreaming, from capacity building to actual operations" (Wamsler, 2015, p. 12). In the management of green infrastructures, a lack of scale is a barrier if sustainability developments are too small or fragmented (Young, 2011).

Built environment and urban amenities

The built environment is a driver of, or, quite often, barrier to (NBS) innovation. When it comes to buildings and built forms, certain aspects can be beneficial. Regarding the implementation of green roofs in particular, the presence of low-rise buildings is a driver, state Zhang et al. (2012), as these have large areas of vacant roof. The potential of project parcels to accommodate nature-based interventions is also important, eg. to collect stormwater through street flows or downspout disconnects (Chaffin et al., 2016). The repurposing of land and buildings can create opportunities for sustainable transformation (Treemore-Spears et al., 2016). A special form of (non-built) urban amenities mentioned as a driver are events, such as fairs or sports events. These create windows of opportunity for developments, such as eco-towns.

In a larger share of articles, the built environment is named as a barrier. Technical difficulties may hinder green interventions, for instance when constructions are not stable enough for the application of green roof systems, roof space (especially in case of high-rises) is already taken up by other services for the building, or owners are afraid of leakage (Hendricks & Calkins, 2006; Zhang et al., 2012). The allocation of space for urban developments by (local) authorities can also undermine large-scale green infrastructure developments (Young et al., 2014)

Environmental qualities and climate

Local environmental qualities are influential for nature-based interventions, such as soil characteristics that are favourable for infiltration and plant productivity (Chaffin et al., 2016; Tian et al., 2012). Choosing the type of vegetation that fits the local soil and climate is essential (Tian et al., 2012). An often-named driver of progression towards sustainability are (environmental) disasters, such as storms or nuclear accidents, laying bare more persistent external pressures such as climate change, decreasing air quality or sea-level rise (Munoz-Erickson et al., 2016; Rohracher & Späth, 2014; R. Young et al., 2014). These external pressures are also often named as drivers on their own (Young et al., 2014). One author names the economic importance of the environment (of Auckland, New Zealand), as a driver for development (Young et al., 2014). A challenge thus lies in finding solutions that fit the local environment, as differences in climate, species and environmental qualities matter for implementing nature-based interventions (Young, 2011). A side-note here on the role of the environment comes from Rohracher and Späth (2014, p. 1428), stating that “activities of urban actor constituencies were often driven by other interests and dynamics than environmental change”.

Societal processes

Not only do environmental qualities and change drive (sustainable) urban development, but the reverse applies as well. Rapid urbanization is one of the main factors influencing environmental degradation, thereby

prompting demand for sustainable solutions (Tian, Jim, & Tao, 2012). Other relevant societal processes include: financial crises leading to foreclosures and home abandonment, rising living costs (Munoz-Erickson et al., 2016), economic transformation and urban revitalization providing opportunities for sustainable development (McCormick et al., 2013), population growth, economic power of certain areas or "economic influences" in general (Young et al., 2014, p. 2581). Social inequity, such as segregation, can be a cause of conflict interfering with the development of sustainable collaboration (Treemore-Spears et al., 2016). In addition to differences in environmental qualities, spatial differences in social variables ("site history, culture, economy, and politics") also prove to be a challenge to navigate in the process towards more sustainable development (Young, 2011).

Local culture and image

Some authors pinpoint (local) culture as an important factor in socio-technical transitions, such as an entrepreneurial culture (Treemore-Spears et al., 2016), cultural frames, identity, consumption habits, lifestyles, the concentration of artistic activity or creative milieus (McCormick et al., 2013; Wolfram, 2015), cultural norms and civic culture (Young, 2011), socio-spatially embedded conventions, practices and meanings (Murphy, 2015) or public aesthetic preferences (Chaffin et al., 2016; Hendricks & Calkins, 2006). Not accounting for these context-specific characteristics hinders the diffusion of sustainability innovations (Murphy, 2015). Bayulken (2015) observed that the built environment and urban amenities can help establish a local identity, and a sense of place and belonging, which (if positive) contribute to the success of sustainability developments. Wolfram (2015) notes urban place and place-based experimentation shape values and identities. Building up an image through city branding, such as the 'eco city', also helps as it implies continued action and creates self-reinforcing dynamics (Rohracher & Späth, 2014).

Land or property ownership

Another factor, often referred to as an influential barrier, is land or property ownership. Either private (Dupras, Drouin, André, & Gonzalez, 2015; Mguni, Herslund, & Jensen, 2015; Wamsler, 2015) or multi-ownership of buildings (Zhang et al., 2012) can hinder the implementation of nature-based interventions.

4.3 Examples of nature-based solutions

In the sample of research papers, we found many references to case studies of nature-based solutions. We present these along with a typology without making a value judgement on whether or not these qualify as nature-based solution (Table 3)

Table3: Examples of Different Types of NBS

Nature of NBS intervention	**Category**	**Example**

Ecological/physical	**Creation of new green and blue spaces**	Green infrastructure throughout Wynyard Quarter and Auckland's central business district (Auckland, NZ) (Young et al., 2014) Rotterdam, NL: a 5000 m2 vegetation wall 50,000 m2 of green roofs have been fitted throughout the city (Tillie & van der Heijden, 2015) Rain gardens in Slavic Village (Cleveland, Ohio) (Chaffin et al., 2016) Rain gardens, tree pits, and permeable pavement in Albany Lakes Civic Park (Auckland, NZ) (R. Young et al., 2014) Skyscraper farms and sky gardens in Singapore and several European cities (Tian et al., 2012) Edible Rotterdam initiative (Tillie & van der Heijden, 2015)
	Maintenance and management	Seattle Seawalls project (Naylor et al., 2012) The Environment Agency Shaldon and Ringmore Tidal Defence Scheme in Devon, UK (Naylor et al., 2012) Green schoolyard in Feijenoord district, Rotterdam (Tillie & van der Heijden, 2015) Shrub species planted at door steps in Berlin (Haaland & van den Bosch, 2015)
	Restoration	
Social	**Policy**	Urban Green Infrastructure Strategy 'Groenplan' in Rotterdam, NL, to connect the urban area alongside the river Maas with the surrounding landscapes (Tillie & van der Heijden, 2015) Temporary nature in Rotterdam (Tillie & van der Heijden, 2015) Eco-city development in Graz, Austria (Rohracher & Späth, 2014) A green and open space concept for the Weststadt area of the city (Nürnberg, Germany); a heritage management plan (Stadt Regensburg 2012a) and a strategic planning framework for the historic city center (Stadt Regensburg 2014/15), all of which have adaptation considerations at their core (Regensburg, Germany); strategic urban development plan (Freising, Germany); a greening office in Munich, Germany (Wamsler, 2015b) New York's regional GI strategy and clean water strategy (R. Young et al., 2014) Practice Notes for Green Innovate Buildings in Hong Kong (Zhang et al., 2012)

	Governance	Green and communally managed spaces providing multiple benefits in Baltimore, Maryland (US). For example, Deep Blue—an innovative public-private partnership (Treemore-Spears et al., 2016) Public park managed by the Dakpark Foundation in Rotterdam, NL (Tillie & van der Heijden, 2015) Field Guide for Vacant Lots as a tool kit to assist in on-the-ground lot transformation in Detroit (US) (Treemore-Spears et al., 2016) Green Pattern Book in Baltimore (US) to foster partnership working The approach to urban community development and social innovation adopted in the city of Seoul (Wolfram, 2015) an organizational structure aimed at integrating green infrastructure planning into all urban developments (Munich, Germany) (Wamsler, 2015b)
	Knowledge	
	Economic	
	Cultural	
Technological	**Product**	Germany, France and Switzerland are world leaders of green roof technologies (Zhang et al., 2012)
	Process	Climate adaptation team in Copenhagen that seeks to most effectively implement SUDS in the entire St Kjelds Klimakvarter demonstration project (a 105-hectare neighbourhood) (Mguni et al., 2015)
	System/infrastructure	SUDS in Metropolitan Melbourne (Brown et al., 2013) Integrated systems for surface water retention (Copenhagen) (Haaland & van den Bosch, 2015) San Antonio (Texas, US) Water System (Young et al., 2014)

5 Concluding thoughts

- The present research generated a wide range of factors influencing innovation for urban sustainability through NBS and related mechanisms (e.g., green infrastructure). When we compare this to existing environmental governance frameworks (Lawrence et al. 2013; van Tatenhove et al. 2000), our set of variables is larger and more diverse. There are several explanations for this. Firstly, we considered a broader set of literature, moving beyond papers on environmental or urban forest governance. In particular, the body of literature on innovation has not been previously taken into consideration in the development of these previous governance frameworks. Secondly, we took a data- as opposed to a theory-driven approach which enabled us to consider variables that influence processes and structures for collective decision-making rather indirectly at a possible point in the future (e.g. learning). Moreover, we also considered variables that say something about the individual traits and disposition of actors involved (e.g., cognitive factors and agency). Thirdly, existing governance frameworks do not consider variables that may be relevant for changes that may occur in the future; instead they focus on systematically analysing the situation at a "certain point in time" (e.g., Arnouts et al. 2012). By considering the dynamic nature of innovation we could include variables that do not appear significant at a certain time but would play a key role if studying the development of an initiative over time.

- There is a rather strong focus on cognitive, discursive and agential factors. This was not a deliberate choice but the outcome of the data-driven review. It would be worthwhile comparing the findings from this review with those of other reviews, particularly looking at regimes, in order to find more on factors related to materiality, structure and power (also see next point).

- So the review has resulted in identifying a range of factors driving NBS innovation through a data-driven approach. Further theoretical work is necessary to relate the findings to relevant, but more generic theoretical frameworks in the field of innovation, and in particular socio-technical transitions. There is substantial promise in undertaking such an effort, given that the factors identify here resonate with framework such as the Technological Innovation Systems approach (e.g. Hekkert et al., 2007, who identified seven systems functions that drive innovation, including entrepreneurial activities, knowledge development, knowledge diffusion, guidance of search processes, market formation, mobilization of resources and countering resistance to change) and transition dimensions in the Multi-Level Perspective (e.g. Geels, 2002, who identified knowledge, policy, markets, user practices, technology, infrastructure culture and industrial networks as key dimensions in transitions). Recent institutional approach to socio-technical transitions, moreover, highlight the important of strategic work in relation to changing some of these systemic conditions (e.g. Fuenfschiling and Truffer, 2016), and further analysis could identify how

such work encounters and potentially overcomes more structural forms of power embedded in incumbent institutions, infrastructures, networks and discourses (Avelino and Rotmans, 2009). The work in WP5 of NATURVATION is expected to further elaborate on such questions and literatures.

- There was considerable variation in the quantity of references within each of the categories of factors influencing innovation for urban sustainability. For example, there were many references by many different papers made that fitted in with the Networks and Partnerships category, whether we found much less about Learning. This could reflect a bias to studying or focusing on certain factors in the literature, a literature sampling bias on our behalf, or be an indication that some factors play a more significant role than others. Related to the first of these three explanations, we noticed that some of the factors in our table were often not being made explicit. For example, the role of networks was often mentioned, but learning less often, while one of the key benefits of networks is mutual learning.

- Although we distinguish between a large range of factors acting as drivers and barriers for innovation for urban sustainability, some of the boundaries between those factors are rather arbitrary. For example, partnership working and participation are often entangled, or become so during a transformation process. For example, an authority may begin by initiating and actively steering a citizen initiative (i.e. Participation). Yet, over time this may empower citizens to engage in much closer partnership working (i.e. co-governance partnership).

- We found several references in the literature suggesting that innovation for sustainability is unlikely to come about by any of the individual factors in isolation. For example, Mees et al. (2015) note the following: “Basel and Stuttgart authorities employ the broadest mix: they use coercive regulations to make green roofs mandatory on new buildings, while simultaneously rewarding green roof installations with financial incentives (stormwater fee reduction and, in the past, also with subsidies). According to respondents, this combination of instruments has helped to make the regulation acceptable” (Mees et al. 2015, p. 816). Therefore, the factors in our framework are ideally studied within the context of other variables together making up the governance arrangement.

- The role of particular factors in our framework in predicting innovation for urban sustainability is not just dependent on other elements of the governance arrangement, but also on the timing. For example, Hendricks and Calkins (2006, p. 2) describe a changing role of research at different stages of the transformation process: “This is confirmed by the Koebel et al. (2004) study which found that early adopter residential builders rely on technology transfer programs and universities more than middle or late stage adopters do. The study found sales and supplier representatives, subcontractors, and trade shows to be

important information sources for all types of adopters". A similar temporal dimension is described by Brown et al. (2013, p. 713): "In response, strategies such as shadow advocacy and lobbying were enacted during times when political influence was required, and training and up-skilling of a broad range of practitioners […] become more targeted and sophisticated over time as new scientific evidence emerged and industry best practice guidelines and targets were established".

- A third factor influencing what factors are most pertinent as drivers and barriers is the operationalization of performance/success. We identified various ways in which success of NBS (and related solutions) delivery has been described in the literature (see Section 3.2).

- Finally, we want to stress that many of the identified factors related to sustainability innovation in reality influence such transformation indirectly as component of a series or chain of events (or a virtuous cycle) leading to the 'tip-over' of a management regime. Figure 1 hypothesises about some of the mutual relationships between factors. Further empirical work is needed here to identify the actual existence and strengths of these relations.

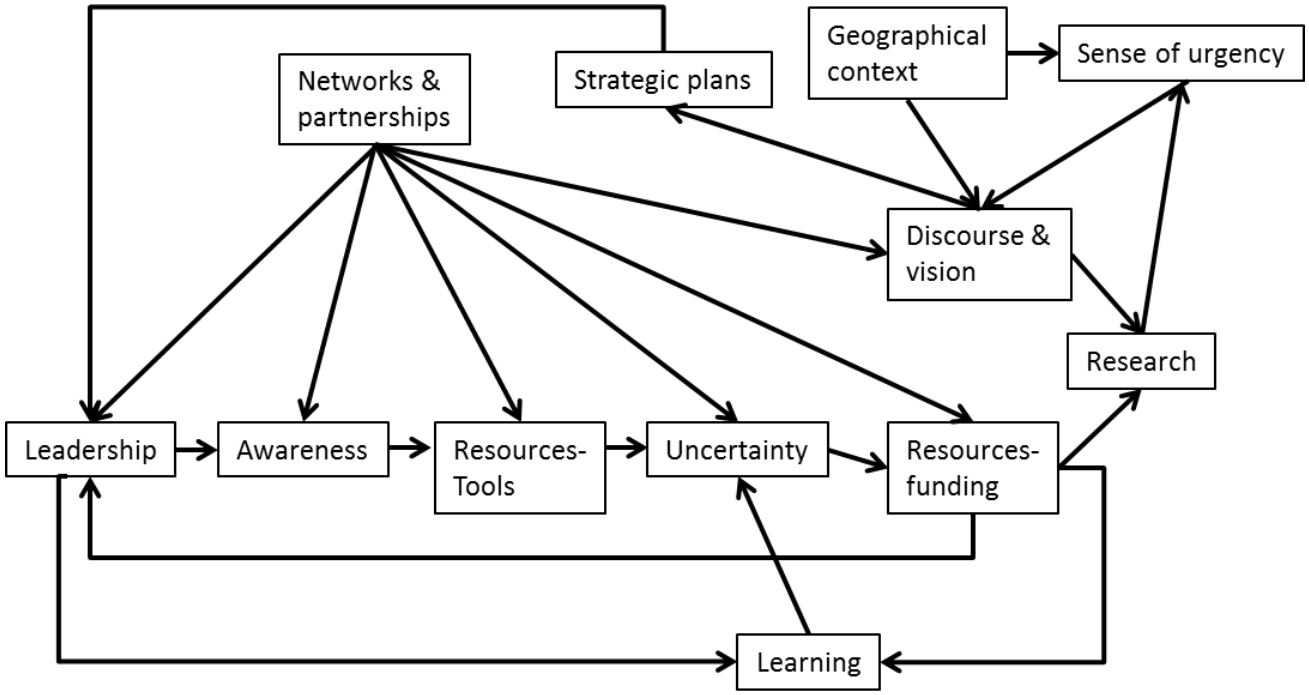

Figure 1. Hypothetical model showing intricate relationships between factors influencing sustainability innovations.

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Appendix A

List of 39 papers selected by UU-Cop for the urban innovation review

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