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INTEGRATED URBAN ENVIRONMENT EFFECT ANALYSIS

OF INFRASTRUCTURAL TRANSFORMATIONS

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INTRODUCTION

This report describes a method for 'Integrated urban environment effect analysis of infrastructural transformations' (in short, 'Infrastructure Effect Analysis'). The aim is to contribute to an improved understanding of the impact of national transport infrastructure projects on urban environments. While the object in focus is national transport infrastructure, the method describes and measures the local effects in the environment that the impact entails. This stems from the acknowledgement that each infrastructure transformation results in a redistribution of accessibility where increasing accessibility on a regional and interurban scale might create encroachments on a local scale, including changes in the character and the function of the built environment and due to e.g. emissions and noise, risk of accidents, barrier effects and fragmentation (Grudemo et al., 2002).

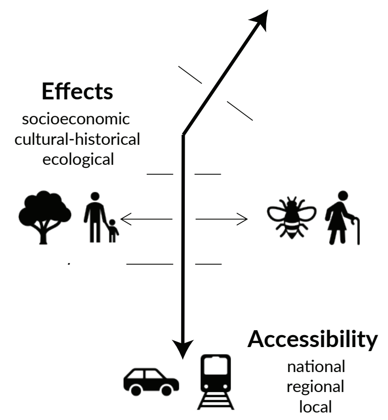


Figure 1.
Integrated urban environment effect analysis of infrastructural transformations including socioeconomic, ecological, social-ecological and cultural-historical effects

Infrastructure Effect Analysis can be used in different contexts from highly urbanized regions, such as Mölndal in Gothenburg region (70 thousand inhabitants), to smaller urban settlements, such as Söderköping (7 thousand inhabitants), but also in larger cities and even smaller settlements. Further, it is applicable in different phases of planning and implementation of roads and railways by the Swedish Transport Authority, which will be discussed in more detail in chapter 5. Moreover, the results of the method support the discussion between different planning authorities, mainly the planning of infrastructure at national and regional level and urban development at municipal level.

The methodology allows for an integrated effect analysis of infrastructure projects including social, ecological and cultural-historical effects (Figure 1). Social effect analyses focus on the changes in the functioning of the built environment for the daily life activities of the people living in, working in, or visiting the area, while the ecological effect analyses emphasize changes in its functioning in relation to other species, natural habitats and ecosystems. Social-ecological aspects are discussed separately to highlight the role of natural habitats and ecosystems for human wellbeing and health. An example is the role of biodiversity in the healing effect of green areas to people or the role of important recreational green areas for social integration. The cultural-historical effect analyses highlight changes in tangible cultural elements with historical value such as buildings, monuments, landscapes, and changes in how these places are experienced by people. These different effect analyses can be linked to the environmental interests highlighted in the Environmental Assessment method (Miljö Konsekvens Bedömning (MKB) in Swedish) used by the Swedish Transport Administration: natural environment, cultural environment and human health (in Swedish: naturmiljö, kulturmiljö, befolkning och hälsa). Natural and cultural environment can be linked to ecological and cultural-historical effect analyses respectively and human health can be linked to social effect analyses.

INTRODUCTION

The overall methodology is based on a before-and-after analysis, systematically comparing the existing situation (how it is, how it functions, how it affects people) with the infrastructure transformation proposed by the Swedish Transport Administration. The method allows to systematically describe the impact of new infrastructure (or retrofits) through the analyses of effects for the direct surroundings as well as expected societal consequences of these effects. New national infrastructure often involves an increase in traffic volume and speed as well as reduction in the number of crossing points, while a retrofit of an existing national road in the local urban context often involves the opposite, a reduction of traffic volume and speed as well as an increase in crossing points. These changes can have socioeconomic, ecological, social-ecological and cultural-historical effects that can be assessed with support of this methodology. For example, lower speed and more pedestrian crossings contribute to better connections between districts located on opposite sides of the infrastructure that may in the long run counteract social segregation.

Effects can be divided into direct, indirect and cumulative effects. Direct effects arise as an immediate result of the new infrastructure. For example, the new infrastructure fragments arable land that as a result becomes more difficult to cultivate. Indirect effects occur subsequently such as, using the example above, arable land that is not cultivated will overgrow and this in turn impacts the readability of the landscape and possibly its cultural value. Cumulative effects are the combined effects from several changes that together can lead to a greater impact. The societal consequences are described by weighing together the size of these effects with the value of the environmental aspect that is assessed. These societal consequences can be linked to the Sustainable Development Goals (Agenda 2030) to relate them to other policy documents at the Swedish Transport Administration. The method contributes to facilitating trade-offs between the Swedish Transport Administration's goal related to accessibility and goals related to safety, environment and health (Bill 2008/09: 93 and adopted by Riksdag 2009).

The method presented in this report has its starting point in the method for integrated landscape analysis ILKA (Integrerad landskapskaraktärsanalys). ILKA is currently used by the Swedish Transport Authority to describe opportunities and sensitivities in the landscape in relation to infrastructure projects. Infrastructure Effect Analysis contributes to ILKA in three ways. First, the focus is shifted towards urban environments, while ILKA focused more on regional landscapes. Second, it is strengthening the integrated approach of ILKA by including socioeconomic, ecological, social-ecological and cultural-historical resources in a similarly systematic way, while ILKA is rather limited when it comes to the socioeconomic perspective. Third, it adds clearer descriptions to assess the effects of new infrastructure. To ensure transparency and comparability between projects, these descriptions are to a greater extent based on geographical data and analyzes (using GIS).

It should be noted that ILKA was not developed with the aim to provide technical descriptions of how to analyse the effects of infrastructure transformations. Instead, it aimed to shift the approach used to describe the landscape.

The "old" approach (before ILKA) was deemed very partial where different experts worked independent from each other. This resulted in a fragmented description of the landscape that ILKA aimed to change into a more holistic one that covered ecological, cultural-historical and to some extend socioeconomic descriptions. Furthermore, it extended the analysis to cover the complete territory instead of focusing mainly on protected areas. The method described in this report builds on this approach and should thus be used as a complement where ILKA describes the character of a landscape, while the complementing Infrastructure Effect Analysis emphasizes the effects and consequences of infrastructure projects.

Three types of infrastructure projects are identified where the method can be applied (Figure 2). First, new infrastructure in cities, impacting existing urban neighbourhoods through the barrier effect the new infrastructure creates. Second, bypass solutions that aim to reduce the negative effects of existing infrastructure in cities. This might cause shifts in centrality caused by both the new bypass and the retrofit of the "old" infrastructure. Furthermore, the new bypass might create new encroachments outside cities. Third, an existing infrastructure can be converted into a city street without investing in a bypass. The latter type of project usually arises due to an urbanization process that has been going on for a long time where a national road has become an integral part of the local movement patterns while its design is still adapted to its previous function. Effects of these three types of infrastructure transformations are partly overlapping but might also need specific analysis. In the case of bypasses for example, the location of exits needs special attention as these mediate the different scales of accessibility, linking the regional and intraurban scale with the local scale. For railway infrastructure, the station fulfills this role of mediator between scales of accessibility.

Outline

In the next chapter, the framework that forms the base of the developed method is introduced consisting of a new approach of planning and designing cities that integrates two traditionally distinct fields of urban morphology and landscape ecology, but also introduces a conceptual model to include barrier effects to the framework. The integrated impact analysis of infrastructure projects includes descriptions of the character and function of the urban environment from three perspectives: the social, ecological and cultural-historical. The third chapter introduces these three perspectives and key concepts that are central to the developed method. In chapter four the method for 'Integrated effect analysis of infrastructure transformations in urban environments' is described divided into three steps. The fifth chapter focuses on how this method can be used and integrated into the planning processes central to Swedish Transport Administration and in the last chapter, the method is applied in two case studies. The first case study is Söderköping where a bypass is proposed to move traffic that currently crosses the small town. The second case study is Mölndal where a new station is planned as part of the new double track railway for high-speed trains and fast regional trains between Gothenburg and Borås.

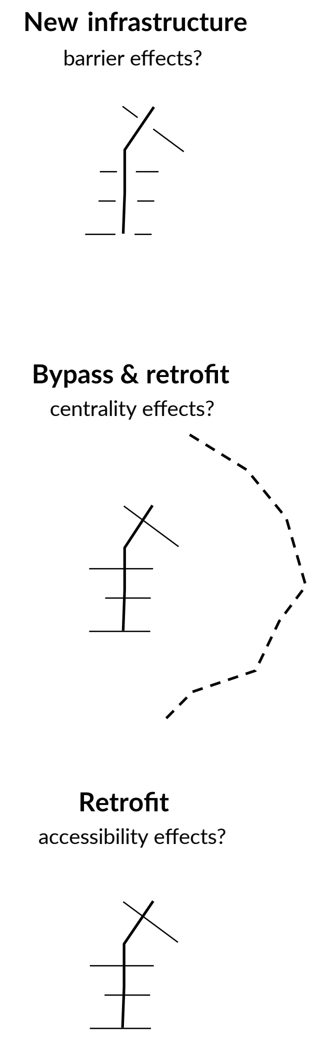


Figure 2.
Three types of projects with specific effects

2. FRAMEWORK FOR INTEGRATED EFFECT ANALYSIS

The method for 'Integrated effect analysis of infrastructure transformations in urban environments' presented in this report builds on a new approach of planning and designing cities that integrates the two traditionally distinct fields of urban morphology and landscape ecology. This new approach is referred to as the social-ecological approach and in relation to urban planning and design is coined 'social-ecological urbanism' (Barthel et al. 2013; Marcus and Colding 2014). Socio-ecological urbanism studies how the city's structure shapes and influences socio-economic and ecological processes in cities, including cultural-historical values and ecosystem services.

From a discourse point of view, social-ecological urbanism can be seen as a new generation of urbanism after the dominance of the sustainable urbanism paradigms such as 'smart growth' and 'compact cities'. Social-ecological urbanism deals not only with mitigation measures to reduce e.g. the emission of greenhouse gases, but also with adaptation measures to enhance ***resilience*** (Holling 1973). It does so by searching for synergies between ecological and social systems, where resilience denotes the capacity to absorb various disturbances and sudden changes, reorganize and continue to develop without losing fundamental functions (Folke 2016).

Despite the wide use of the idea of a 'social-ecological system', it is a poorly defined concept (Colding and Barthel 2019). Berkes and Folke (1998:4) originally used the term to emphasize the concept of 'humans-in-nature', arguing that social and ecological systems are in fact intertwined, and that the delineation between the two is artificial and arbitrary. Many researchers have also pointed out the many similarities between urban and ecological systems. For example, Marcus and Colding (2014) described how several resilience principles inherent to natural systems (Folke et al. 2003; Biggs et al. 2015) also confer resilience of desirable social processes in urban systems. Therefore, in this method for integrated effect analysis, we regard the built environment as an overlapping zone between culture and nature, corresponding to the definition of a social–ecological system (Hassler and Kohler 2014), consisting of a set of critical socioeconomic, cultural-historical and natural resources whose flow and use is regulated by the physical urban environment (Marcus and Koch 2016; Colding et al. 2020).

Benefits that nature can provide to humans have been described by ecosystem services (Burkhard et al., 2017) and, from the perspective of social-ecological urbanism, this is extended and includes besides ecological services, also socioeconomic and cultural-historical services. A helpful conceptualization of the delivery process of these services is the cascade framework, created first by Haines-Young and Potschin (2010). In this framework, the delivery process is decomposed into a linked set of components which span both the supply and demand side of the service delivery process. This can apply to ecosystem services alone or be expanded to include socioeconomic services and cultural-historical qualities (figure 3).

The cascade framework has similarities with the descriptive layers used in ILKA with a division between:

1. 'Character' describing the built environment. (How it is).

2. 'Function' describing how the character of the built environment supports movements and flows of, for example, people, animals, plants, water and wind. (How it functions).

3. 'Benefit' describing whether the function also provides a service (or disservice) to people. This depends not only on the function but also on the ability to utilize it (How it affects).

4. 'Value' describing people's needs and thus how they value a benefit. (How it is valued).

The effect analyses describe changes in the character and function because of infrastructure transformations. The distinction between 'function' and 'benefit' is used to describe on the one hand, the potential the urban environment provides (based on function), and on the other hand, the actual delivery of it to society by including benefit in the function analysis. For instance, the distance to a school can decrease because of a new infrastructure and create a potential benefit, but this will only be actualized in case children are affected by this change in function (i.e. actual benefit). Values are used to describe consequences of infrastructure transformation by weighing effects with the value associated with that function.

When discussing socioeconomic, cultural-historical, and ecological resources, it is useful to keep the descriptions and analyses of the supply and demand side of the service separate, although it is not always possible to distinguish the two fully. The reason is that the functioning of the urban environment is a technology that outlives the specific demands of today and should better be understood as provider of potential services over long time. When a new infrastructure is cutting through a green area, this will, from the ecological perspective, cause a loss of and fragmentation of habitats and from the socioeconomic perspective, this will reduce accessibility of green areas. These two functional losses can first be described without considering where people live today or whether the green area is visited a lot and thus describes the potential loss of benefits, that is, the functional loss. To discuss the actual loss of benefit, the number of people that will be affected by this reduced access should be included in the analysis. Even specific population groups (based on demography or socioeconomic profiles) can in this step be included and studied.

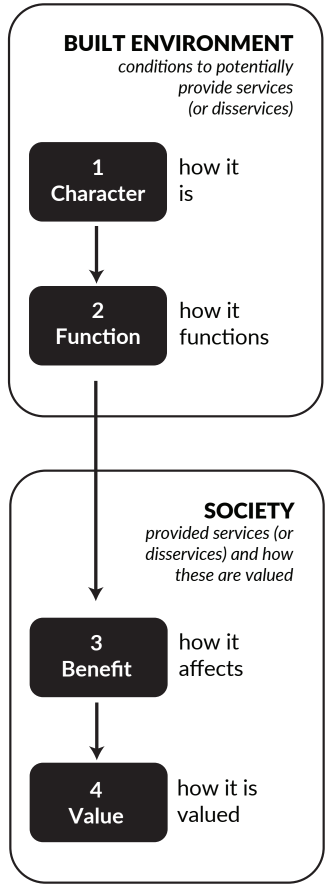


Figure 3.
Proposed conceptual framework for urban services based on the cascade framework developed by Potschin & Haines and Young (2010).

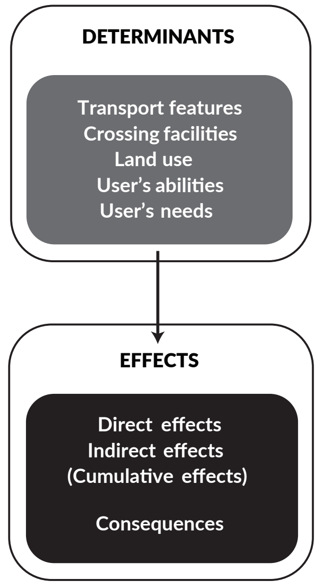


Figure 4.
Conceptual model to describe effects of infrastructure transformations based on Van Eldijk (2022) and environmental impact assessment (MKB).

Besides the social-ecological approach, the methodology builds on research on barrier effects (also referred to as 'encroachment' and 'severance')[1]. As discussed in the introduction, new national infrastructure increases accessibility on regional and interurban scale, but often also imposes delays, discomfort, and reduction of accessibility locally that can be described as barrier effects. Van Eldijk (2022) proposes a framework, based on an extensive literature review, of five determinants and a three-level hierarchy of barrier effects. This framework is adapted to fit the terms used in environmental impact assessments (MKBs) where effects are separated from consequences. (figure 4). Consequences are in MKB described by weighing together the effects with the value of the environmental aspect that is assessed.

The five determinants are: 1) transport features; 2) crossing facilities & street network; 3) land use; 4) user's abilities; 5) user's needs. The first describes the infrastructure feature itself such as road width and fences, and the second how this infrastructure is embedded in the structure of the local urban environment, such as the number of crossing points and height differences. Also, properties that affect the perception of a barrier are included here, such as traffic volume and speed that can lead to a decrease or increase of barrier effects (referred to as dynamic barriers). Because of the infrastructure transformation proposed, these features change with potentially socioeconomic, cultural-historical, and environmental effects. In combination these two first determinants describe the physical conditions and represent the supply side in the cascade framework.

The other three determinants describe the user's perspective, including land use that defines to a large extend who potentially needs to cross, people's and other species ability to cross, and the need to cross the infrastructure. These three represent the demand side of the cascade framework. In other words, the transport features and crossing facilities that represent the character of the built environment support movements and flows and thus the function the built environment potentially can support. The presence of users (people and other species), their abilities and needs, defines on the other hand whether the function turns into a benefit or disbenefit that might be valued or not.

As was discussed in the introduction, the methodology is based on a systematic comparison of the existing situation with the future scenarios proposed by the Swedish Transport Administration.

1. In part based on the work of van Eldijk (2022)

Effects are measured using the three-level hierarchy of effects:

1. Direct effects arise as an immediate result of the infrastructure transformation. Direct effects measure change using the current situation as a benchmark, while not inferring that the change is significant. This is the essential first step in effect assessment (Duinker and Servos, 2013). Assessing the relevance (or significance) of that change, while important, is secondary.

2. Indirect effects occur subsequently. Indirect effects are described based on known thresholds, that are extracted from empirical studies (literature), professionally based guidelines or expert knowledge.

3. Cumulative effects are the combined effects from several changes that together can lead to a greater effect for the environmental aspect concerned. The cumulative effects can be either additive, synergistic, or counteracting. An additive effect occurs when two or more effects together lead to an effect that is equal to the sum of the individual effects. A synergistic effect is an effect where the combination is greater than the sum of the individual activities. A counteracting effect means that the effects from more than one activity are less than the sum of each.

The last step describes the societal consequences by weighing the size of these cumulative effects with the value of the environmental aspect that is assessed that can also be linked to the Sustainable Development Goals, SDG. This results in the conceptual model for effect analysis that is shown in Figure 5.

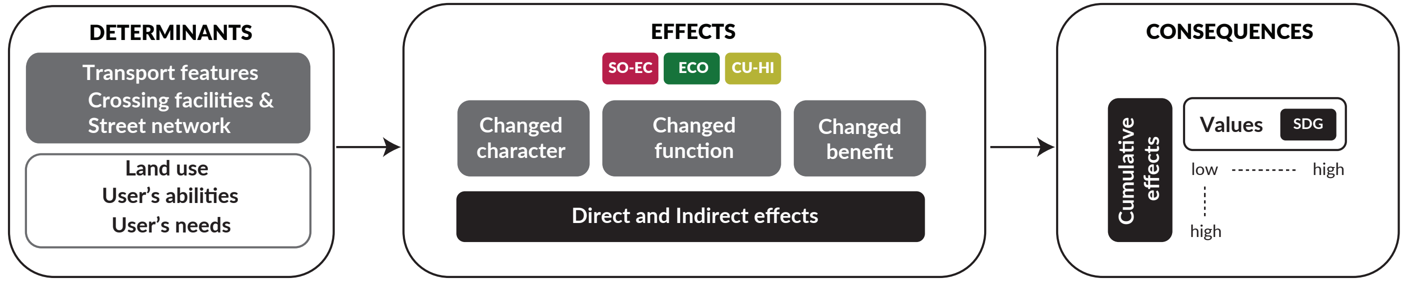


Figure 5.
Conceptual model of integrated effect analysis

3. KEY CONCEPTS TO DESCRIBE THE EFFECTS OF INFRASTRUCTURE TRANSFORMATIONS IN URBAN ENVIRONMENTS

The integrated effect analysis of infrastructure projects involves descriptions of the character and functioning of the urban environment from three perspectives: the social, ecological and cultural-historical. Based on the discussion in the former chapter, these cannot be described separately. Instead, they should be considered as three dimensions of the same landscape that are intertwined with one another. However, at the same time, they have their specificities that need to be considered separately to be able to understand how an infrastructure transformation impacts the functioning of the environment. In this chapter, we therefore introduce the key concepts to describe and understand these three aspects of the environment to, based on that, develop an integrated approach to describe the consequences of infrastructure transformations.

Describing effects of infrastructure transformations for people's everyday lives
Conditions for people to live their everyday lives are created by the built environment and include various components and their relationships. This is partly about the how activities and functions are distributed in the built environment (where things are located), partly about the physical connections that influences people's patterns of movement and make these functions and activities accessible. For the former, there are developed methods for description and characterization. In the report 'Lär känna din ort' (Boverket 2006), methods are listed to describe the most important morphological components of the built environment (buildings, streets, squares, parks), patterns created with these components (building types, neighbourhood types, scale of the urban grid) and distribution of activities (functions such as schools but also public spaces as important social places). This inventory can also include how people with local knowledge value the built environment.

The second approach is to characterize the built environment as 'lived-space' (in Swedish människors användning av den fysiska miljön) for which we need to understand how the environment affects people's movement patterns. Movement flows, and hence co-presence in space, is central to be able to relate the built environment to socioeconomic processes, as described in the theory of 'natural movement' (Hillier et al., 1993).

To describe the urban environment from this perspective, descriptions of the city as a network of components is needed. Instead of describing the separate components such as streets and buildings, the environment is described as a system. The street network is thus understood as a system that because of its configurational properties, creates places with high centrality and places with low centrality. These variations in centrality have been proven very important for the number and diversity of people that are found in these places. In the same way, buildings are not described as objects, but their position in the system and accessibility are in focus.

Space syntax offers methods and theories to describe the built environment as 'lived-space'. To describe the distribution of people in the built environment, one needs to consider the whole street network and the distribution of attractions (activities and functions). The theory of 'natural movement' (Hillier et al., 1993) describes the primacy of the street network over attractions, because it is the configuration of streets that, through its impact on movement flows, drives a willingness to invest in a location that results in changes in land use and built density. At the same time, a higher density and more activities attract more people that, in turn, attract more investments and activities. This phenomenon is described with the concept 'multiplier effect' (Figure 6). Numerous studies have investigated this triangular relation between centrality (Hillier & Iida, 2005; Hillier et al., 1993; Peponis et al., 1989, Stavroulaki et al. 2019), attractions (Berghauser Pont & Marcus, 2015; Legeby, 2013; Netto et al., 2012; Ozbil et al., 2011, 2015; Peponis et al., 1997; Read, 1999; Ståhle et al., 2017) and pedestrian movement.

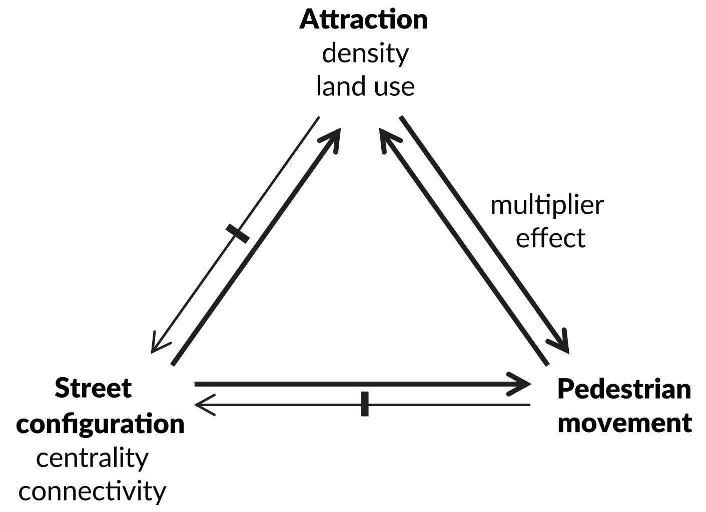


Figure 6.
Theory of Natural Movement
(Hillier et al. 1993)

These configurational properties of the built environment are important also for social processes that depend on the presence and distribution of people in the environment (their co-presence). Olsson (1998) describes three reasons why this is important. First, it relates to the need people have to be seen and to see others and, in a city, public space and social infrastructure (such as libraries, schools but also shopping malls) are important places for people to meet. The second reason is related to tolerance that is the result of different kinds of ongoing negotiating processes for which interaction is needed, in cities, taking place in public space. Third, urban life improves cohesion in society at large, a phenomenon that refers to a kind of civic spirit where people are willing to do things for the common society (Hillier and Vaughan 2007, 212).

Movement patterns of people are also an important driver for economic concentration of retail, restaurants and other activities that are dependent on people passing by or vice versa, dependent on remoteness (e.g. Scoppa et al. 2015, Bobkova et al. 2019). A shift in centrality or density can cause changes in flows that can have big impact on these processes and in turn, on land prices and land uses (e.g. offices, housing, shopping malls). These changes can take place at regional, urban or neighbourhood scale with different consequences. For example, a change in local centrality might impact the local community, while a change in regional centrality can cause regional redistributions of economic activities.

Infrastructure transformations proposed by the Swedish Transport Administration can directly or indirectly affect these social and economic processes in positive and negative ways. An example of a direct negative effect is when a new infrastructure creates a barrier and the distance to an elementary school becomes longer. Also, the direct vicinity to the infrastructure and the accompanying noise levels (direct effect) that, depending on the sleep disturbance caused by it, can have indirect negative health effects. Another example is when centrality in the city changes because of the new infrastructure and a cluster of shops and restaurants lose centrality (direct effect) and because of that, the number of visitors might diminish and thus the turnover in these stores and restaurants. In the long run, this could lead to a relocation of such a cluster of shops and restaurants (indirect effect).

Describing effects of infrastructure transformations for cultural environments

By cultural environment is meant man-influenced traces in the landscape from historical events and processes that led to today's landscape. People's conditions, activities and life patterns at different times can be followed in the landscape's physical structures and people's use of the physical environment. By cultural-historical characteristics is meant such characteristics in the physical environment that are connected to and important for the readability of the environment's historical development. In the built environment, this can apply to everything from an individual building with its building details, to archeological layers, urban plans with typical street patterns, squares and park and green structures and the built environment's overall characteristics with landmarks, building types, neighborhood structures, scale, volumes and building silhouettes.

The cultural-historical perspective is partly about the direct physical environment, partly about cultural-historical functions and historical connections in the physical environment. For the former, there are developed methods for description, characterization and valuation. These are developed in various reports such as Plattform Kulturhistorisk värdering och urval (Riksantikvarieämbetet 2015), Landscape As An Arena: Integrated Landscape Character Assessment – Method Description (Trafikverket 2017) and in Boverket's Checklista karaktärsdrag. The cultural environments own legislation and the general considerations stated in a number of other laws mainly concern the physical environment. Methods for analyzing and evaluating cultural-historical connections and functions are less developed, but an increased focus is noticeable in e.g. The Swedish Transport Administration's cultural heritage analyzes. By cultural-historical functions and connections is meant people's use of the environment when this can be linked to a historical continuity or to special historical events. It can be about a certain land use and special activities with a historical anchorage, or about opportunities to move along historically established streets. The ability to orientate oneself in and read the historical emergence of an urban environment is often strongly dependent on how people can move in the urban fabric, how to enter the city or approach central places or buildings in the city. The opportunity to get an overview of the urban environment from historically relevant viewpoints is also important for the readability of the city's historical development and morphology.

The cultural-historical functions of an urban environment can be affected both directly and indirectly by an infrastructure transformation, and they can both be weakened and strengthened or recreated. An example of a direct negative effect on the possibility of moving in the urban environment is if parts of the historic street network are cut off, if new infrastructure facilities create barriers that eradicate the possibility of moving along a certain street or if the entrances to a city or building are shifted. In all these cases, the infrastructure transformation impacts the physical structure directly and movement patterns disappear or weaken. An example of an indirect effect is when an infrastructure transformation leads to a change in the centrality of the city and historically established main streets or central public places lose their role as central streets or target points in the city. In this example, the physical structure thus remains, but people's movement patterns and use of the urban fabric change.

Describing ecological and social-ecological effects of infrastructure transformations

The natural environment includes several different habitat types both on land and in water, including human-influenced environments such as parks, arable land and roadsides. In order to understand effects that infrastructural changes can give rise to, it is important to look at the natural environment from two different perspectives: a purely ecological and a social-ecological.

Unlike the other perspectives, the purely ecological perspective is not primarily based on human needs and use of the landscape or urban environment. Instead, it is the ability of all other organisms to use the landscape that is in focus. The purpose of having a purely ecological perspective when planning new or changed traffic infrastructure is of course rooted in a human need to preserve and protect natural environments and their biological diversity of species for future generations. The purely ecological perspective is thus based on the needs and possibilities of the existing species to use the landscape. From a purely analytical point of view, it is a matter of being able to identify which parts of the biological diversity may be affected by the planned changes and then try to predict what direct and indirect effects they will have on the long-term survival chances of the species concerned.

The long-term survival of a species is regulated both by the total amount of functional habitat and how good the distribution possibilities are between separate habitat fragments. If the amount of functional habitat decreases, the conditions for a species' long-term survival generally deteriorate. The chances of survival also inevitably deteriorate if the possibilities of spreading between habitat fragments are reduced. Construction of new infrastructure can of course give rise to both direct loss of habitats and reduced opportunities for different species to spread between existing habitats.

It is not just the amount of (functional) habitats and the dispersal relationships of the species that need to be understood from the ecological perspective. Changes in traffic volumes can also directly affect the long-term survival of populations. With increased traffic, the risk of individuals being killed or injured increases. Increased mortality can in turn lead to reduced chances for affected species to survive in the long term. Increased traffic volumes can also lead to a deterioration of ecological function in adjacent habitats through increased noise. In the case of birds, for example, their communication during the breeding season is made more difficult. Similar effects on the quality and ecological function of habitats can occur with an increased frequency of visits by humans and dogs.

Furthermore, losses or deterioration of the species' habitats can be expected to arise in the long term because of the indirect effects on societal development that the planned infrastructural changes can be expected to give rise to in the form of new buildings or increased frequency of visits to green areas. This means that the other changes in the urban environment and its socio-economic effects form an important basis for understanding the full extent of the infrastructural changes on the long-term survival of species.

The number of species and habitats that may be affected in each infrastructure project can as a rule be expected to be very large. To focus the effect analyses on the changes with highest impact, choices must be made to limit the number of species and their habitats to something that is manageable but at the same time sufficiently representative of the landscape that is affected. There are, of course, several alternative ways of dealing with

the complexity of biodiversity. Within the framework of urban planning, however, it may be most relevant to start from a relatively small selection of species, or rather species groups, which are ecologically associated with some of the most characteristic or distinctive habitat types that occur in the landscape in question. The habitat types selected for analyzes should be common in the landscape and may thus be designated as "responsible environments" for the region. This means environments that the region has a national or global responsibility to safeguard.

Another important criterion that should form the basis for the choice of habitats to analyze is the species' sensitivity to infrastructural changes. This means that one primarily chooses to analyze species where roads and railways have been shown to have barrier effects in the landscape or those that have been shown to be sensitive to increased traffic volumes through increased mortality or increased noise disturbance.

Finally, when planning, it is important to understand the project's impact on both protected species and protected areas. This is especially important in the early stages of investigation so that unauthorized damage to the natural environment can be avoided completely or protective measures can be taken early to avoid a negative impact.
From the social-ecological perspective, it is important to understand the extent to which the planned infrastructural changes may affect people's opportunities to utilize the landscape's natural environments both in terms of utilization of renewable natural resources and for recreation and utilization of pure experience values. In this perspective, people are put in focus and what needs to be analyzed are the direct and indirect effects that the infrastructural changes can be expected to have on people's use of various ecological functions. It may be that the infrastructure provides increased accessibility to existing green areas so that more people can appreciate the biodiversity that has existed there as a rather underused resource.

To be able to evaluate a landscape's sensitivity and potential from the social-ecological perspective, one first needs to create a picture of what ecological functions the landscape's habitats currently offer. In addition, knowledge is needed about how people value the ecosystem services that existing functions offer or could offer if they could start being used. What effects a certain infrastructure project can be expected to be analyzed by combining analysis results from both the ecological perspective (expected impact on habitats, species and habitats) with information about people's movement patterns, which has a direct impact on ecosystem services' availability and possible use in the future.

4. METHOD

To systematically organize the series of analyses proposed in the method for 'Integrated effect analysis of infrastructure transformations in urban environments', a workflow is developed divided in three main steps:

1. inventory of the character of the built environment
2. analysis of the functioning of the built environment
3. effect analysis of proposed infrastructure transformations (before-after analysis) as well as description of societal consequences (figure 7).

The first two describe the existing situation, while the third involves before-after analysis including direct, indirect and cumulative effects and societal consequences. Each step includes three inquiries (socioeconomic, cultural-historical and ecological) that when combined, allow for an integrated social-ecological assessment of infrastructure transformations[2]. Three checkpoints are included in the workflow where important decisions are made for the continuation of the work. These checkpoints require a holistic approach where the different perspectives are combined, and various stakeholder perspectives are involved. How many persons will be involved in these discussions will depend on the project size and budget. Larger complex projects with more budget will involve different experts with deep knowledge on the socioeconomic, ecological and cultural-historical perspective respectively, and representatives for the national transportation authority, the municipality, other stakeholders and the public concerned.

STEP 1. Inventory of the character of the built environment

The first step in the workflow aims at describing the character of the built environment from the socioeconomic, ecological and cultural-historical perspective, and the values associated with it. This includes an initial description of the built environment using simple analog mapping. It also includes a description of who uses the built environment (both people and other species), including their abilities, preferences and needs. Many of the inquiries described in the ILKA methodology as well as the report 'Lär känna din ort' (Boverket 2006) can be used here including site visits, description of the character of the built environment, an inventory of planned urban development projects (to include future land uses) and relevant trends (e.g. natural processes, demographic changes). In this step, expertise of the local conditions is crucial, hence it should preferably be conducted in close collaboration between the Swedish Transport Authority, its consultants, the municipality (or municipalities) that will be affected by the infrastructure project and other relevant stakeholders.

2. See checklist in the Appendix

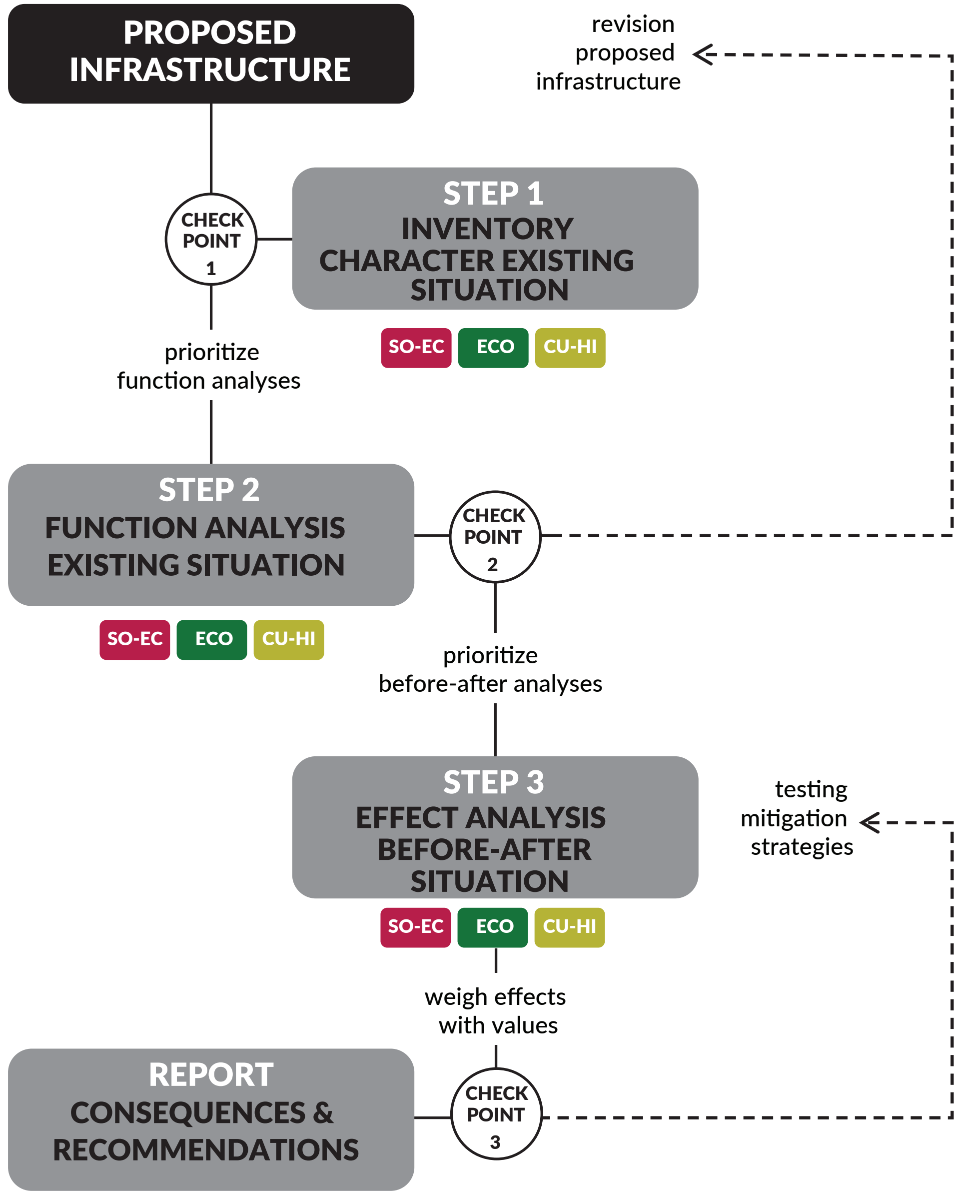


Figure 7.
General workflow of the 'Integrated effect analysis of infrastructure transformations in urban environments.

METHOD. STEP 1. INVENTORY OF THE CHARACTER

The **first checkpoint** involves the joint identification of sensitivities and opportunities in the built environment impacted by the planned infrastructure transformation. This can be juridical or policy-related but also sensitivities and opportunities identified by experts and stakeholders. The new infrastructure could for instance support the municipality to achieve certain objectives or could counteract them. More concretely, if the municipality has the objective to increase the number of children walking to school, analysis that focus on this should be done to check if and how the new infrastructure affects that objective. For similar reasons, protected species, habitats, buildings and areas with cultural-historic value should be identified and based on that, priorities can be made for the continued work.

Questions that could be discussed during the meeting(s) are for instance: Are there cultural-historical elements in the area that might be sensitive to changes caused by the infrastructure? Which species and natural environments are of special value in the area that might be negatively affected by the new infrastructure? Are there specific functions in the area, such as a primary school, that can become less accessible for specific groups because of the new infrastructure? It is crucial for the methodology and for the understanding of the area that this is done integral and not in separate meetings for different subject areas.

Equally important is to make an inventory of opportunities created by the new infrastructure and need attention when planning and implementing the new infrastructure. The same questions that were posed to identify sensitivities, can be rephrased to identify opportunities: Can cultural-historical places be strengthened using the infrastructure project? Can the infrastructure create new habitats for species that are currently threatened in the area?

To identify sensitivities and opportunities, the 'layers approach' is applied to describe the character of the physical environment, consisting, in its simplest form, of three layers: the layer of substratum, the layer of the physical networks and the layer of occupation (Meyer et al. 2020). The layers approach assumes that the substratum physically transforms slower than the networks, which in turn transforms at a lower rate than the occupation layer (see Figure 8). The first layer defines the conditions for the next which should be considered in urban planning. The occupation layer can further be divided in five sub-layers with varying dynamic including, from slow to fast: the layer of landownership, the layer of public space, the layer of buildings, the layer of use and the layer of users. This results in seven layers to characterize an area, where each can be described from the socioeconomic, ecological and cultural-historical perspective respectively and for each one, sensitivities and opportunities can be identified.

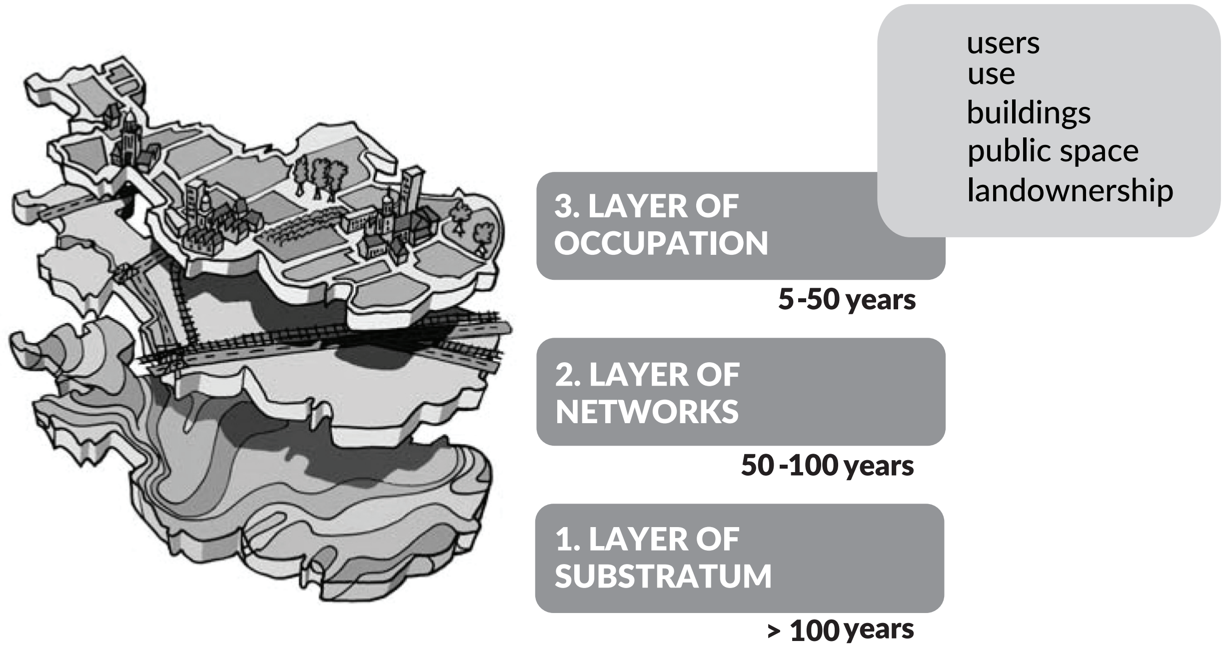
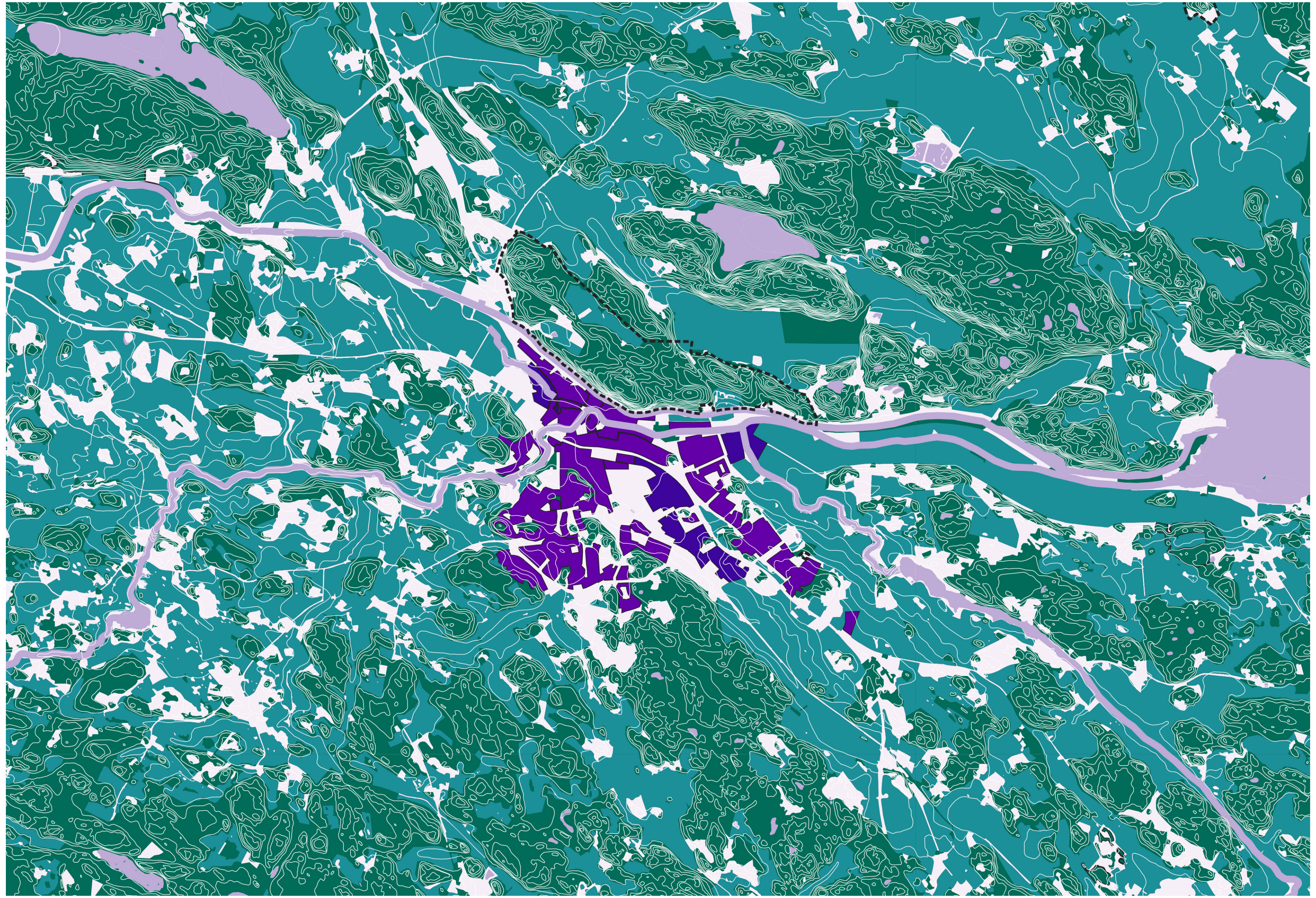


Figure 8.
Dynamics in the layers approach in schematic form (based on image by H2Ruimte and beeldleveranciers.nl, 2009).

	LAYER	DESCRIPTION OF LAYER	QUESTIONS (INPUT FOR STEP 2)		
			SOCIO-ECONOMIC	CULTURAL - HISTORIC	ECOLOGICAL
1	SUBSTRATUM				
2	NETWORKS				
3A	LAND OWNERSHIP				
3B	PUBLIC SPACE				
3C	BUILDINGS				
3D	USE				
3E	USERS				

Table 1.
Overview of questions related to the different layers used as input in step 2 of the workflow.

METHOD. STEP 1. INVENTORY OF THE CHARACTER



Three layers to describe the character of the built environment

1. The **layer of substratum** describes both the two- and three-dimensional quality of the surface (land cover and topography). Land cover information is important to characterize the built environment and in combination with topography, it constitutes the conditions for species survival and reproduction, flood risks and urban development in general. Topography and land cover also often constituted the conditions in the past and are therefore important for the understanding of the built environment from a cultural-historical perspective.

2. The **layer of networks** includes both road and rail infrastructure and is key to understand accessibility and centrality. Many urban processes depend on movement of people, structured by the layer of networks. Processes that to a large extend depend on this are for example local markets (restaurants, retail) and social encounters and integration. The role of a street today can differ much from its role in the past. If the street as entity is kept but not its role in the street network, the historical street becomes a static piece of history in contrast with a living piece of history. In ecological terms, the layer of the network includes the habitat network that species use to move between habitat patches. From a cultural-historical perspective, the urban fabric with its street and green structures also reflects the urban planning ideal of different times.

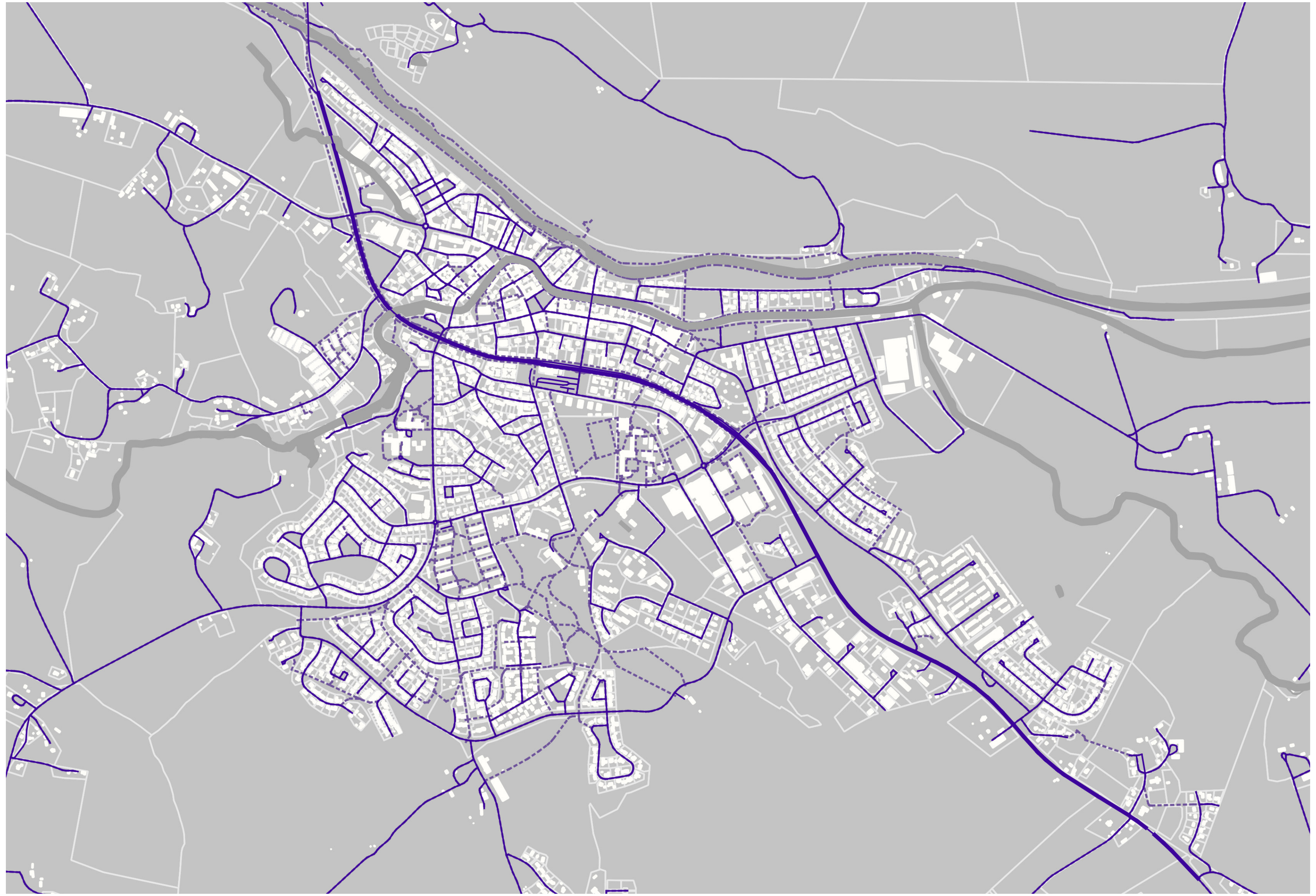
3. The **layer of occupation** includes the layers of landownership, public space, buildings, land uses and users and are described in detail below.

a. The **layer of landownership** separates public land from private land and thus impacts accessibility where public land is accessible for all while for private land accessibility is often restricted to few users. Furthermore, the division of land in plots (also called 'lots' or 'parcels') is important for the possibility to act and change the land because plots constitute a juridical unit of land that regulates its use. It is argued that the differentiation of land into plots supports the diversification in cities, both in terms of economic activities and biodiversity (Marcus 2001, Bobkova 2019).

Built-up land
Forest
Cultivation field
Water bed
Open field

Map 1.
Layer of substratum (land cover and topography), Söderköping

METHOD. STEP 1. INVENTORY OF THE CHARACTER



b. The **layer of public space** includes all land that is publicly accessible and includes streets, squares, and parks. public space give room for interacting with other people, protesting, socializing, and encountering difference. Therefore, public space is central to political and social life in cities. Public space often includes places that have been important for many years and make us aware of a common cultural and historical background. From an ecological perspective, public space is important because it is usually regulated and maintained collectively which can ensure that green structures exist and are preserved.

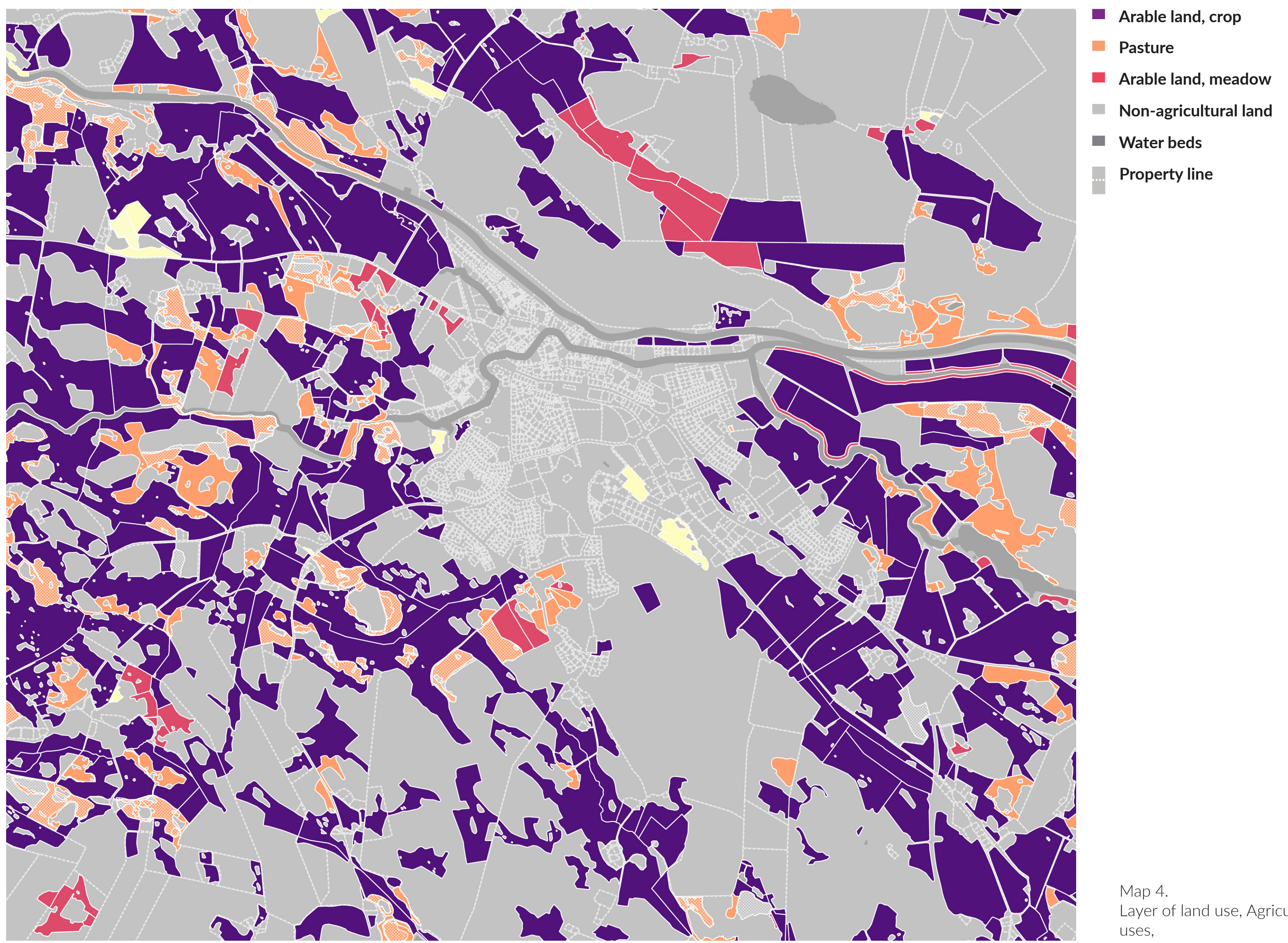
c. The **stock of buildings** allows us to use land more efficiently by stacking more floors on the same land surface. This creates variations in density. Buildings are also important as they characterize the area to a great extent, both through the height and size of buildings, which also creates conditions for its use (e.g. deep buildings are less useful for residential functions). From the cultural-historical perspective, buildings can function as landmarks and reference points in an area. Furthermore, buildings can also have an impact on species' ability to use cities and on how species can move through urban areas.

d. The **layer of land uses** describes the services in an area from public to commercial services and the main land uses (working, residential, recreation, etc) but also historical uses such as port areas, post-industrial areas, old production sites or traditional businesses, and trade, that often define area of cultural heritage. Also, the green and blue infrastructure is divided here by their specific uses such as arable land versus forest and different recreational uses.

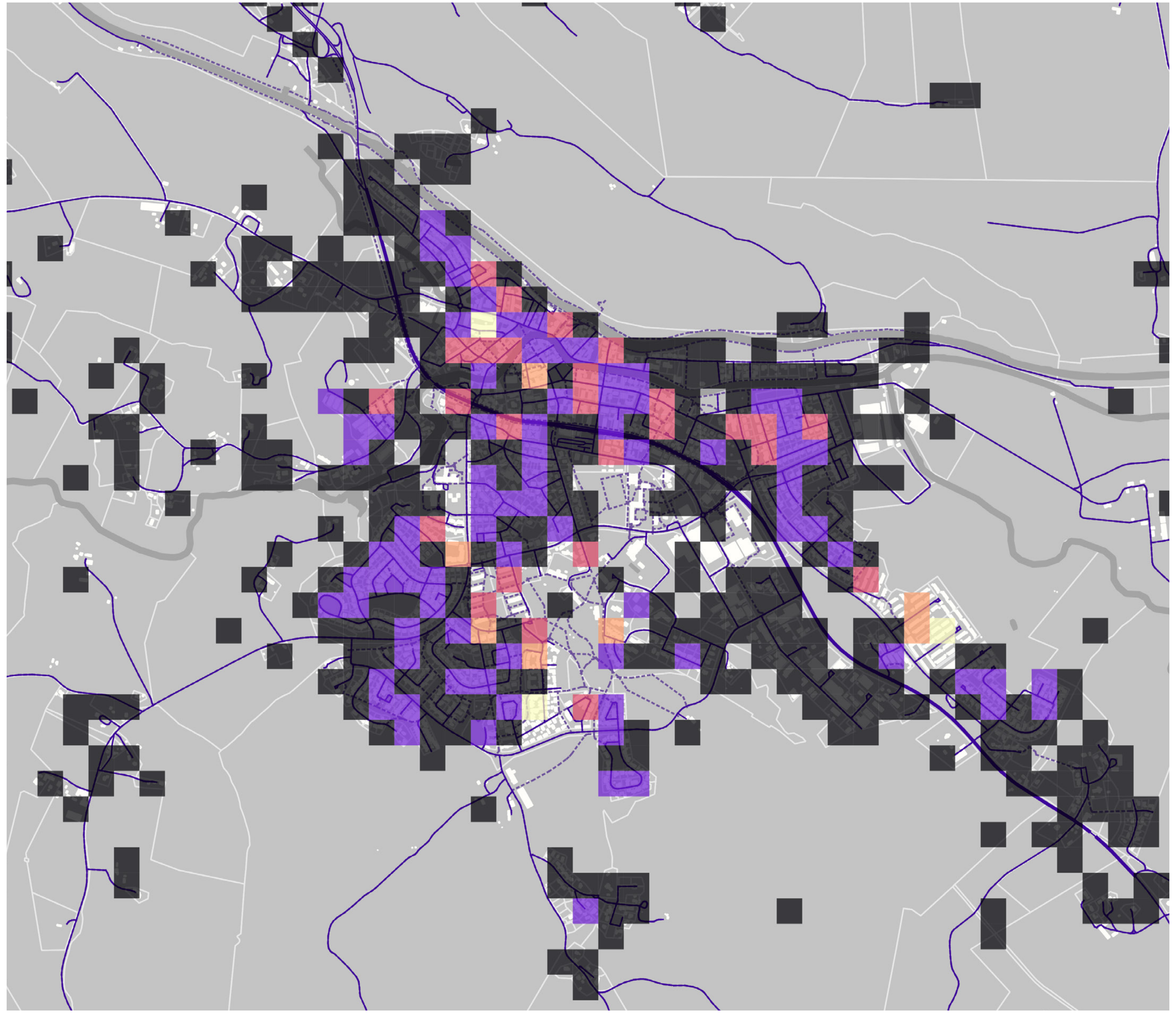
e. The **layer of users** that includes both the population and species and habitats that have a specific value in the region. Population can be further divided in demographic groups, ethnic groups and groups with different socioeconomic profiles. Species can be red-listed species, legally protected species but also species and environments with important values for the area affected by the infrastructure. Often, these so-called target species and habitats are already pointed out by the municipality or other public authorities.

Map 2.
Layer of networks,
layer of landownership and
stock of buildings, Söderköping

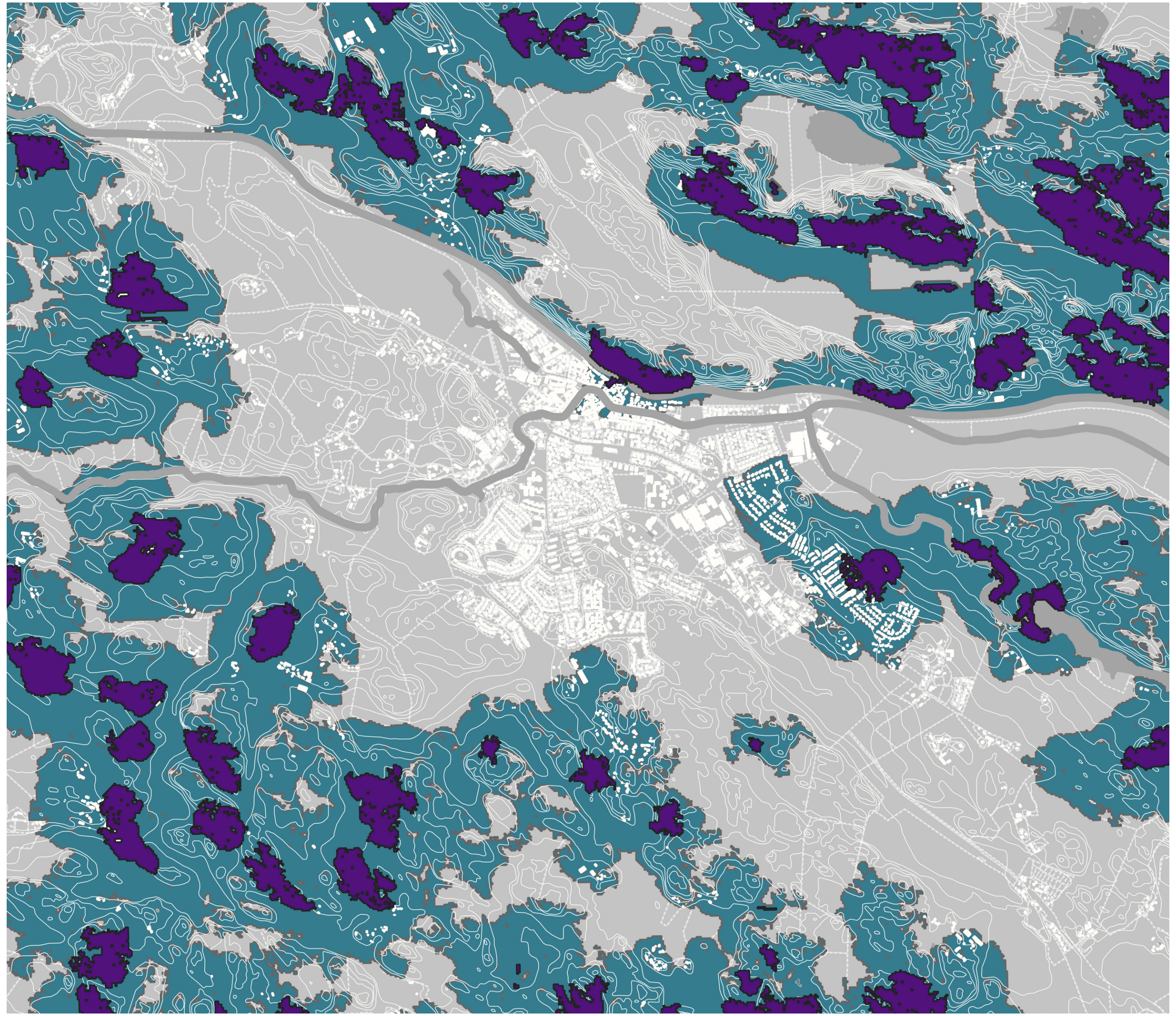
Map 3.
Layer of building uses,
Söderköping



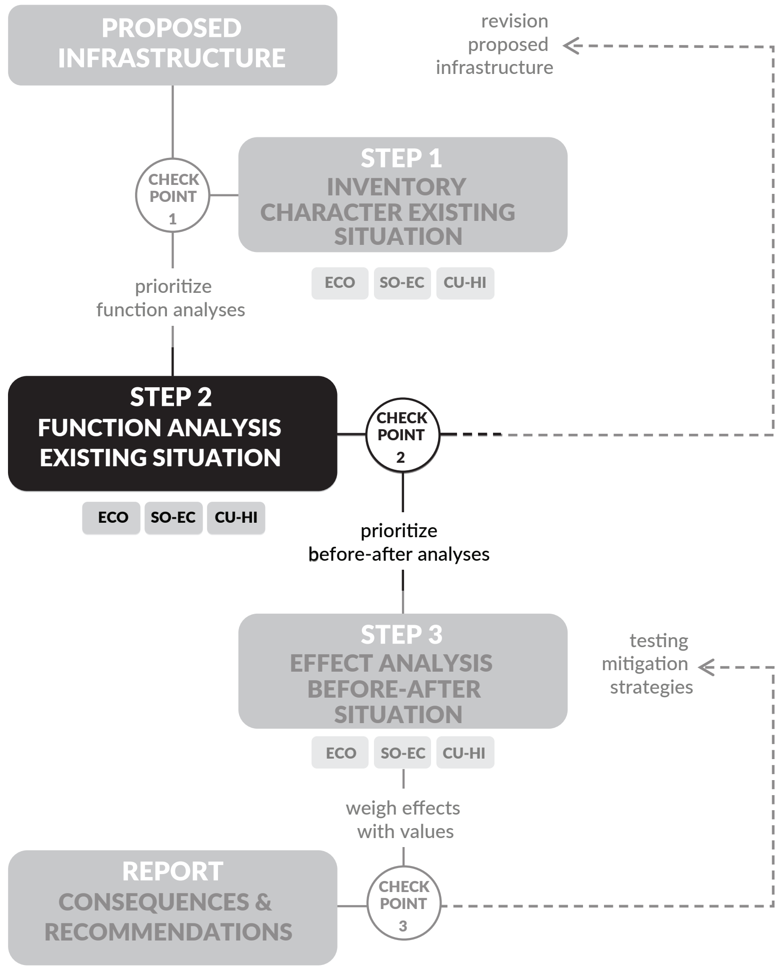
Map 4.
Layer of land use, Agricultural
uses,



Map 5.
Layer of users, Population,
Söderköping



Map 6.
Layer of users. Native species:
smooth snake, Coronella austriaca,
Söderköping



STEP 2. Analysis of the functioning of the built environment

The second step in the workflow focuses on how the built environment functions today and how it affects people, other species, natural habitats, ecosystems and cultural-historic resources. Like in step 1, this includes socioeconomic, ecological and cultural-historical analyses. An example of a socioeconomic function analysis is the proximity to elementary schools that inform us of how the street network and the location of elementary schools influence the functioning of the area. The distribution and demographic profile of people adds to this function analysis an estimation of the expected benefit. If very few families with children have a long distance to the elementary school the “problem” of lack of accessibility is less severe than if many families would be affected.

The questions identified during step 1 are the base for the function analysis. During the first checkpoint, each question is translated in an analysis that can provide information of how the area functions in relation to that question.

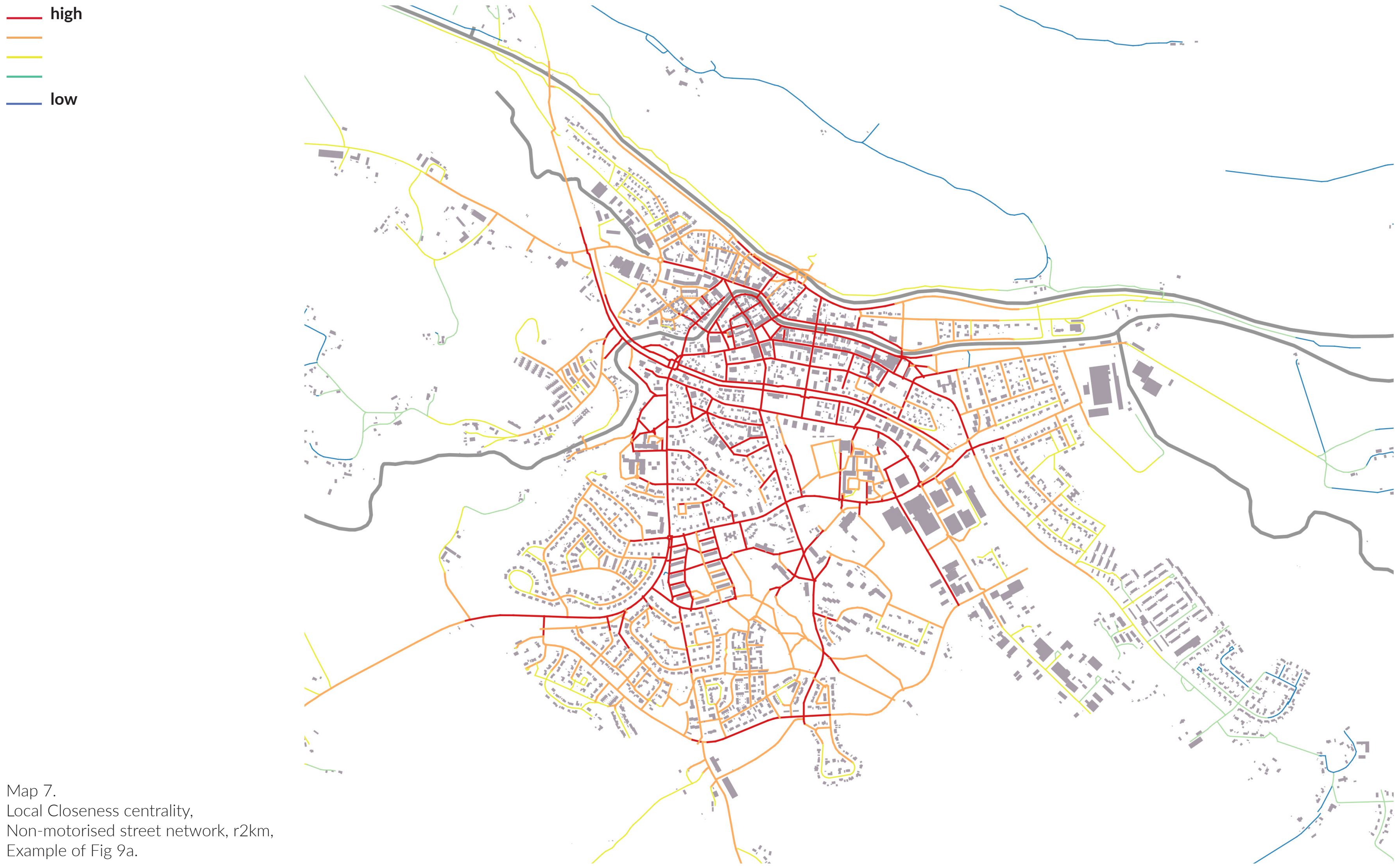
Four main groups of function analyses are identified that play an important role for sustainable urban development in relation to the three perspectives central to the methodology. The analyses are ordered according to their geographic scales of impact starting with network centrality analyses to identify the impacts of the infrastructure transformations on the whole street network. Centrality of streets is related to movement patterns of people and affects not only the number of people we meet in public space, but also who we meet. This, in turn, influences social integration and the concentration of economic activities[3].

The second group of analyses involves accessibility analyses and includes the proximity to services including commercial and public services, parks and cultural-historical resources. Further, it entails which services can be reached within a certain distance threshold in terms of both density (number of a specific function that can be reached) and diversity (number of different functions can be reached).

The third group covers connectivity and includes analyses disclosing how well habitats are connected to form functioning ecosystems. Also, it involves cultural-historical analyses that reveal functional and visual connections that are of great importance for the readability of the urban environment’s historical development.

The fourth group describes exposure in the direct surroundings of the infrastructure and include effects of this proximity such as noise pollution, but also the loss or deterioration of buildings, functions or habitats.

3. In Appendix 2, an overview of references can be found that support the choice of the analyses included in the methodology.



Map 7.
Local Closeness centrality,
Non-motorised street network, r2km,
Example of Fig 9a.

Four groups of analyses to describe the functioning of the built environment

1. Centrality analysis (figure 9) considers each street from the perspective of the whole system to understand its position (i.e. centrality) in this system. Centrality is important because it is a key factor for pedestrian movement patterns in cities (e.g. Hillier & Iida, 2005; Hillier et al., 1993; Peponis et al., 1997, Stavroulaki et al. 2019). This, in turn, is decisive for many other urban processes such as the concentration of economic activities (Scoppa et al. 2015, Bobkova et al. 2019) but also housing prices (e.g. Marcus et al. 2019, Law et al. 2017) and segregation (e.g. Legeby et al. 2015, Legeby 2013, Hanson 2000). Centrality analyses can, in combination with the location of cultural-historical functions, reveal how people today perceive these functions, which can be compared to the historic situation (e.g. Psarra 2018, Koch et al. 2019) and with the future situation with a modified infrastructure. For buildings, the position of the entrances in relation to centrality is important, while for the city, the position of the historical high street in relation to centrality is important. Three measures of centrality are used[4]:

a. Closeness centrality measures the connectivity of each street with all other streets. Higher values indicate that the street is spatially better integrated.

b. Betweenness centrality measures the role of the street when moving between areas. Higher values indicate the importance of that street as a path connecting different parts of the city. Both measures have great influence on the movement patterns in cities.

c. Attraction betweenness centrality weights betweenness centrality with the distribution of population or services to highlight the paths that are important for the connection of these services. For instance, a commercial street that is dependent on a high centrality, but should also be the logical path connecting retail and restaurants. Similarly, recreation paths can be identified using centrality in combination with green areas or cultural walks can be identified using centrality in combination with cultural-historical sites.

4. More references about the direct and indirect effects of network centrality to, for example, walkability, bikebility, segregation, economic activities, property values, safety and security, can be found in Appendix 2a.

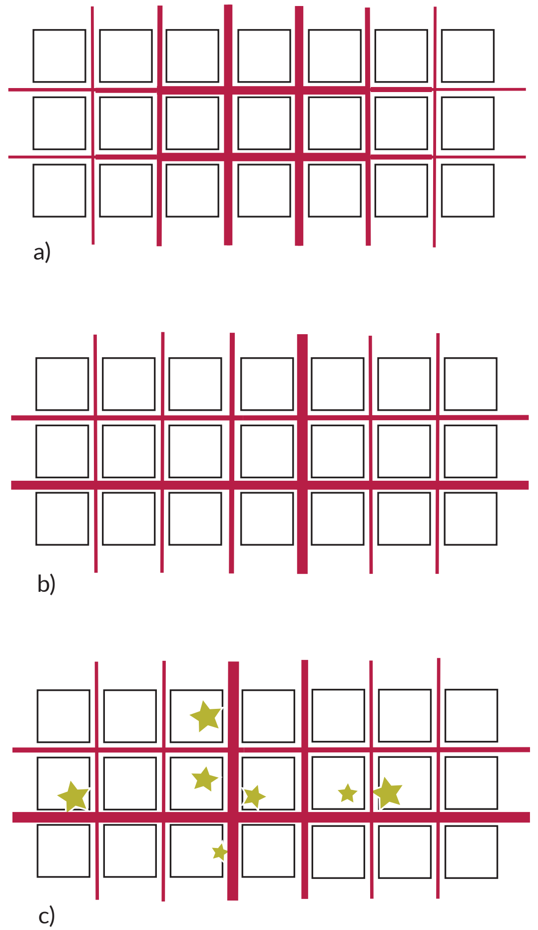
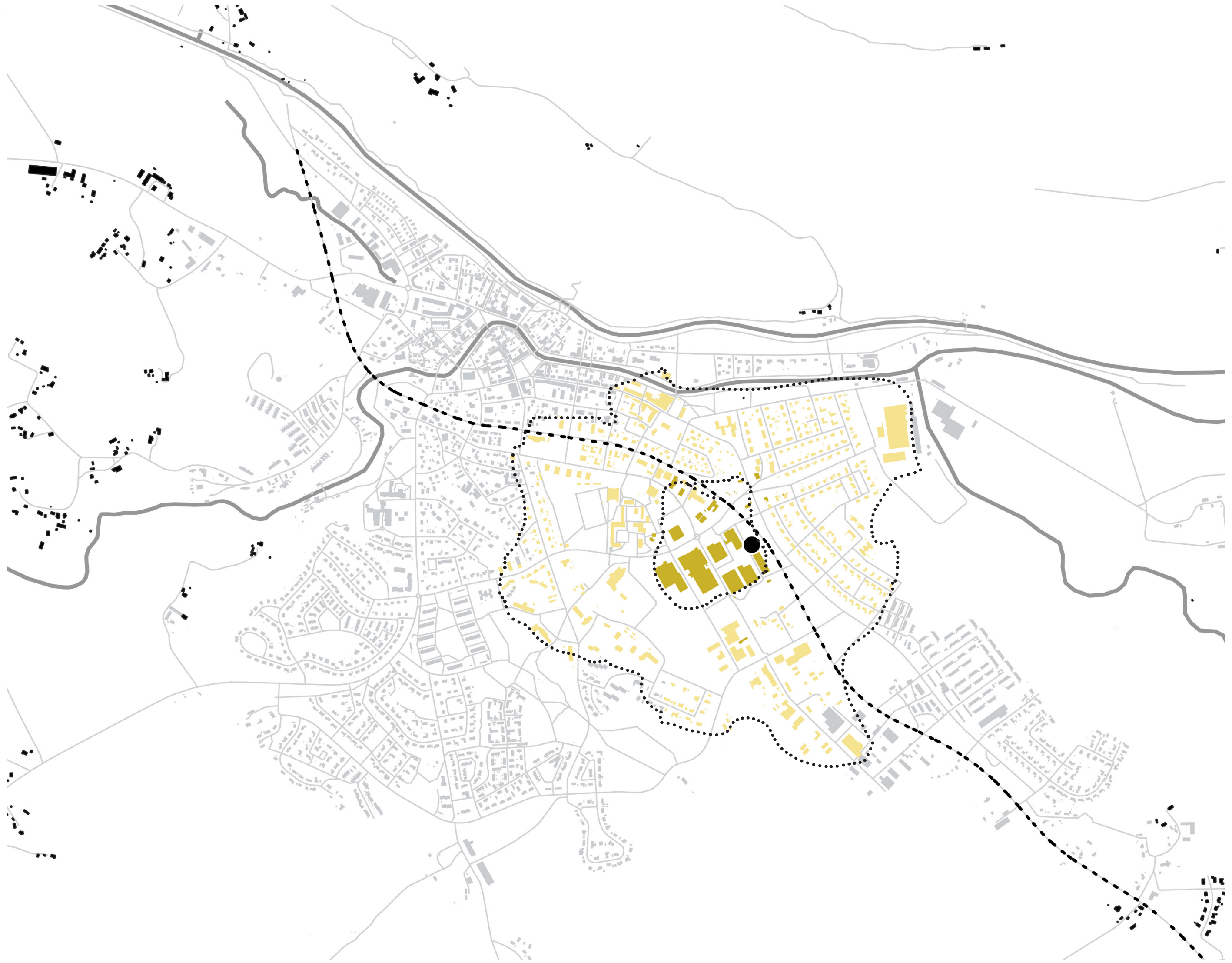


Figure 9.
Examples of centrality analyses:
a) Closeness centrality,
b) Betweenness centrality,
c) Attraction betweenness.



Map 8.
Catchment area of Dollar store (large retail) in 500m and 1km walk. Example of Fig 10a.

2. Accessibility analyses (figure 10) focus on the physical access of places in the urban environment. Accessibility has similarities with connectivity but in accessibility analyses, the access for people using the street network is in focus and not habitat connectivity nor functional connectivity from a cultural-historical perspective. What is included though is access to, for instance, parks and historical buildings. Three measures related to accessibility are used:

a. Proximity which can be measured as Euclidean distance (straight line between two points) or as network distance (walking distance), taking into account the actual street network that is used to reach the service. This analysis answers the question of how far it is to for instance the nearest primary school, park or bus stop. This is important, because we know that distance plays an important role for people's willingness and ability to access the service (e.g. Rodriguez-Lopez et al. 2017). If the bus stop is too far, less people will choose to walk to the bus and might choose to take the car instead (e.g. Yang et al. 2011).

Proximity can also be measured in respect to a specific service, attraction or point of interest, for example a retail store. It answers the question of how far are the different buildings, households, addresses etc from it. This measure highlights the service area that the given point of interest has in different distances (e.g. how many households are reached within 500m walking or 3 min cycling from the given retail store) and is also named **Catchment**.

b. Density within a distance threshold is another measure of accessibility that answers the question how many shops, park area or people one can reach within, for instance, 500 meter (any distance threshold can be used in the analysis). This is an important indicator for the customer base for stores (both local and regional scale) , but also for freedom of choice and equality in the distribution of functions in the urban environment as well as social integration (e.g. Lee and Moudon 2008, Jiao et al. 2012, Legeby et al. 2015).

c. Diversity provides information on how diverse the services or habitat types within the area are. Diversity in general is important because the different urban services or natural habitats complement each other and create resilience in the system[5].

5. More references about the direct and indirect effects of accessibility to, for example, walkability, bikebility and active travel, liveability, spatial inequalities and willingness to pay, can be found in Appendix 2a.

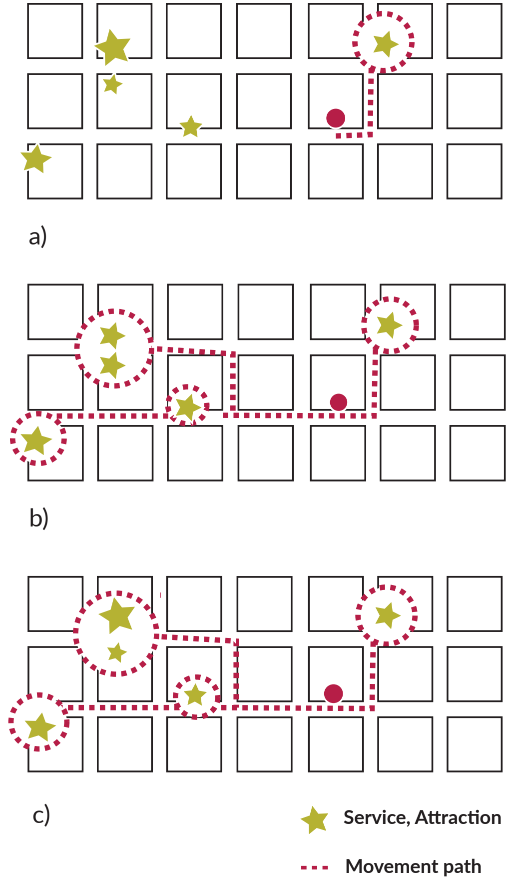
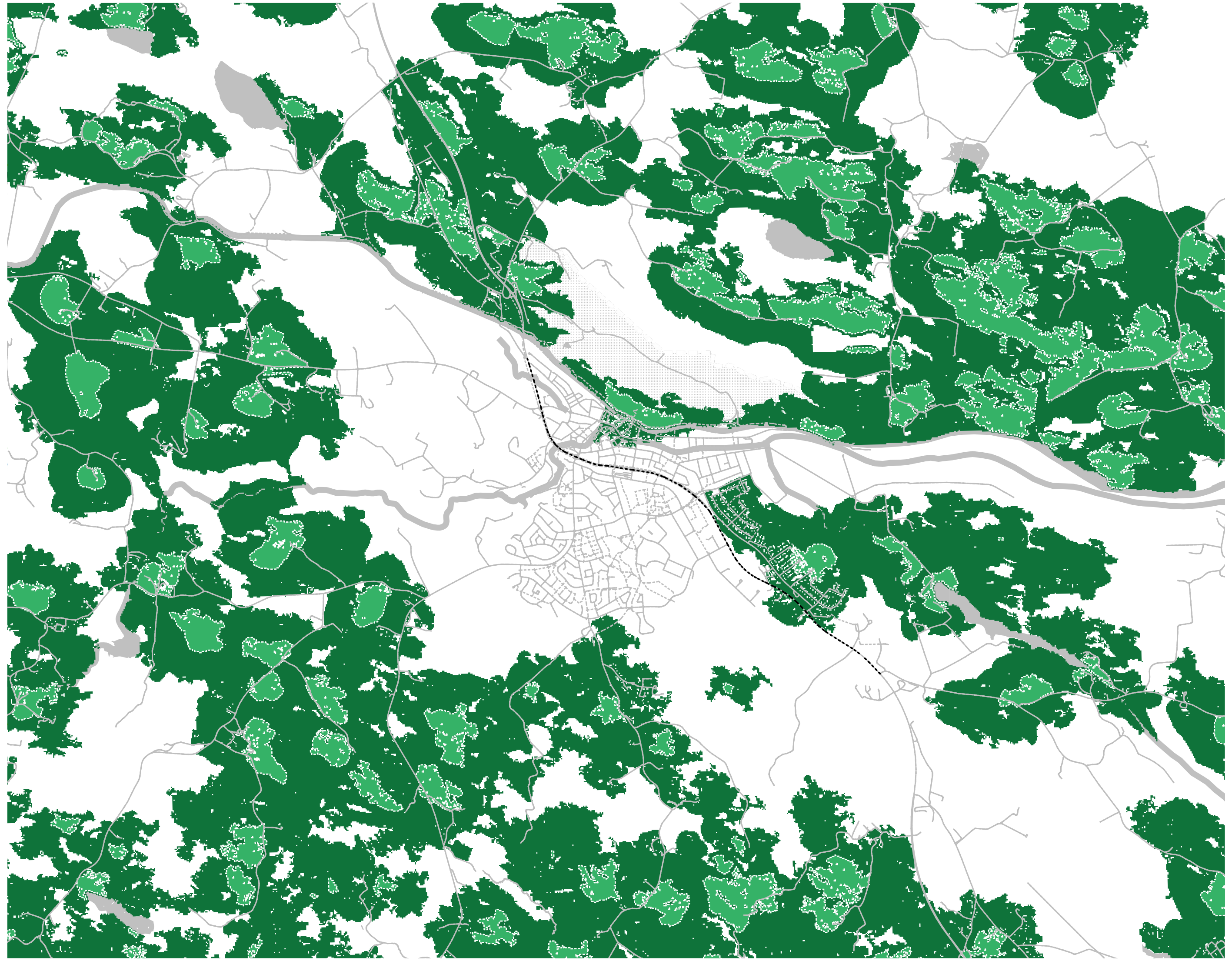


Figure 10.
Examples of accessibility analyses:
a) distance from the red dot to the nearest service (i.e. proximity analysis)
b) number of services reached within a distance threshold (i.e. density analysis)
c) number of different types of services reached within a distance threshold (i.e. diversity analysis)

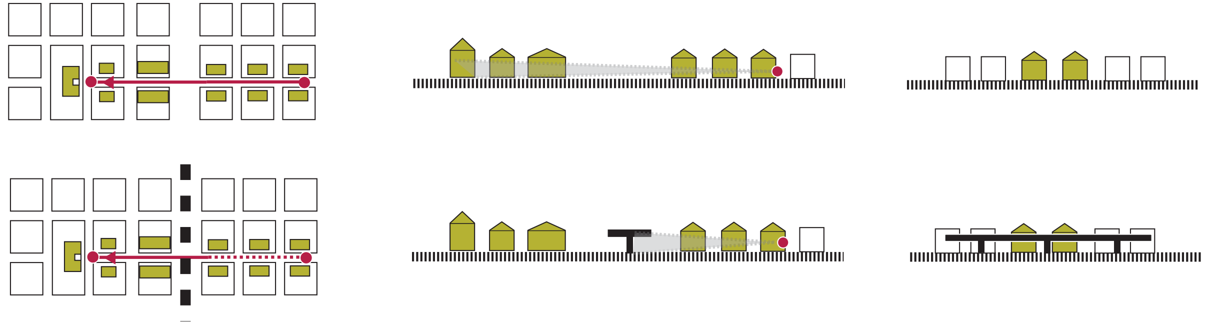


Map 9.
Habitat loss and fragmentation for the species smooth snake (hasselsnok in Swedish). Example of Fig11.

3. Connectivity analyses show how different parts of a system, be it ecosystems or historical urban environments, are connected and form a functioning whole.

a. Ecological connectivity (figure 11) identifies the functional habitat by analysing the dispersal potential between separate habitat fragments. This analysis varies for different species, because their habitats vary, but also their possibilities to move through the landscape in between existing habitat patches[6].

b. Physical and visual connectivity (figure 12) reveals functional and visual connections. From the cultural-historical perspective, such connections are of great importance for the readability of the urban environment's historical development (e.g. Psarra 2018, Koch et al. 2019). It is important to not only address 'what can be seen' or 'is it seen', but also 'how it is seen' in relation to the historic visual conditions.



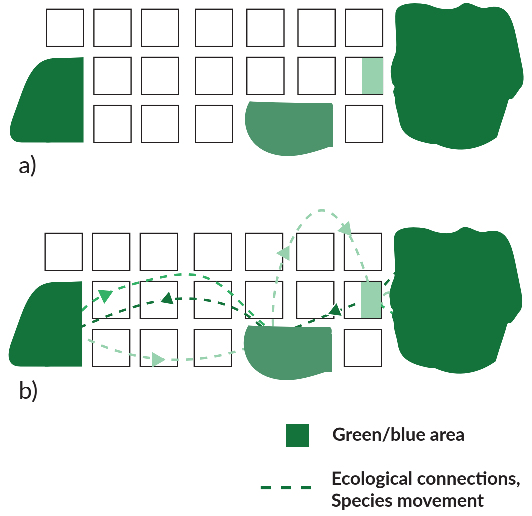


Figure 11 (right of page).
Examples of ecological connectivity with
a) the patches and
b) links between the patches creating metapatches.

Figure 12. (center of page)
Examples of visual and physical connectivity with the effects of a barrier presented on the map (on the left) and in sections (on the right). The dotted line represents a bridge that creates a visual barrier.

6. More references about the direct and indirect effects of habitat loss and fragmentation to, for example, species population, pollination, biodiversity and farm performance, can be found in Appendix 2b (for example, Potts et al. 2010; Spiesman & Inouye 2013, Fahrig 2003, 1997, Tamburini et al. 2019, Hanski 2011, Rotchés-Ribalta et al. 2018.)

METHOD. STEP 2. ANALYSIS OF THE FUNCTIONING OF THE BUILT ENVIRONMENT

Map 10.
Direct infrastructure exposure
residential buildings
Example of Fig13a

4. Infrastructure exposure (figure 13) analyses describe the impact of the infrastructure on buildings, public spaces, habitat patches or uses found in the direct surroundings of the infrastructure (direct exposure).

Functions that are very close to the infrastructure are at risk to disappear, while functions a bit further away can suffer from higher levels of air- and noise pollution (e.g. Miskinyte 2014, Margaritis and Kang 2016, Reijnen & Foppen 1994, Reijnen et al. 1995, Eriksson et al. 2013) light (e.g. Stone et al. 2015). and soil pollution (e.g. Li et al. 2015, Zhao et al. 2013, Sobhanardakani 2018) neglect of maintenance, but also direct species mortality as a result of road kills (e.g. Hels and Buchwald 2001, Ceia-Hasse et al. 2018). Besides such negative impacts, the closeness to infrastructure can also generate opportunities for densification or visual exposure (e.g. advertisement).

Closeness to infrastructure can also cause indirect effects through the measures that are taken to reduce a direct effect, for example, to reduce noise pollution, different types of noise measures are implemented in the form of planks, dikes or facade measures, which affect individual buildings and the built environment.

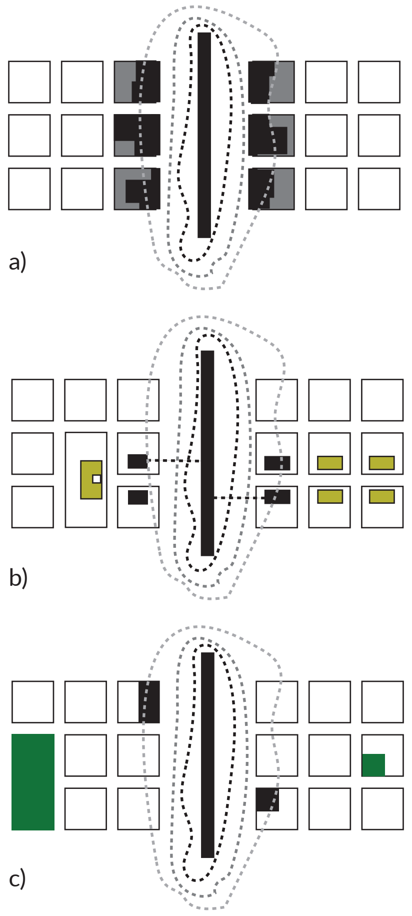
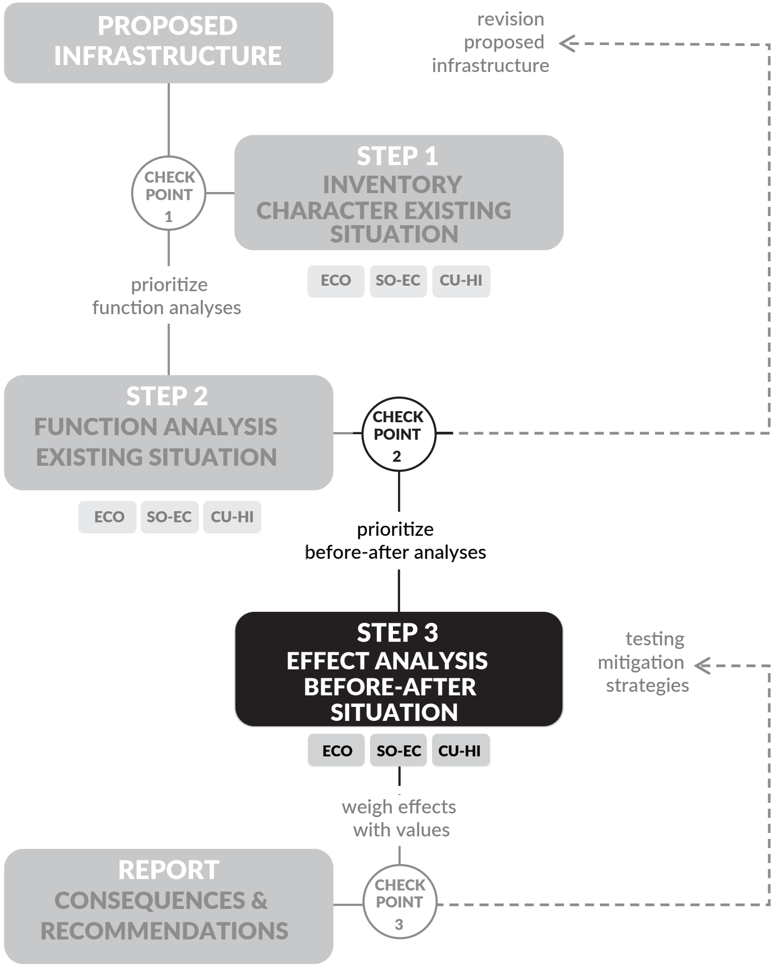


Figure 13.
Examples of infrastructure exposure from the three perspectives:
a) socioeconomic perspective, e.g. noise exposure near the infrastructure, b) cultural historic perspective, e.g. continuity of a historical axes is disturbed,
c) ecological perspective, e.g. disappearance of green patches.

METHOD. STEP 3. BEFORE-AFTER ANALYSIS TO REVEAL DIRECT AND INDIRECT EFFECTS



QUESTIONS (STEP 1)	DESCRIPTION OF ANALYSES (STEP 2)	EXPECTED SENSITIVITIES AND OPPORTUNITIES	RECOMMENDED BEFORE-AFTER ANALYSES (INPUT STEP 3)
QUESTION 1			
QUESTION 2			
QUESTION n			

Table 2.
Overview of the questions from step 1, the type of analysis that is conducted in step 2, description of sensitivities and opportunities and recommended before-after-analyses (input for step 3).

The **second checkpoint** involves the joint identification of sensitivities and opportunities in the functioning of the built environment related to the planned infrastructure transformation.

Thresholds are used to identify sensitivities and opportunities in the functioning of the area, where scores close to the threshold are identified as sensitive, while scores that are far above or below the threshold are either not sensitive, or there could be an opportunity to improve the situation. Based on that, choices can be made of prioritized before-after analyses that will be conducted in the next step. Function analyses that show high sensitivity must be included in the before-after analyses; function analyses that indicate opportunities are recommended to be included while functions with low sensitivity can be excluded from next steps of analyses. For instance, in the analysis of proximity to public transport, important thresholds for people's willingness to walk are 500, 700 and 900 meter depending on the building type and built density[7]. Above these thresholds, it is less probable that people will walk to the public transport stop, which affects the use of public transport negatively. Besides the decrease in walking and public transport ridership, this will also contribute to an increase in private motorised transport, which negatively impacts both climate change and public health. These thresholds are, if possible, based on empirical studies, but can also be based on local guidelines like in the example above or can be estimated based on expert knowledge[8].

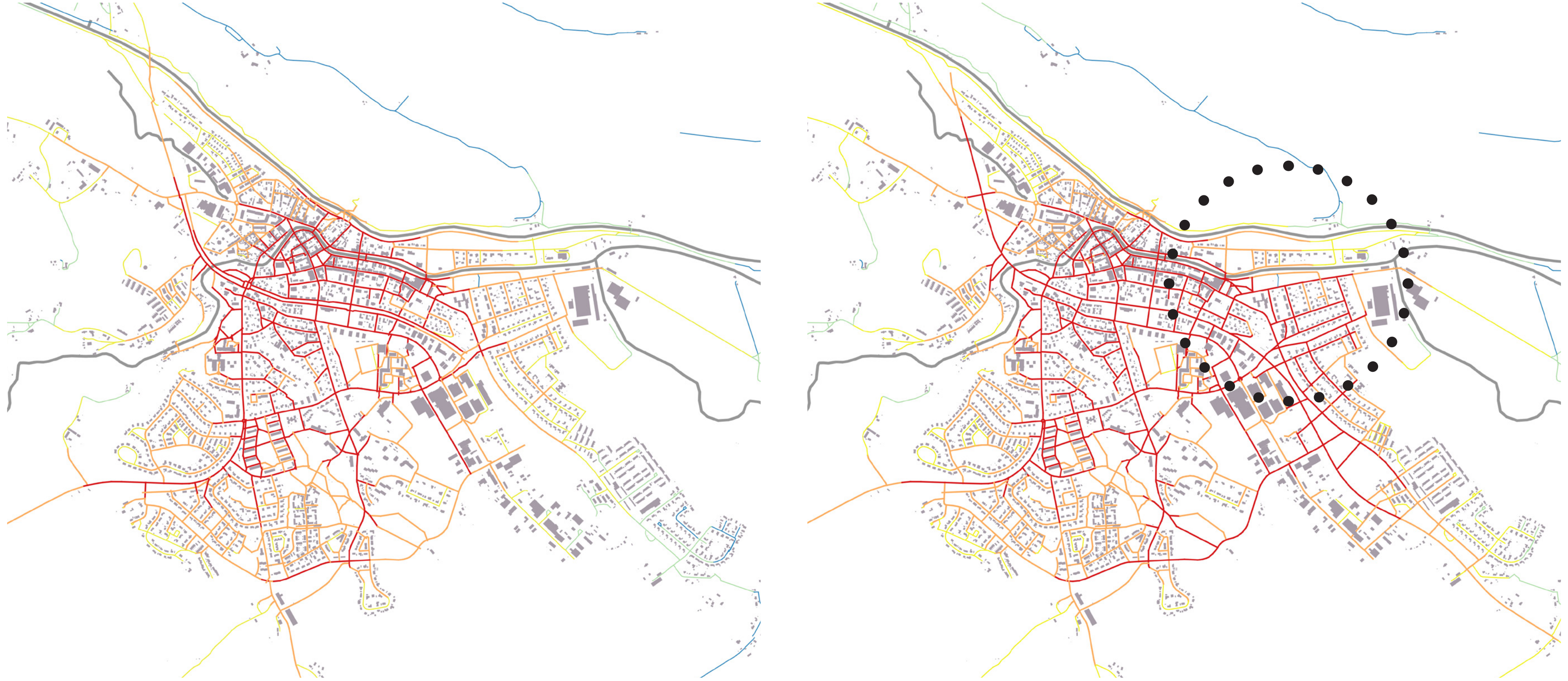
STEP 3. Before-after analysis to reveal direct and indirect effects

Before-after analysis is used to compare scenarios for the planned infrastructure with the current situation as benchmark. In this step, also the effectiveness of mitigation strategies, that are aiming to reduce expected negative effects of the new infrastructure, can be assessed. Like in step 1 and 2, this includes socioeconomic, ecological and cultural-historical analyses. The centrality analysis can for instance reveal that the current and historic high street that attracts a high flow of people and where many shops can be found loses centrality because of the new infrastructure. This change in centrality is the direct effect of the new infrastructure. Because of this direct effect, it is probable that less people will take this path which can impact the viability of the shops and change the long historical continuity of the street's function (all indirect effects).

The changes are described numerically, and all results are reported. However, the changes that are important for decision making should be significant changes. With a significant change (negative or positive), we mean that a change results in the exceeding of a threshold that is known to be important for the character or function. For instance, if the distance to the bus stop increases from 200 meter to 400 meter, the numerical change is 200 meter, yet we are still below the critical threshold of 500 meter. A 200 meter change would be considered significant, following the same example, if the distance to the bus stop increased from 400 to 600 meter. It is the same numerical change of 200 meter, but now the bus stop is more than 500 meter away.

7. Riktvärden för gångavstånd i Stockholm (https://www.sll.se/globalassets/2.-kollektivtrafik/kollektivtrafik-for-alla/riktlinjer-planering-av-kollektivtrafiken-i-stockholms-lansl-s-419761.pdf)

8. In the Appendix1, an overview of the type of assessment is given that can be based on numerical thresholds, relative thresholds, or qualitative assessments



high

low

Map 11.
Local Closeness centrality,
Non-motorised street network, r2km,
before (left) and after (right)
Affected area in dotted circle
Example of Fig14a.

The before-after analyses follow the same order as in step 2:

1. Change in centrality (figure 14) describes how changes in the street network related to the new infrastructure impact the whole network, because a new infrastructure not only affects the local accessibility because of a reduced number of crossings, but the centrality in the whole network. Centralities can shift as a result of the new infrastructure that can have repercussions far away from it. Changes in centrality affect movement patterns (Hillier and Iida 2005, Stavroulaki et al. 2019, Hillier at al. 1993) that, in turn, affect economic and social processes, e.g. concentration of economic activities (e.g. Scoppa et al 2015, Bobkova et al. 2019), segregation (e.g. Legeby et al. 2015, Legeby 2013) and housing prices (e.g. Marcus et al. 2019, Law et al. 2017). It can also affect the function of a place with cultural-historical value (e.g. Psarra 2018, Koch et al. 2019, Hanson 2000). The place might be preserved but its function might become obsolete because the flow of pedestrian movement is directed towards another part of the city.

These changes can be measured using the three centrality measures discussed earlier:

a. Change in closeness centrality

b. Change in betweenness centrality

c. Change in attraction betweenness

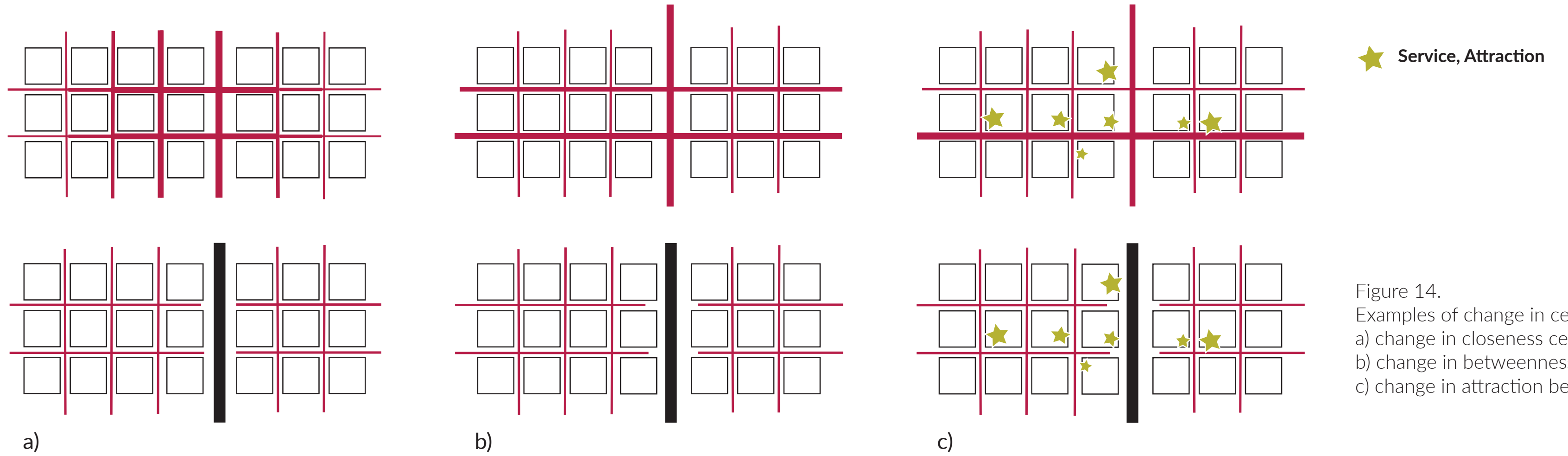


Figure 14.
Examples of change in centrality:
a) change in closeness centrality,
b) change in betweenness centrality,
c) change in attraction betweenness

buildings within 500m walking distance

buildings within 1km walking distance

Map 12.
Catchment area of Dollar store (large retail) in 500m and 1km walk, before (left) and after (right)
Example of Fig15a.

2. Change in accessibility (figure 15) is the effect most often associated with barrier effects (e.g van Eldijk et al. 2020, 2022; van Eldijk 2020, Litman 2020, Heran 2011).

The infrastructure itself often generates higher accessibility on the regional and interurban scale, while it causes a decrease in local accessibility[9]. It is the latter that is in focus here, divided into:

a. Change in proximity to services (how far is it to various services and attractions?), including **changes in Catchment** of specific attractions or services .

b. Change in density within a distance threshold (how much of something can I reach, e.g. how many services can I reach in 500m walking?)

c. Change in diversity within a distance threshold (how many different things can I reach, e.g. how many different services can I reach in 500m walking?)

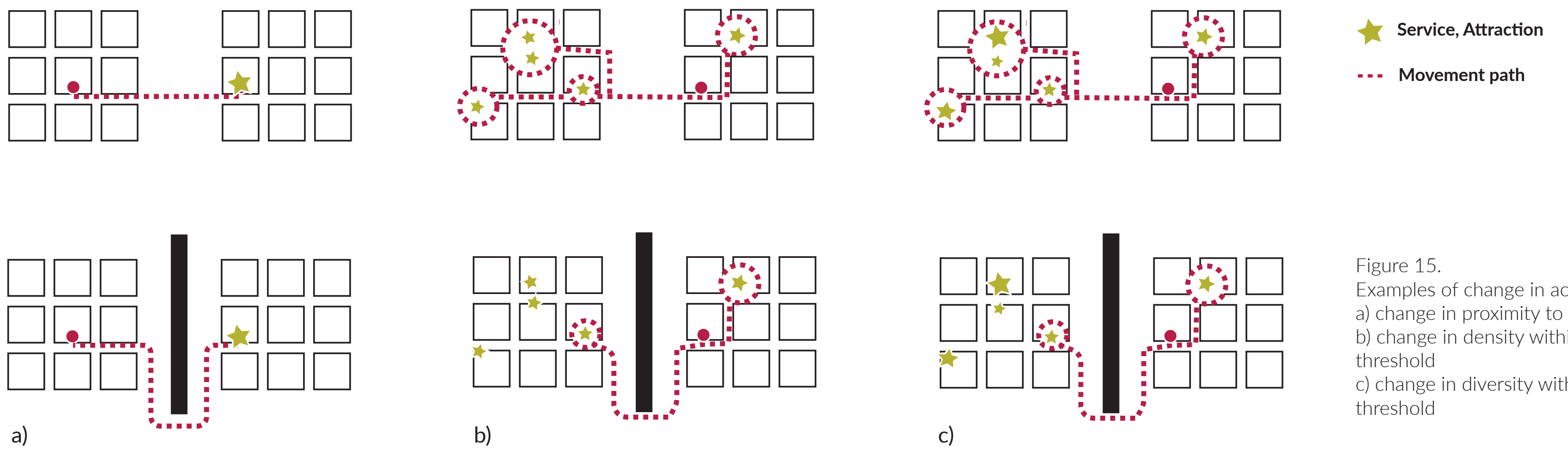


Figure 15.
Examples of change in accessibility:
a) change in proximity to services,
b) change in density within a distance threshold
c) change in diversity within a distance threshold

9. More references about the direct and indirect effects of accessibility to, for example, walkability, bikebility and active travel, liveability, spatial inequalities and willingness to pay, can be found in Appendix 2a.

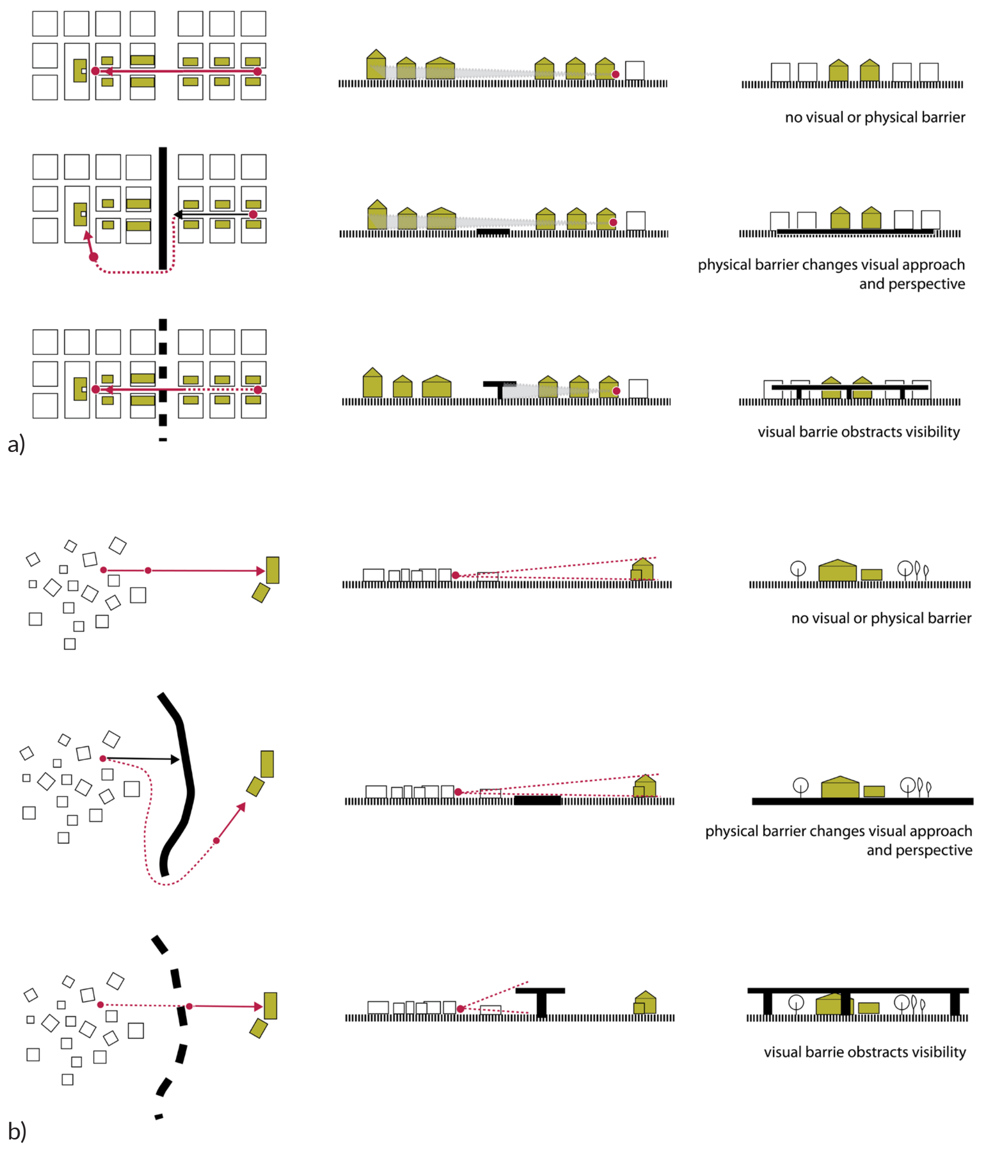


Figure 16.
Examples of fragmentation of cultural-historical ensembles in a a) more urban environment and b) rural environment

3. Change in connectivity describes the process where larger parts are divided in smaller ones because of a loss in connectivity (fragmentation) or, vice versa, where parts are added that support connectivity. New infrastructure often causes fragmentation of the urban or natural landscape, but this is not always the case such as in the case of retrofits where connections can be restored.

a. Fragmentation of cultural-historical ensembles (figure 16) can be caused by a loss of physical or visual connections. For instance, buildings or landscapes on the other side of the barrier are no longer visible or the approach of the building or landscape changes significantly because of the new infrastructure. For instance, a church is cut off from a residential neighbourhood as a result of a new railway. The church might still be accessible, because a tunnel is constructed to cross the railway, but the church is no longer visible when approaching it or the church is now approached from the side instead of the front. These changes can, from a cultural-historical perspective, be described as a significant negative changes.

b. Habitat fragmentation (figure 17) is the result of loss of green connectivity and affects the mobility of species that in turn affects population size which is important for the species' survival on the long-term (e.g. Potts et al. 2010; Fahrig 2003, Hanski 2011, Rotchés-Ribalta et al. 2018).

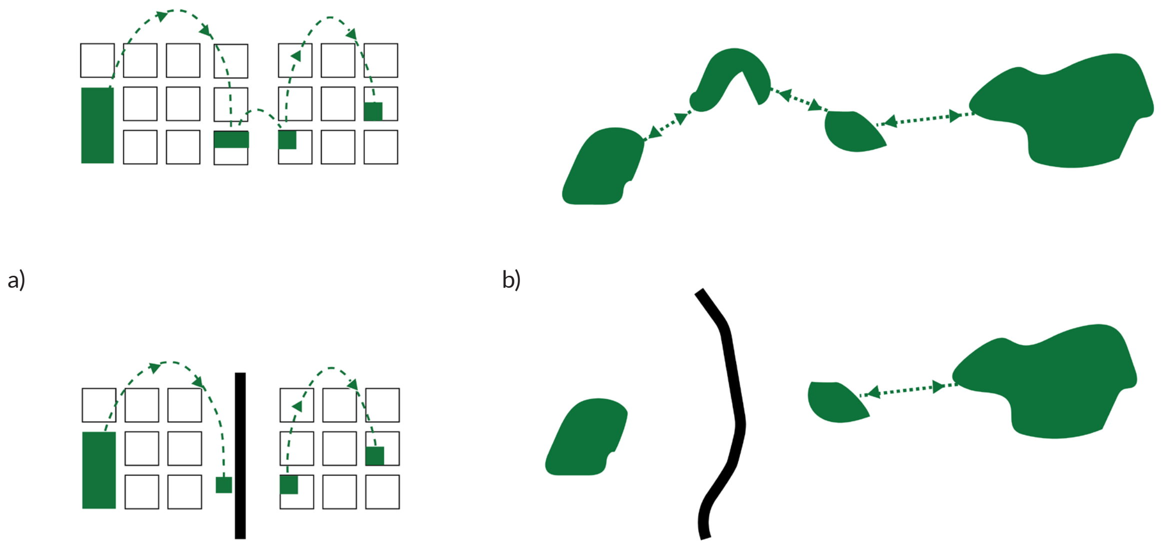
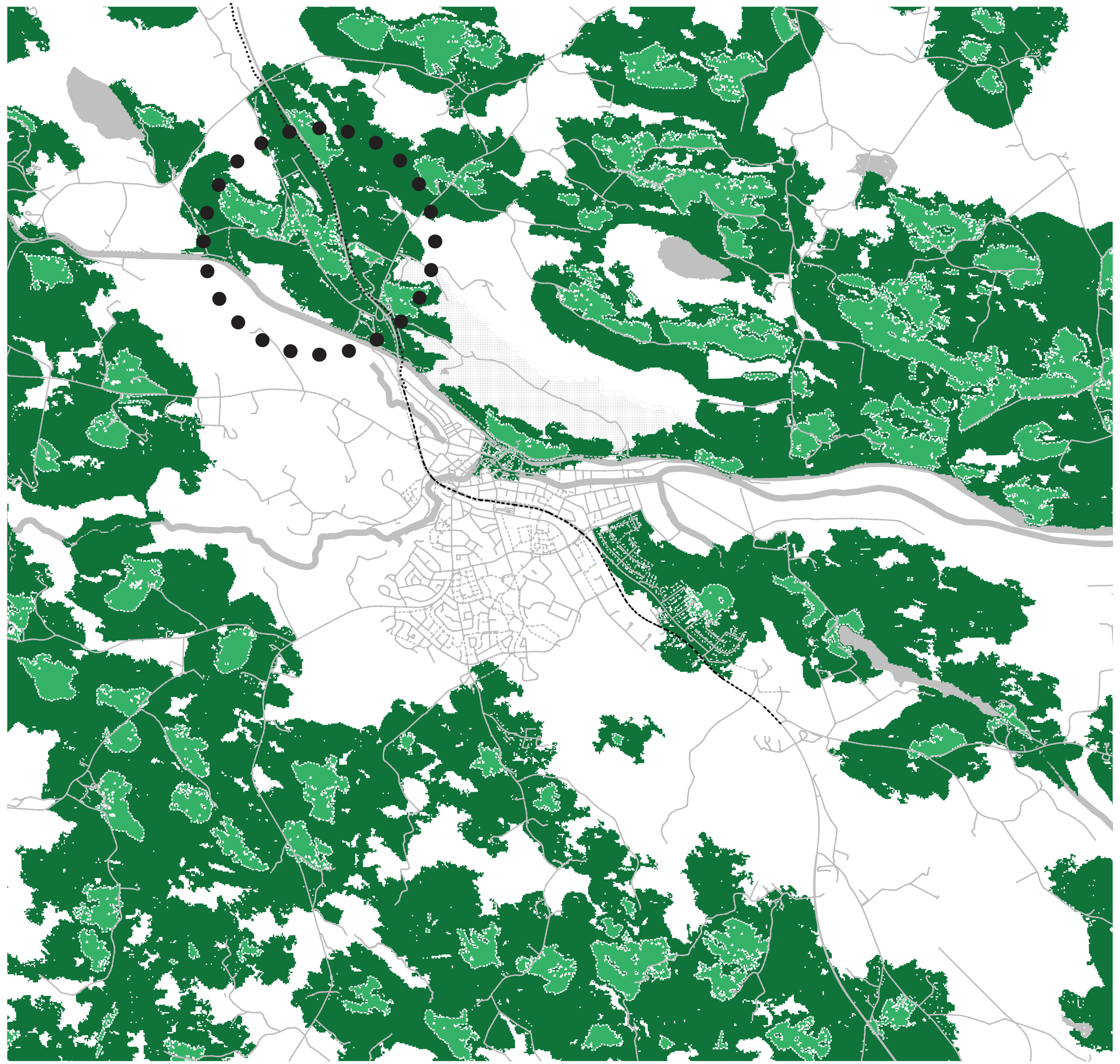


Figure 17.
Examples of habitat fragmentation in a) a more urban environment and b) a rural environment



habitat network

habitat patches

Map 13.
Habitat loss and fragmentation for the species smooth snake (hasselsnok in Swedish) before (left) and after (right). Affected areas in dotted circles. Example of Fig17b and Fig18c

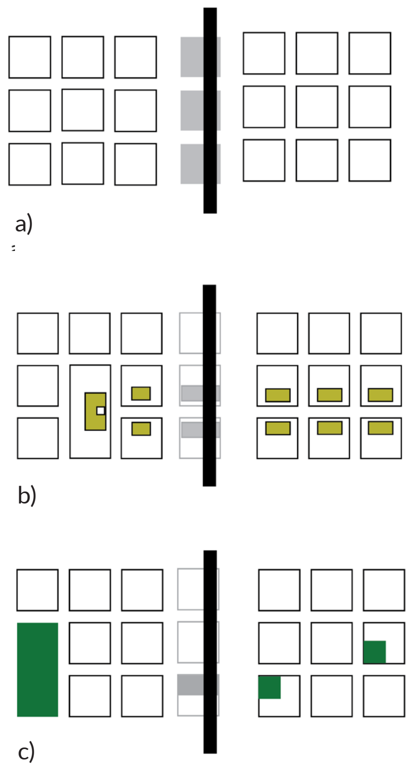


Figure 18.
Examples of changes in direct exposure:
a) loss of buildings,
b) loss of buildings with cultural-historical value, and
c) loss of green patches.

4. Changes in infrastructure exposure

- Direct gain/loss of buildings, land and/or habitat (figure 18).

The loss of buildings can be related to a loss of cultural-historical or social-economic values, dependent on the type of building. Furthermore, green patches can be lost and depending on the type of patch, this can cause a loss in patch diversity[10]. However, also the opposite can be the case. Very often new infrastructure is developed with new green patches along it. Furthermore, new infrastructure attracts investments that can transform existing buildings, change functions and can result in densification.

- Structural change (figure 19 and 20) means that the area changes to such an extend that its character is affected.

For instance a landscape that transforms from rural to urban or a neighbourhood where a new building type is added that structurally changes the original building type patterns. An example of the latter is the retrofitting of a national road into an urban boulevard which often also involves densification and introduction of new building types along the boulevard. Thus, new or modified infrastructure can provide opportunities to densify the land in vicinity to the infrastructure which can provide a socioeconomic benefit but a cultural-historic loss in case the densification project deviated from the historical patterns.

However, also the opposite can be the case. Very often new infrastructure is developed with new green patches along it. The new patches can be positive because they add new habitats, but they can also be negative when alien and not native species are introduced (e.g. Vakhlamova et al. 2016, Goodenough 2010, Kalwij et al. 2008). Furthermore, because of the proximity to infrastructure, these new patches can result in direct species mortality (e.g. Hels and Buchwald 2001, Ceia-Hasse et al. 2018).

10. More references about the direct and indirect effects of habitat diversity, can be found in Appendix 2b (for example, Kindvall 1996, Baldi 2007).

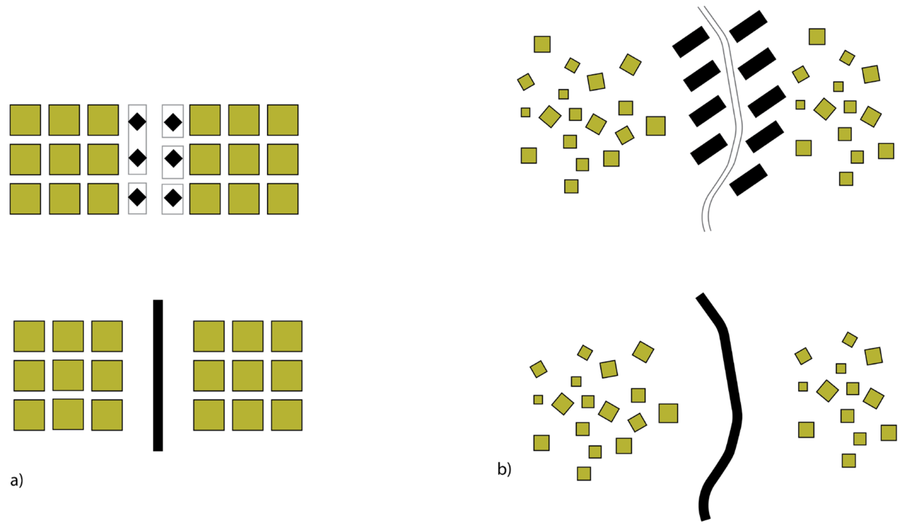


Figure 19.
Examples of structural change when the area near the infrastructure densifies with new building types that structurally changes the original building type patterns. This change can take place in a more urban environment (a) and a rural environment (b).

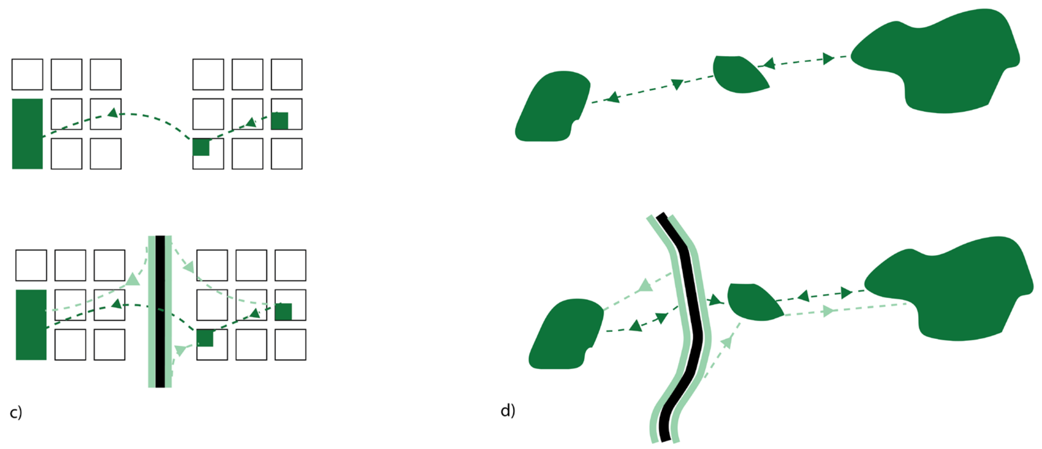


Figure 20.
Examples of structural change when new green patches are added near the infrastructure which can have both positive and negative effects dependent on the species added. This change can take place in in a more urban environment (a) and rural environment (b).

- - - highway E22

■ <100m

■ 100 to 500m

■ 500 to 1000m

■ >1000m

Map 14.
Direct infrastructure exposure
residential buildings before (left)
and after (right)
Example of Fig21a

- Change in disturbance (figure 21) describes the consequences in relation to noise-, light, air and soil pollution, and its effects on both people and other species (e.g. Miskinyte 2014, Margaritis and Kang 2016, Reijnen & Foppen 1994 Reijnen et al. 1995, Eriksson et al. 2013, Stone et al. 2015, Li et al. 2015, Zhao et al.,2013, Sobhanardakani, 2018). These disturbances can potentially also cause decay and neglect when it comes to buildings and public space.

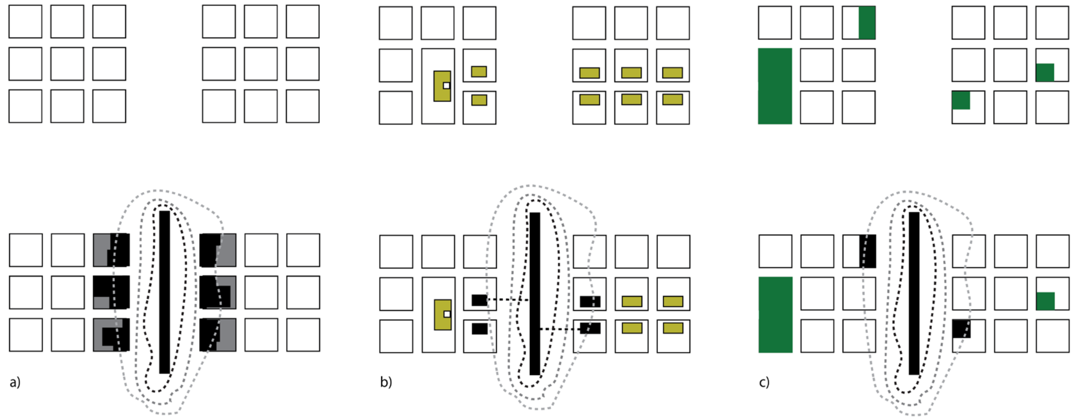


Figure 21.
Examples of change in disturbance from the three perspectives:
a) socioeconomic perspective, e.g. noise exposure near the infrastructure,
b) cultural historic perspective, e.g. continuity of a historical axes is disturbed,
c) ecological perspective, e.g. disappearance of green patches.

Societal consequences

The third checkpoint involves the joint identification of sensitivities and opportunities in the before-after analyses related to the planned infrastructure transformation. This involves also cumulative effects involving all three perspectives. For example, analyses of centrality can be combined with cultural-historical points of interest and provide a picture of how cultural-historical functions are affected. Next, consequences are described by weighing together the size of effects with the value of the environmental aspect that is assessed. The criteria for valuing the environmental aspects are not discussed in detail in this report though. These values can be identified through surveys with inhabitants or could be linked to national or local policies such as the sustainable development goals (SDG).

Based on the combined assessment of effects and values, mitigation strategies can be discussed to reduce possible negative consequences of the proposed infrastructure, which leads to a new iteration of step 3. When the proposal has been iterated a few times and a final proposal is defined, a report is written including an overview of the proposed infrastructure transformation, the societal consequences and recommended mitigation strategies.

Data requirements
For all steps, certain geospatial analysis must be done, requiring data. The MoSCoW method (Clegg and Barker 1994) will be used to prioritize analysis to be done and data needed to perform them. The term is an acronym derived from the first letter of each of four prioritization categories: M - Must have, S - Should have, C - Could have, W - Won't have. In the appendix a list with datasets and analyses can be found using this coding in relation to the steps in the workflow.

VALUE	**EFFECT**			
	GREAT NEGATIVE EFFECT	MODERATE NEGATIVE EFFECT	SMALL NEGATIVE EFFECT	POSITIVE EFFECT
HIGH VALUE	**HIGH CONSEQUENCE**	**HIGH CONSEQUENCE**	**MODERATE CONSEQUENCE**	**POSITIVE CONSEQUENCE**
MEDIUM VALUE	**HIGH CONSEQUENCE**	**MODERATE CONSEQUENCE**	**LITTLE CONSEQUENCE**	**POSITIVE CONSEQUENCE**
LOW VALUE	**MODERATE CONSEQUENCE**	**LITTLE CONSEQUENCE**	**LITTLE CONSEQUENCE**	**POSITIVE CONSEQUENCE**

Table 3.
Conceptual model to describe consequences

It is recommended to use available national databases or open access data to ensures data availability and comparability between projects. Furthermore, it is recommended to use the same datasets between different analyses, approaches and working groups. This does not only resource efficient but ensures better communication between working groups.

Visualization

The analyses results should be visualised in such a manner that opportunities and sensitivities are easy to detect on the maps that show the before and after situation. To distinguish these, the functioning of the areas today must be visualised where thresholds are used to identify and highlight problems. The same thresholds are used to visualise the situation with the new infrastructure. The analysis of the current situation gives insight of current problems, while the analysis of the new situation gives insight where problems are expected to occur tomorrow. To visualise the changes and especially to identify the significant changes, a third map should be made depicting the changes where five categories should be distinguished:

- No change

- Numerical insignificant change (negative or positive) that is a change without exceeding a given threshold. For instance when the distance to the nearest public transport stop increases from 200 meter to 400 meter, the numerical change is 200 meter, but we are still below the critical threshold of 500 meter, that we know from literature that if exceeded, the probability of people walking to the bus stop will decrease significantly.

- Significant change (negative or positive) that is a change when the given threshold is exceeded. In the example above, when the change of 200 meter creates a situation when the distance to the public transport stop increases from 400 to 600 meter, it is the same change of 200 meter but now the stop is more than 500 meter away.

5. PLANNING PROCESS FOR NATIONAL INFRASTRUCTURE PROJECTS

Planning process. Swedish Transport Administration.

The Swedish Transport Administration is mainly responsible for planning, design, construction and management of the state infrastructure. The authority is also responsible for developing long-term goals and plans for developing the transport system in general, including also transport infrastructure that is owned and managed by other public authorities. This primarily applies to municipal and regional roads and transport systems, such as public transport and cycle paths. At the Swedish Transport Administration, the work is divided into different departments that have different responsibilities. In summary, it can be described as follows: 'Strategic development' is responsible for the strategic long-term work; 'Planning' investigates and plans the development and upgrading of the state transport infrastructure, based on directives from the government; 'Investment' and 'Large projects' plans, designs and builds while 'Maintenance' manages the state transport infrastructure.

In short, the planning process of an infrastructure project at the Swedish Transport Administration can be described as follows. Based on recognized needs that can either be identified by the Swedish Planning Administration themselves (*behovsanalys*, see Figure 22) or by third parties (e.g. regions, municipalities), a deficiency analysis (*bristanalys* in Swedish) is started to investigate, based on these needs, problems with the current infrastructure. In case serious deficiencies are identified, alternative scenarios are investigated (*åtgärdsvalstudier* in Swedish) that can result in a decision that no transformations are needed or that changes are required. If a need for transformation is identified, an order will be placed by the Planning department from which point 'Investment' takes over. Based on this order, a project is started, and the infrastructure will be planned and designed in detail, while also conducting a series of analysis to assess the impact of the project. These analyses involve mainly ecological and cultural-historical values but can also include social impact assessments, such as an assessment on the impact of the infrastructure on children (*barnkonsekvensanalys*). Two groups of analyses can be distinguished in this phase. First, inventories (project analysis) and second, impact assessments. In this phase, mitigation strategies are often developed to reduce negative impact of new or modified infrastructure. After the design phase and the construction, the infrastructure is handed over from 'Investment' to 'Maintenance'.

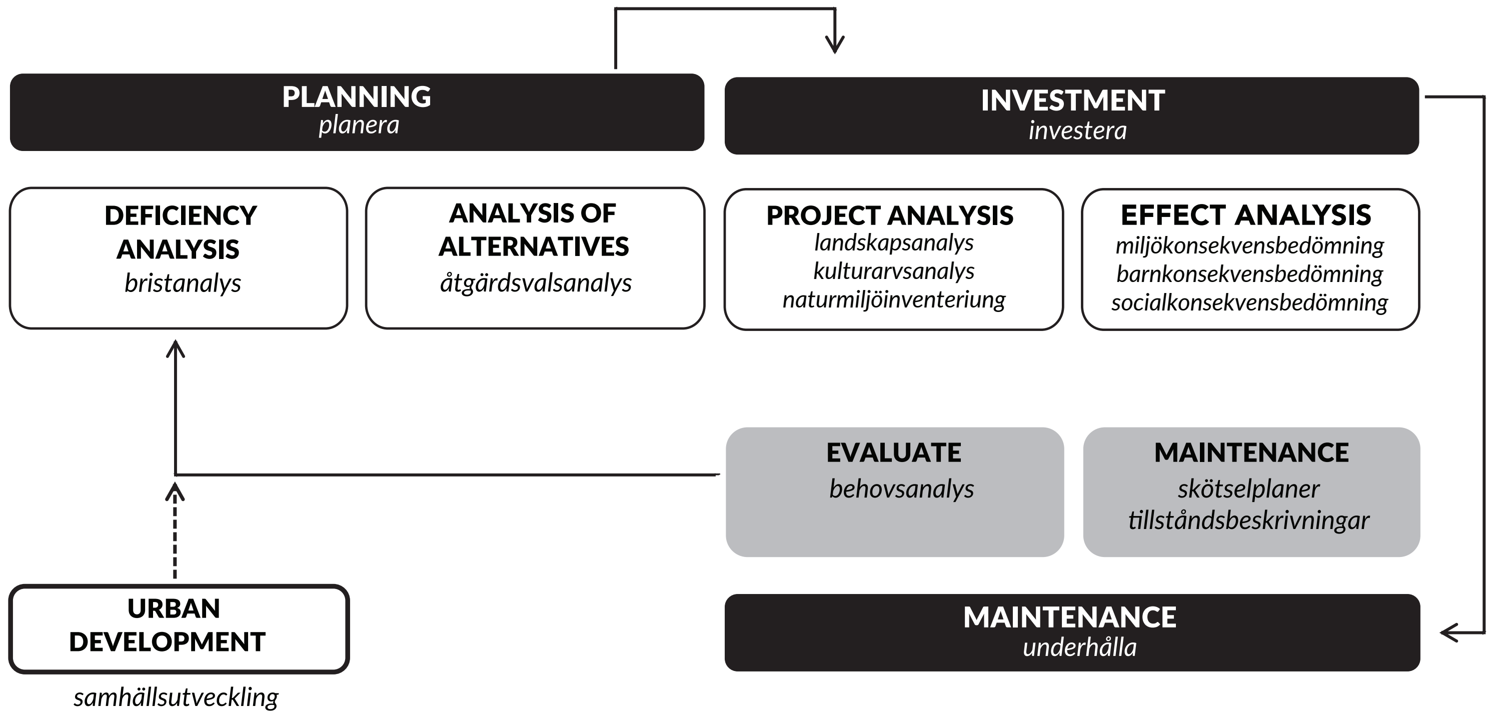


Figure 22.
Planning process Swedish Transport Administration

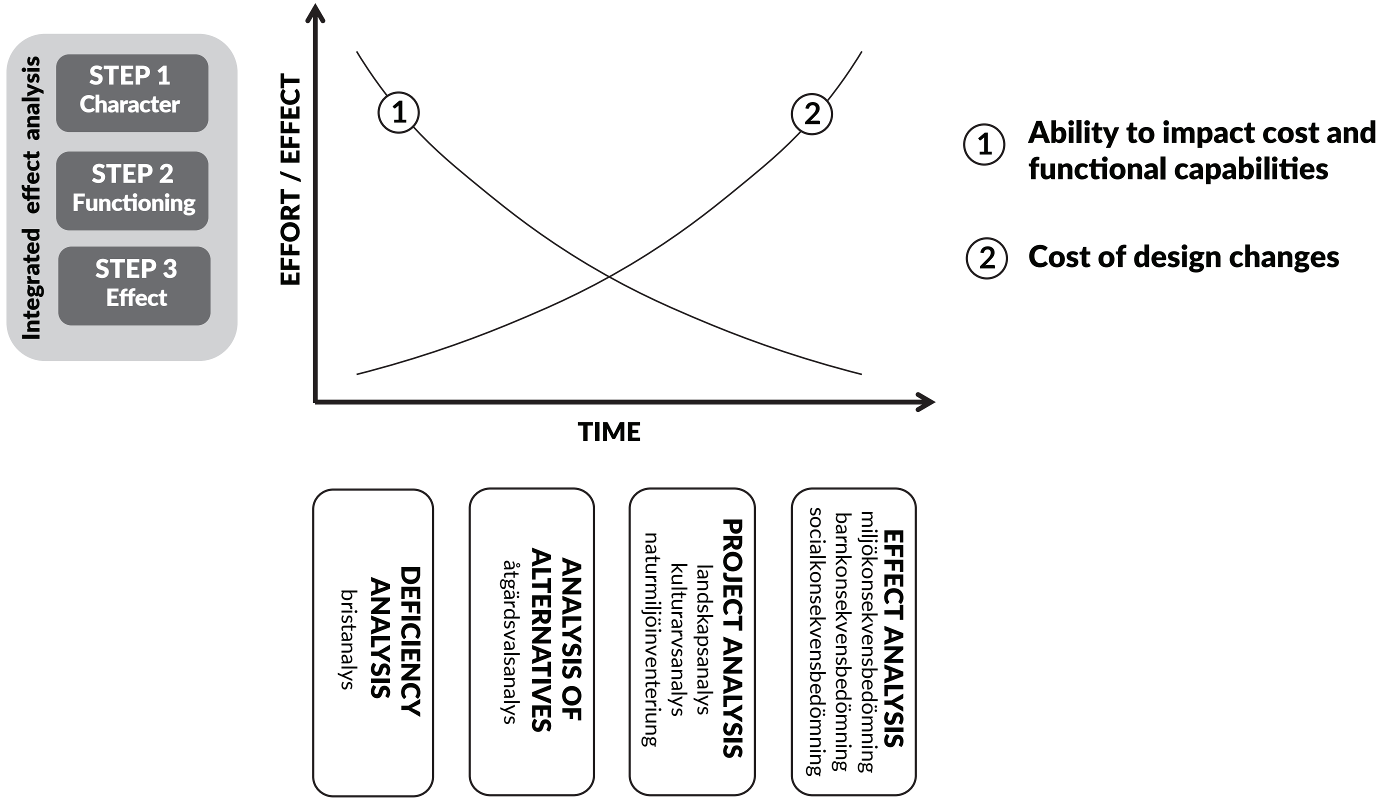


Figure 23.
The design-cost cycle

Integration of 'Infrastructure Effect Analysis' in the Swedish Transport Administration planning process.

The Infrastructure effect analysis aims to provide an expanded basis for the Swedish Transport Administration's assessment of how the *functioning* of the urban environment are affected by an infrastructural change. The analysis also aims, like the ILKA methodology, to contribute at an early stage with an integrated analysis of the environment. It is important to already during the earliest planning phases use the methodology proposed in this report, because the ability to impact cost and performance are biggest in the early phases of the project to then reduce as the planning proceeds. The costs of design changes show an opposite trend and costs are lowest in the early phases of the planning process to then increase. The challenge is to balance this design-cost cycle with the reality of the Swedish Transport Administration where often little budget is available for advanced analysis in the early phases of the planning process ('Planning'), while more budget is available in the phase of 'Investment' (Figure 23).

By producing an effect analyses at the various stages of the planning process, added value and areas of conflict, as well as prioritized mitigation measures, can be identified at an early stage. To support the analysis of needs and deficiencies during the first investigations, the inventory of the area's character and functioning is most relevant (steps 1 and 2 of the infrastructure effect analysis), while for the comparison of different alternatives (*åtgärdsvalsanalys* in Swedish), the before-after analyses become more important (step 3).

When the infrastructure effect analysis is carried out within the planning phase 'Investment', it should be carried out in a coordinated manner with other analyses such as landscape analysis, cultural heritage analysis, natural value inventory. The infrastructure effect analysis contributes to the early identification of potential negative (and positive) effects and the design of mitigation measures to reduce negative effects. Further, it can be used as a basis for the environmental impact assessments and give input to for example the assessment of *Population and health*, *Animal and plant species and biodiversity*, as well as *Landscape, buildings and cultural heritage*. How the infrastructure effect analysis can contribute both the earliest phases and later stages of an infrastructure project is visualized in Figure 24.

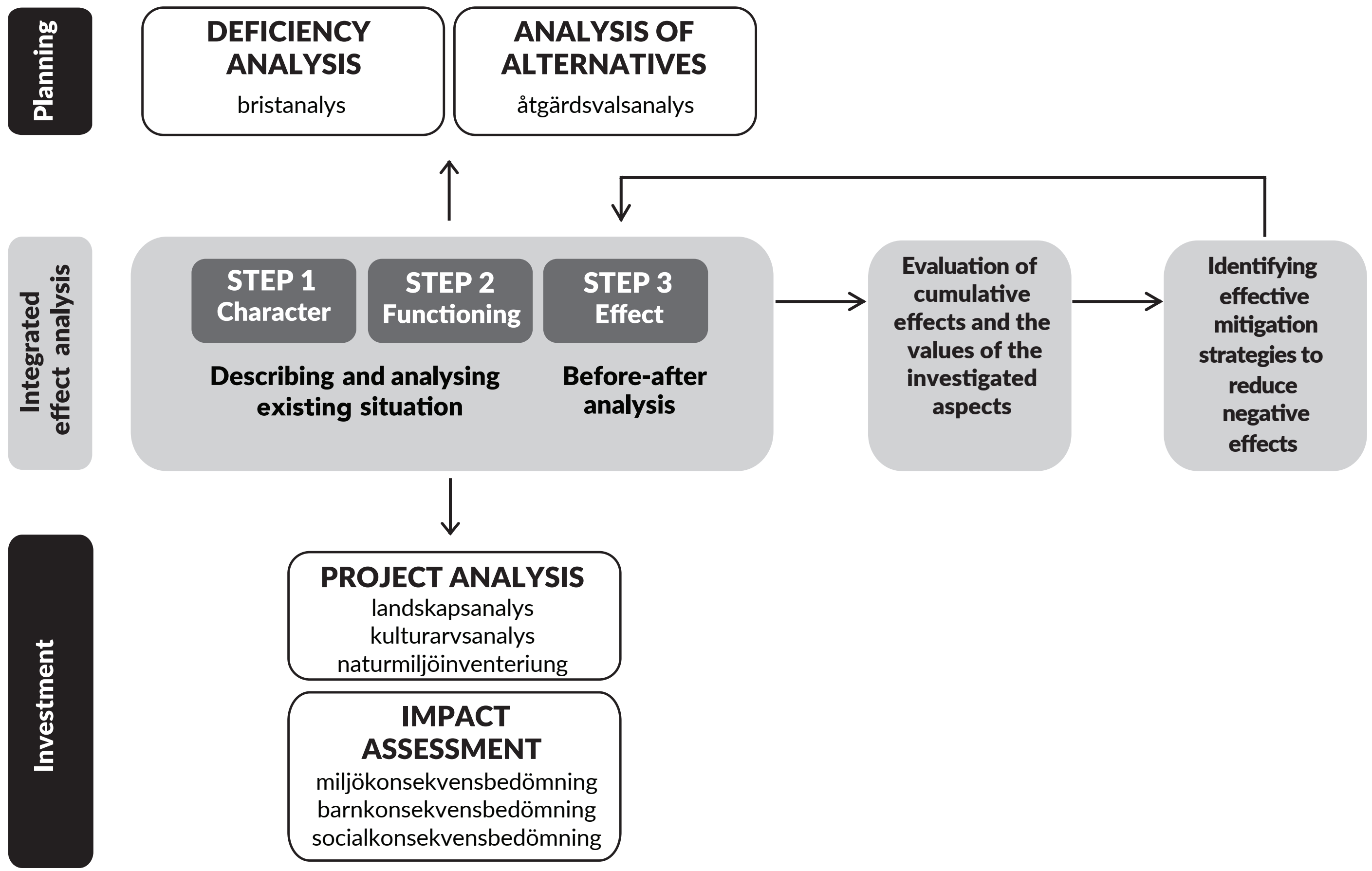


Figure 24.
The result of the integration of 'Infrastructure effect analysis' in the Swedish Transport Administration's planning process

It is important to already during the earliest planning phases use the methodology proposed in this report, but if budgets do not allow advanced spatial analyses, parts of the inventories and analyses can be conducted analog by experts with local knowledge and a good understanding of the socioeconomic, ecological, and cultural-historical perspectives. More advanced and precise digital analyses (using GIS) can then be conducted at a later stage. The analyses (analog or digital) should always involve all three steps:

1. What is the nature of the area and what sensitivities and opportunities should be considered? The answer is achieved through an inventory of the character of the built environment and an inventory of groups in society (people and species) that the analysis must target. This results in a list of issues to be further investigated in step 2 after a round of prioritization.

2. How does the area work for people and other species using it? The answer is achieved through an analysis of the functioning of the built environment with a focus on the prioritized questions in step 1. This results in an overview of sensitivities and possibilities and based on that, a prioritization of before-after analyzes to be carried out in step 3.

3. What does an infrastructure change mean for the area? The answer is achieved through a before-after analysis to reveal direct and indirect effects. Several iterations will be needed to test alternative scenarios and measures to reduce the negative effects of the project.

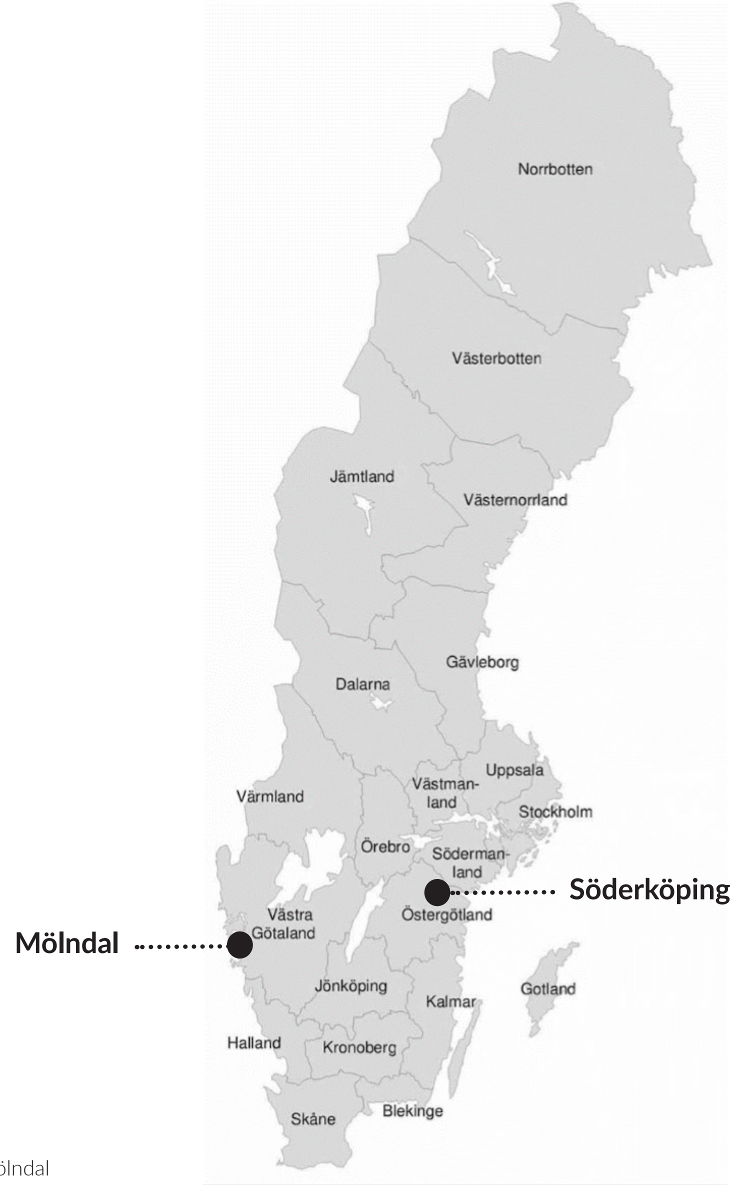


Figure 25.
Two case studies:
Söderköping and Mölndal

6. CASE STUDIES

The method for 'Integrated impact assessment of infrastructure transformations in urban environments' is applied in two case studies. The first case study is Söderköping where a new road infrastructure is proposed to move traffic that currently crosses the small town to a bypass south of the settlement. The second case study is Mölndal where a new station is planned as part of the new double track railway for high-speed trains and fast regional trains between Gothenburg and Borås (Figure 25). It should be emphasized that the analysis of these two case studies is by no means complete and is not intended to support these two ongoing projects. They are used here to showcase how the methodology can be used in a real case and what kind of questions it could help to answer and how it could be used in support of the decision-making process.

Söderköping

The national road E22 crosses the town of Söderköping, which today causes several problems that are more severe during the summer months when the traffic crossing the town is biggest because many people travel to the coast and southern parts of Sweden, while at the same time the boat traffic on the canal that links Östersjön to the West coast is most intense. The E22 crosses the canal near the town and when the bridge opens twice every hour, this causes long queues. A bypass aims to will solve this problem and allows the current E22 to be transformed into an urban boulevard with more crossings to better connect the two sides of the settlement. Four scenarios for the planned bypass were evaluated of which alternative West 3 that runs south of the settlement with an aqueduct under the canal, was chosen as final solution by the Swedish Traffic Administration (see Figure 26).

The four scenarios are summarized below:
Scenario West 1 and 2: Both alternatives are located on a large distance from the current settlement to allow Söderköping to expand west. Very long bridges are required across the flat valley to cross the canal (alt. West 1 about 1.1 km and 800 m in total West 2). The current bridge over the canal (old E22) remains in function. The traffic through the city is relieved by 1/3, which leads to better environmental conditions.

Scenario West 3 (tunnel or bridge): These alternatives are located near the current settlement and replaces the current bridge over the canal. Traffic through the city is relieved by just over half, but still leads to significantly better environmental conditions. The option reduces the value for recreation in the western part of the city and affects the opportunities for future development in this direction. The bridge proposal affects the cultural-heritage values of canal environment negatively (tunnel or aqueduct is thus preferable over bridge).

Figure 26.
Case study Söderköping
with the four scenarios for the planned bypass
(Vägverket, vägutredning 2000-11)
In red the scenario included in the before-after analysis.

Scenario East: The road passes north of the settlement and crosses the canal with a 700 meters long bridge. This alternative significantly serves long-distance traffic on E22. The local traffic from the city to Norrköping will continue in the future to use the current route through the city and across the canal. Traffic through the city is relieved with just over 1/4, which still means better environmental conditions. The road does not affect Söderköping to any great extent and sets no boundaries for an expansion of the city.

On the next pages, we will discuss step by step the method for 'Integrated impact assessment of infrastructure transformations in urban environments' for the case study Söderköping.

In the first step, the character of the built environment as well as sensitivities and opportunities in the built environment related to the planned infrastructure transformation are identified. The second step in the workflow focuses on how the built environment functions today and how it affects people, other species, natural habitats, ecosystems and cultural-historic resources. In the third step, before-after analyses are used to compare alternative West 3 for the planned infrastructure with the current situation as benchmark.

STEP 1. Inventory of the character of the built environment

The project starts with the identification the character of the built environment as well as sensitivities and opportunities in the built environment related to the planned infrastructure transformation. Depending on the project's requirements, this can entail one or more meetings with the project group including at least one representative from the Swedish Traffic Administration, one from each municipality that is affected (in this case Söderköping), and one or more consultants with socio-economic, ecological and cultural-historical expertise linked to infrastructural projects.

During project group meetings, sensitivities and opportunities are identified using the layers approach. The list of layers of the built environment can be used to structure this inventory and can be formulated as questions that sometimes can be answered without further analysis and can thus be described directly by the experts involved, but sometimes need additional analyses to be conducted in step 2 and 3. In table 4, questions that require further analyses are highlighted in bold text. This list is the result of step 1 which the project team decides on (Checkpoint 1 in figure 7) and defines the basis for the analyzes in step 2.

	LAYER	EXPECTED SENSITIVITIES AND OPPORTUNITIES	QUESTIONS (INPUT FOR STEP 2)		
			SOCIO-ECONOMIC	CULTURAL - HISTORIC	ECOLOGICAL
1	**SUBSTRATUM**	The canal is of cultural-historic value and requires either a bridge of tunnel/ aqueduct to cross it	How does the solution change accessibility along the canal?	How is the cultural heritage value of the canal affected by the solution?	
2	**NETWORKS**	Current E22 can be transformed in an urban boulevard, reducing its barrier effect	**How does the infrastructure transformation impact accessibility and local movement patterns?**	**How does the infrastructure transformation affect the medieval center?**	
		Bypass changes exposure to air and noise pollution	**Which existing buildings and services (incl green areas) are affected by the bypass in terms of increased or decreased pollution?**		
		Bypass creates new barriers	What are the effects for the hiking trails?		**Does the infrastructure transformation cause fragmentation of important habitats (in the case of Söderköping: smooth snake)?**
		New exits E22	**Will accessibility of the important commercial services that depend on visitors from E22 (e.g. Fixområdet, but also medieval center) change?**	Are important sightlines or entrances to the city impacted by the change of E22 and especially how one approaches the city?	
3A	**LAND OWNERSHIP**	Agricultural land and ownership along the bypass			Will agricultural units fragment?

	LAYER	EXPECTED SENSITIVITIES AND OPPORTUNITIES	QUESTIONS (INPUT FOR STEP 2)		
			SOCIO-ECONOMIC	CULTURAL - HISTORIC	ECOLOGICAL
3B	**PUBLIC SPACE**	The medieval town is important for cultural heritage and tourism		**Does position medieval center change in relation to the settlement as a whole?**	
		Important natural areas north and south of the town (important recreational areas)	**Will accessibility of the important recreational areas change?**		
		Brunnsparken (park with heritage value)		Does position Brunnsparken in the city change?	
3C	**BUILDINGS**	Medieval churches		Will visibility and accessibility of the churches change?	
		Buildings along the current E22	**How many buildings are directly exposed to infrastructure?**	Are there buildings with cultural heritage value along the old E22?	
3D	**USE**	Commercial centers (Fix området)	**Will accessibility of the commercial centers (e.g. Fixområdet) change?**		
		Schools and sport facilities	**Will accessibility of schools and sport facilities change?**		
		Public transport	**Will the public transport stops change and how does this affect accessibility to other services (especially the high school with many students travelling by bus)?**		
3E	**USERS**				

Table 4.
Checklist that can be used in step 1 (the list is decided at checkpoint 1 and defines the basis for the analyses in step 2)

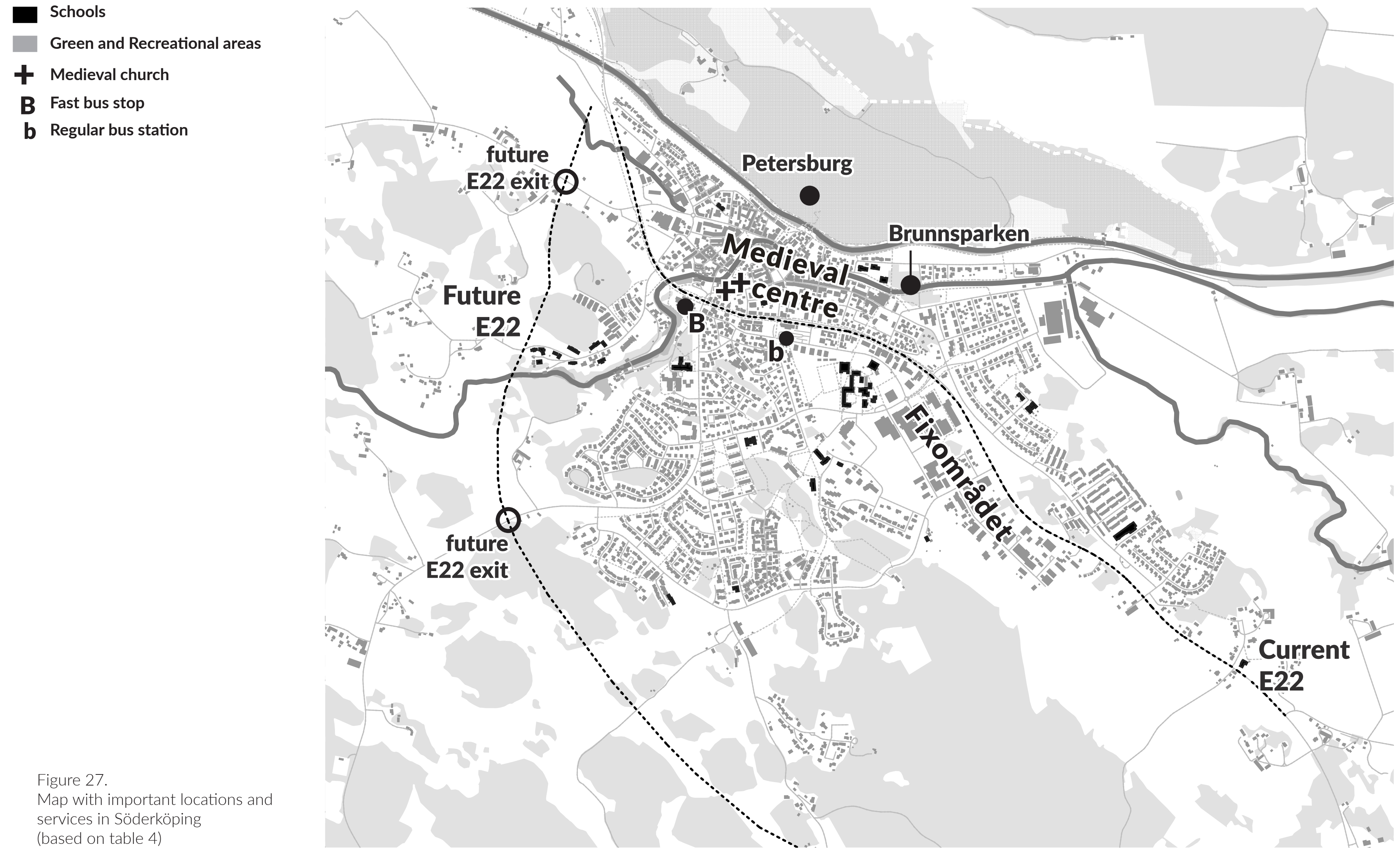


Figure 27.
Map with important locations and services in Söderköping
(based on table 4)

STEP 2. Analysis of the functioning of the built environment

The questions that are identified in relation to sensitivities and opportunities in the area (Table 4) are investigated further in step 2 of the workflow. First, the relevant analyses are identified based on the prioritized questions. For instance, the first question 'How does the infrastructure transformation impact accessibility and local movement patterns?' can be addressed with closeness and betweenness centrality analysis to give insight if the proposed bypass will change the movement flows of pedestrians and, in turn, the locations for commercial activities. Overlaying this analysis with the medieval street pattern will help to answer the second question 'How does the infrastructure transformation affect the medieval center?'.

A summary of the prioritized questions, analysis to investigate these, estimation of sensitivities and opportunities and recommended before-after analyses is given in table 5. This list is the result of step 2 which the project team decides on (Checkpoint 2 in figure 7) and defines the basis for the analyzes in step 3.

QUESTIONS STEP 1	DESCRIPTION OF ANALYSES (STEP 2)	EXPECTED SENSITIVITIES AND OPPORTUNITIES	BEFORE-AFTER ANALYSIS (STEP 3)
How does the infrastructure transformation impact accessibility and local movement patterns?	Closeness centrality Betweenness centrality	It can be expected that the centrality will change with consequences for the Medieval core of Söderköping and its value in terms of cultural heritage and tourism	Recommended for all scenarios
How does the infrastructure transformation affect the medieval center	Overlaying centrality analyses with the medieval center	See above	Recommended for all scenarios
Will accessibility of the commercial centers change?	Distance from E22 exits	The distance to the nearest exit will change for the Eastern center with consequences for the economic survival of these centers	Recommended for all scenarios

Table 5.
Checklist that can be used in step 2
(continues to next page)

QUESTIONS STEP 1	DESCRIPTION OF ANALYSES (STEP 2)	EXPECTED SENSITIVITIES AND OPPORTUNITIES	BEFORE-AFTER ANALYSIS (STEP 3)
Will accessibility of the commercial centers change?	Overlaying global centrality with location commercial centers	There is a risk that the centralities will shift with consequences for the economic survival of these centers.	Recommended for all scenarios
	Catchment area for pedestrians	Because the current E22 has already many crossings, the change is not expected to impact local catchment areas so much.	No priority
Does the infrastructure transformation cause fragmentation of important habitats (smooth snake)?	Habitat connectivity	Habitats are affected by the new road causing a risk for habitat fragmentation	Recommended for all scenarios
Will accessibility of the important recreational areas change?	Distance from buildings to access points parks	Because the current E22 has already many crossings, the change is not expected to impact local catchment area.	No priority
Will accessibility of schools and sport facilities change?	Distance from buildings to schools	Because the current E22 has already many crossings, the change is not expected to impact local catchment area.	No priority
How many buildings are directly exposed to the infrastructure?	Distance from infrastructure to buildings, residential buildings, schools, green areas	Because large areas and many buildings will be affected, impact is expected to be high.	Recommended for all scenarios
Will the public transport stops change and how does this affect accessibility to the high school? (the fast bus will have its stops on the new E22)	Distance from high school to public transport stops	The distance between the high school and the current bus stop is almost 500 meters and the infrastructure transformation will most probably have a significant negative effect	Recommended for all scenarios

Table 5. (continuation)
Checklist that can be used in step 2

STEP 3. Before-after analysis to reveal direct and indirect effects

Based on the inventory of questions and priorities above, we have grouped the analyses in four sets that will be presented below in combination with the results of the before-after analyses:

1. Centrality analyses that provide insight in how the bypass affects movement patterns in Söderköping. This in turn is important to understand the impact of the bypass for the medieval center and commercial centers in Söderköping.

2. Habitat fragmentation that provides insight in how the bypass affects for the area important species and their survival.

3. Accessibility to service with focus on schools and in relation to bus stops

4. Direct infrastructure exposure with focus on air- and noise pollution.

Centrality analysis

To answer the question how the infrastructure transformation might impact movement patterns, centrality analyses are conducted. The results show that the streets with highest centrality are located where the medieval town center is located (figure 28 and 29). The two medieval squares (Rådhustorget and Hagatorget) and one of the oldest commercial streets (Skönbergagatan) have a high betweenness centrality and can be expected to be frequently used by people passing from one part of Söderköping to the other.

CASE STUDY: SÖDERKÖPING

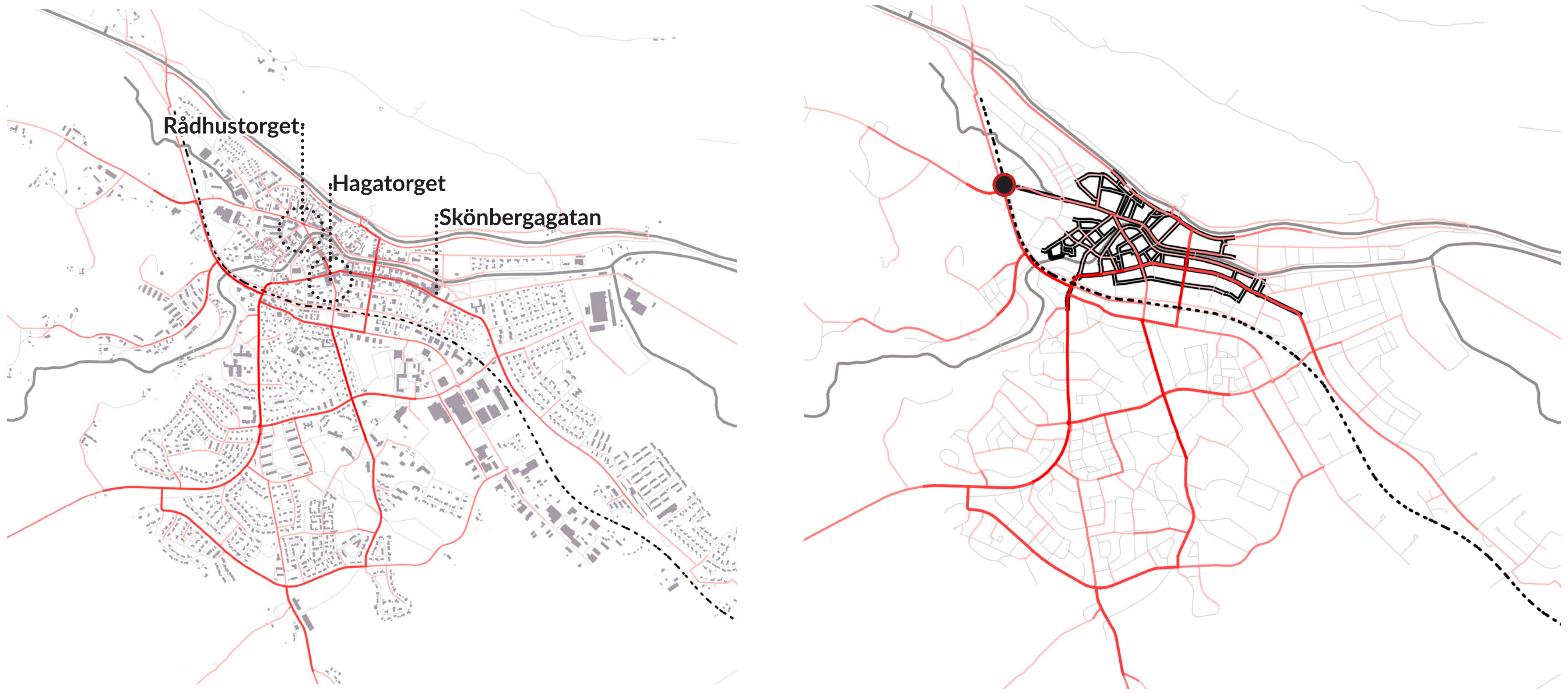


Figure 28.
Betweenness centrality 2km (left) overlayed with map of medieval street pattern (right)

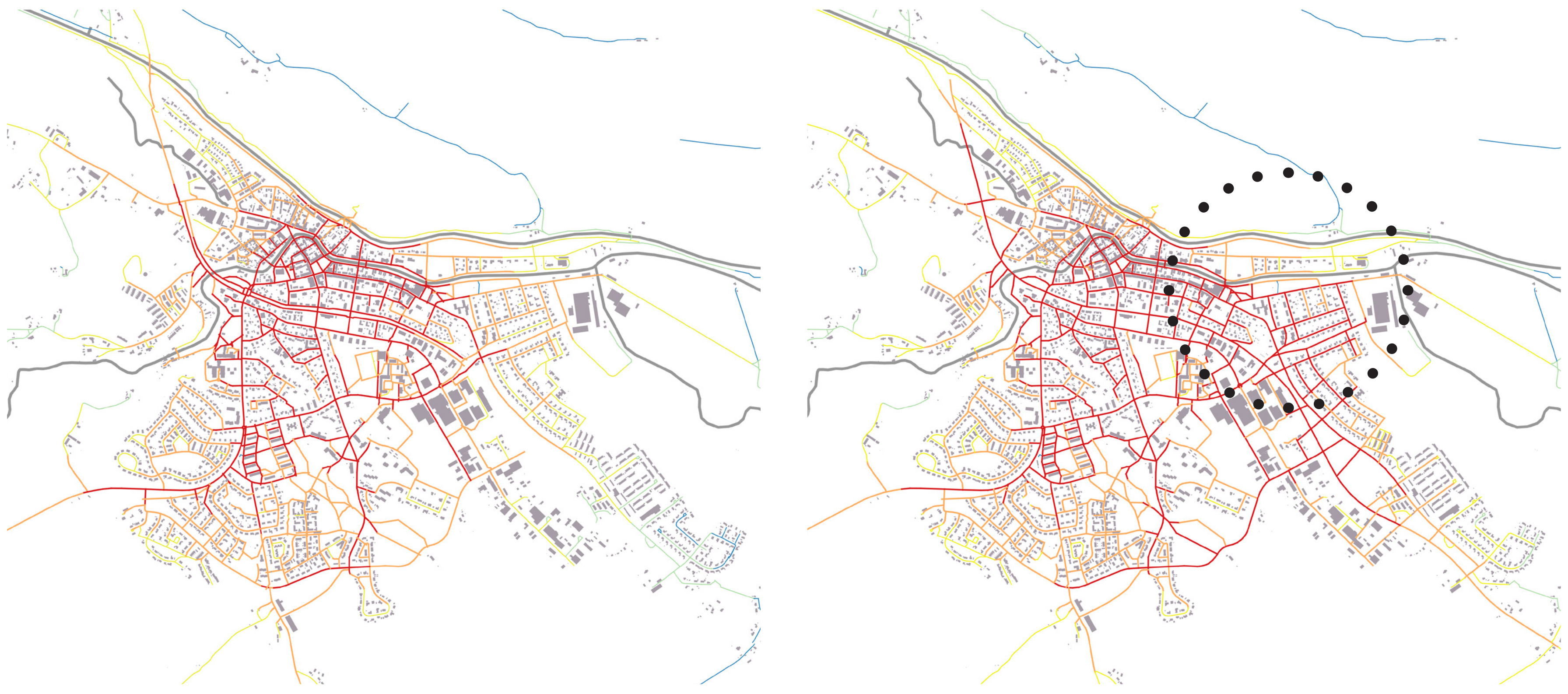


Figure 29.
Closeness centrality before (left) and after (right)

When the new bypass is constructed and the current E22 is transformed into a boulevard, closeness centrality on the meso scale (2km) shifts towards east, meaning that this area will become more of a destination in the local movement patterns (Figure 29). The analysis also shows that it does not reduce the centrality of the current medieval town center. The changes in betweenness centrality are most profound for the new boulevard (current E22) at the cost of Skönbergagatan, one of the medieval commercial streets (Figure 30). This shift in centrality will most probably also cause a shift in movement and we can expect that this will impact the commercial activities in both streets. Thus, the new boulevard might get a more important role as commercial street at the cost of the medieval street. Possible effects are that the medieval streets decrease in their role as a target point in central Söderköping and that people's movement patterns are shifted outside the medieval core. Such changes can lead to a decrease in the orientability of the city, and to a reduced readability of the historic city's entrances, lanes and layout.

Centrality also plays an important role for commercial activities outside the medieval center. Söderköping has two commercial centers located on the eastern and western edge of the settlement. Many people passing through Söderköping by car stop at one of these centers and this is the reason why Söderköping has so many shops relative to the local population (Söderköping only has 7 500 inhabitants and three large grocery stores). From the betweenness centrality analysis on the global scale (15km), it can be concluded that both centers are located strategically for those passing through Söderköping by car (dotted lines in figure 31).

The centrality analyses show that the commercial center in the East loses centrality at the regional scale (figure 31) while the values increase at the local scale (figure 30). The Western center shows the opposite trend. This means that the Eastern center will become more a local hub, while the Western center will become more important as the regional hub.

This result is confirmed in the analysis of the local catchment area of the Eastern commercial center (figure 32) as well as the closeness centrality analysis that showed a shift towards the east (figure 29).

Figure 30.
Betweenness centrality before (left) and after (right)

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high

low

Figure 31.
Betweenness centrality on a regional scale (15km) before (left) and after (right)

+ 121 buildings within a 500m walk in the 'after' situation

+ 95 buildings within a 1000 walk in the 'after' situation

buildings within 500m walking distance

buildings within 1km walking distance

Figure 32.
Local catchment areas for the Eastern center (Fixområdet) before (left) and after (right)

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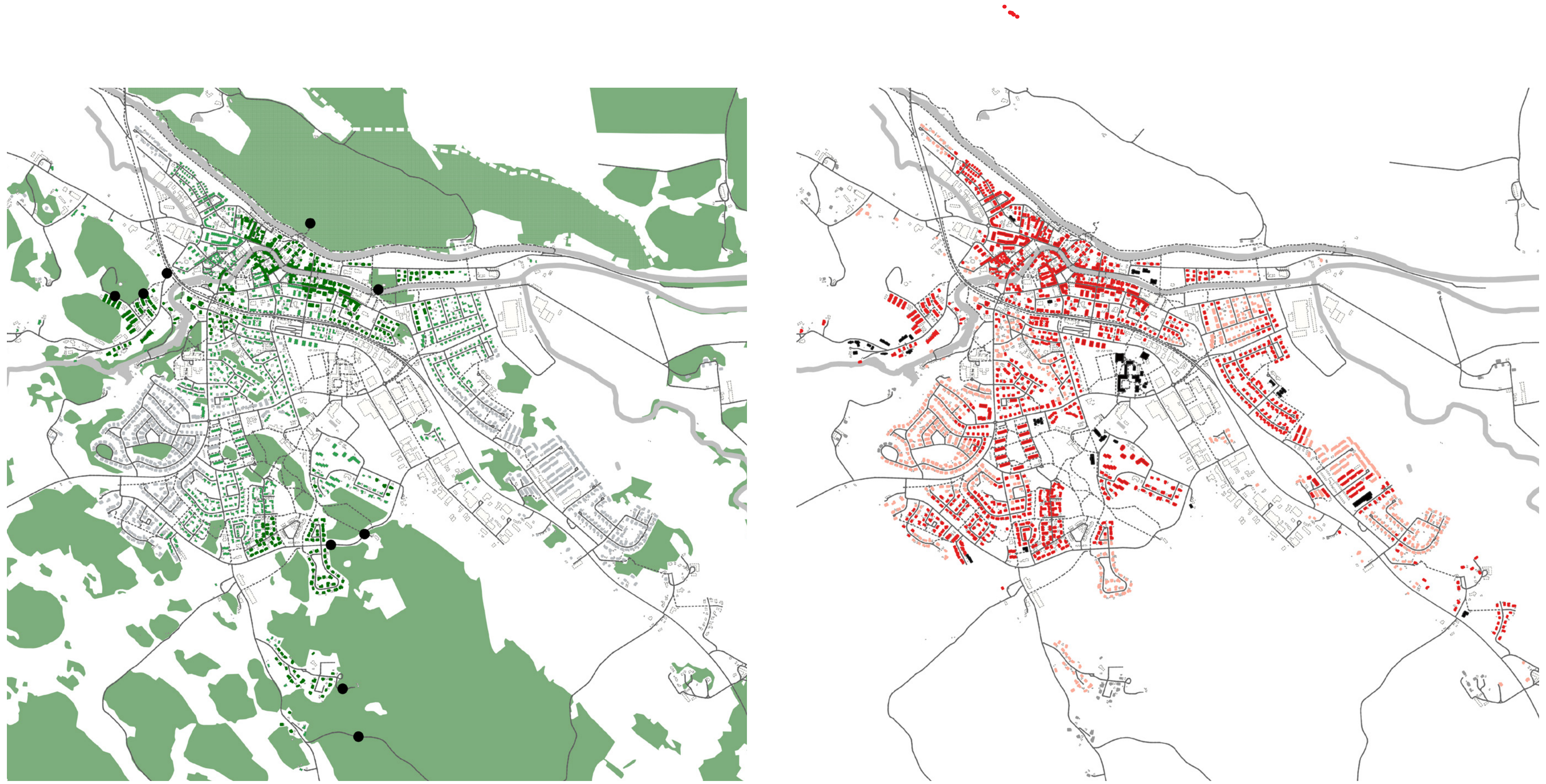

Figure 33.
Proximity of residential buildings
to recreational areas (left)
and schools (right)

Accessibility to service

In relation to the questions about distance to recreational areas and schools (Figure 33), we do not expect big changes because of the infrastructure transformation. The current E22 already has many crossings and therefore, the addition of more will not result in a numerical change and the before-after analysis is therefore not prioritized.

Besides distance to schools from each building in Söderköping, it is of importance to evaluate the distance to schools from a public transport perspective, especially for the high school that is very much dependent on students travelling by bus. The question is whether some fast buses between Valdemarsvik and Norrköping will change route because of the bypass with new bus stops near the highway exits. This will affect the distance from the bus stop to the high school negatively with the risk that students from Valdemarsvik will chose a school in Norrköping. The results of the before-after analysis show that the distance from the bus stop to the high school increases from almost 500 meters to 1,3 km (figure 34). This is far too long to expect students to walk from the bus stop to school and the risk of continuing by bus into Norrköping is big, which can have negative consequences for the number of students at the highschool in Söderköping

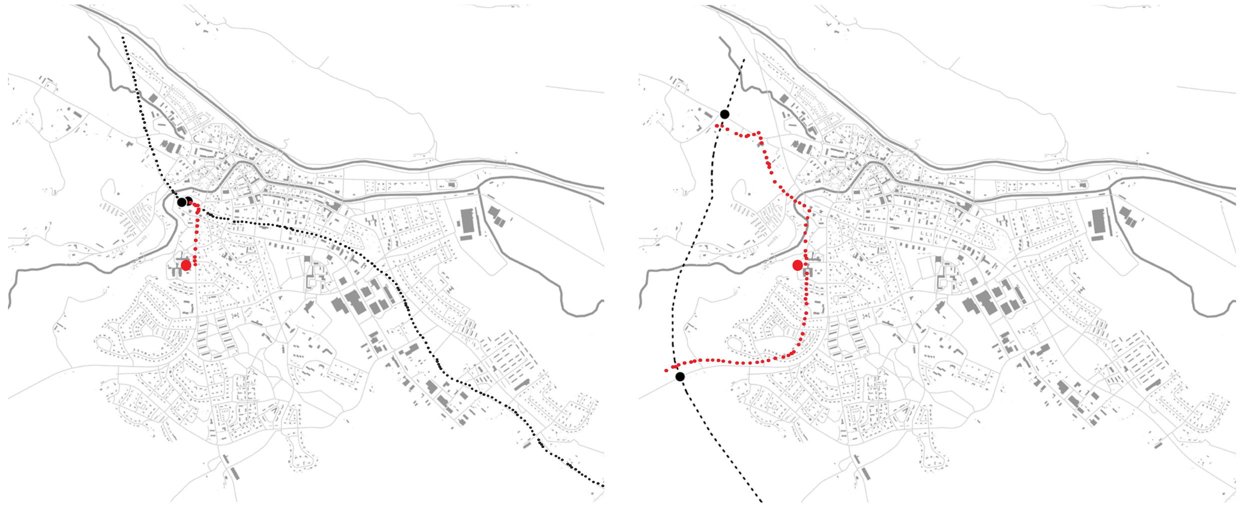

Figure 34.
Distance between bus stop (fast bus between Valdemarsvik and Norrköping) and high school before (left) and after (right)

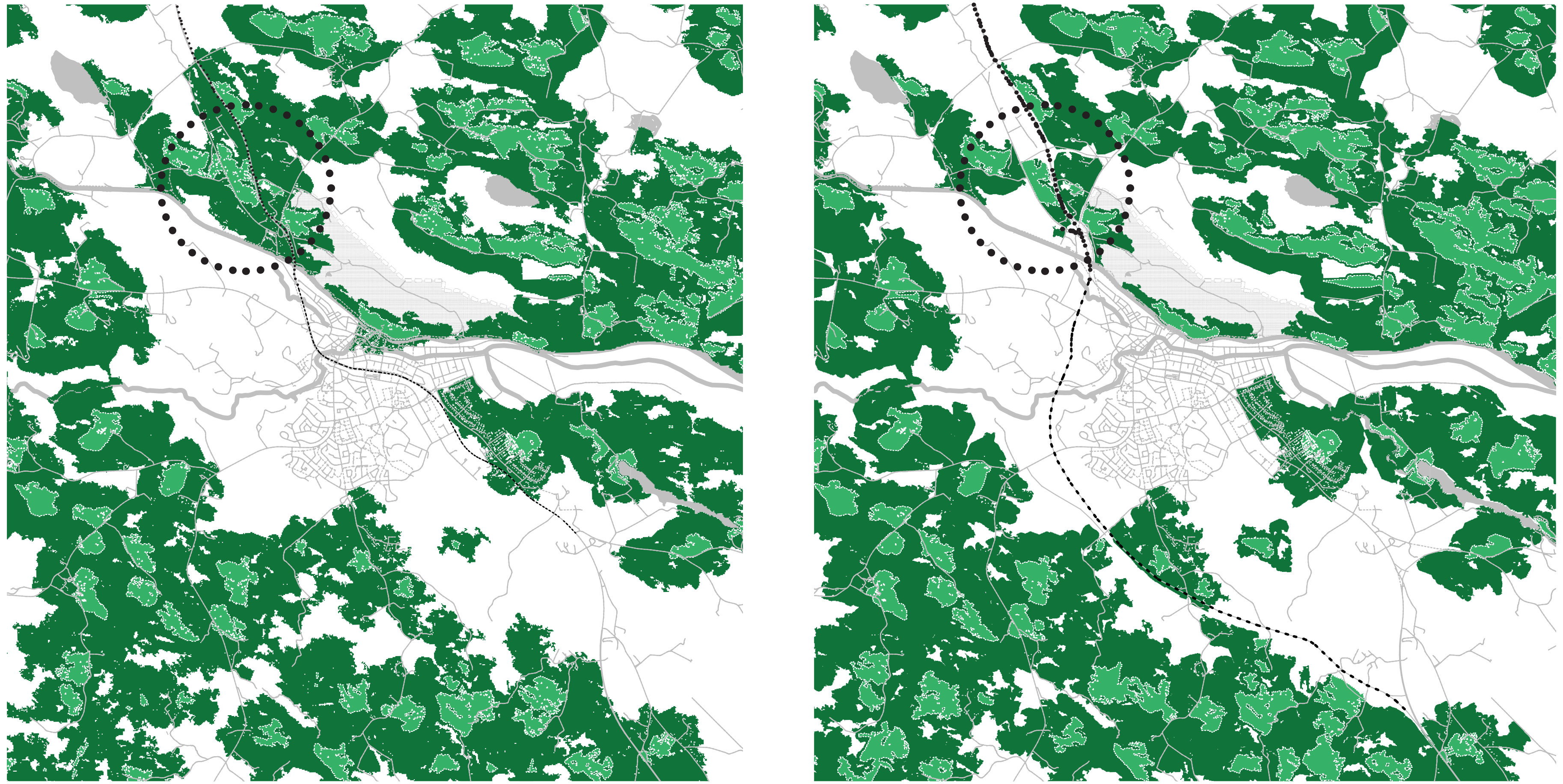

Figure 35.
Habitat loss and connectivity for the species 'smooth snake' (hasselsnok in Swedish) before (left) and after (right)

.Habitat fragmentation

The question about fragmentation focuses on the habitats that are of importance for the protected species smooth snake (hasselsnok in Swedish) that is found in the areas surrounding Söderköping. Both habitat networks and habitat patches are affected by the new road causing a risk for both habitat loss and habitat fragmentation. The analysis shows that especially the changes in the northern part of the infrastructure transformation can have severe negative consequences for the protected species smooth snake (figure 35). Mitigation measures to compensate for the losses in habitats should be used and evaluated by iterating this analysis.

Direct infrastructure exposure

Although it is obvious that the bypass will decrease exposure to air- and noise pollution along the new boulevard (current E22), it is harder to estimate the number of buildings and especially the number of residential buildings that will be affected. The results of the analysis of the current situation shows that the number of buildings that are located very near the current E22 is a bit over 400 buildings of which approximately 150 are residential buildings (figure 36, left). The before-after analysis shows that the number of residential buildings that are exposed to noise- and air pollution most (closer than 100 meters from current E22), reduce from approximately 150 to almost zero (figure 36, right). Besides the separate maps showing the results of the analysis before the infrastructure transformation and after, a change map can be an effective way to communicate the impact of the change, distinguishing positive, negative, and especially significant positive and negative effects (Figure 37). Almost 90 residential buildings profit from a significant positive effect and none suffer from a significant negative effect.

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Figure 36.
Direct infrastructure exposure residential buildings before (left) and after (right)

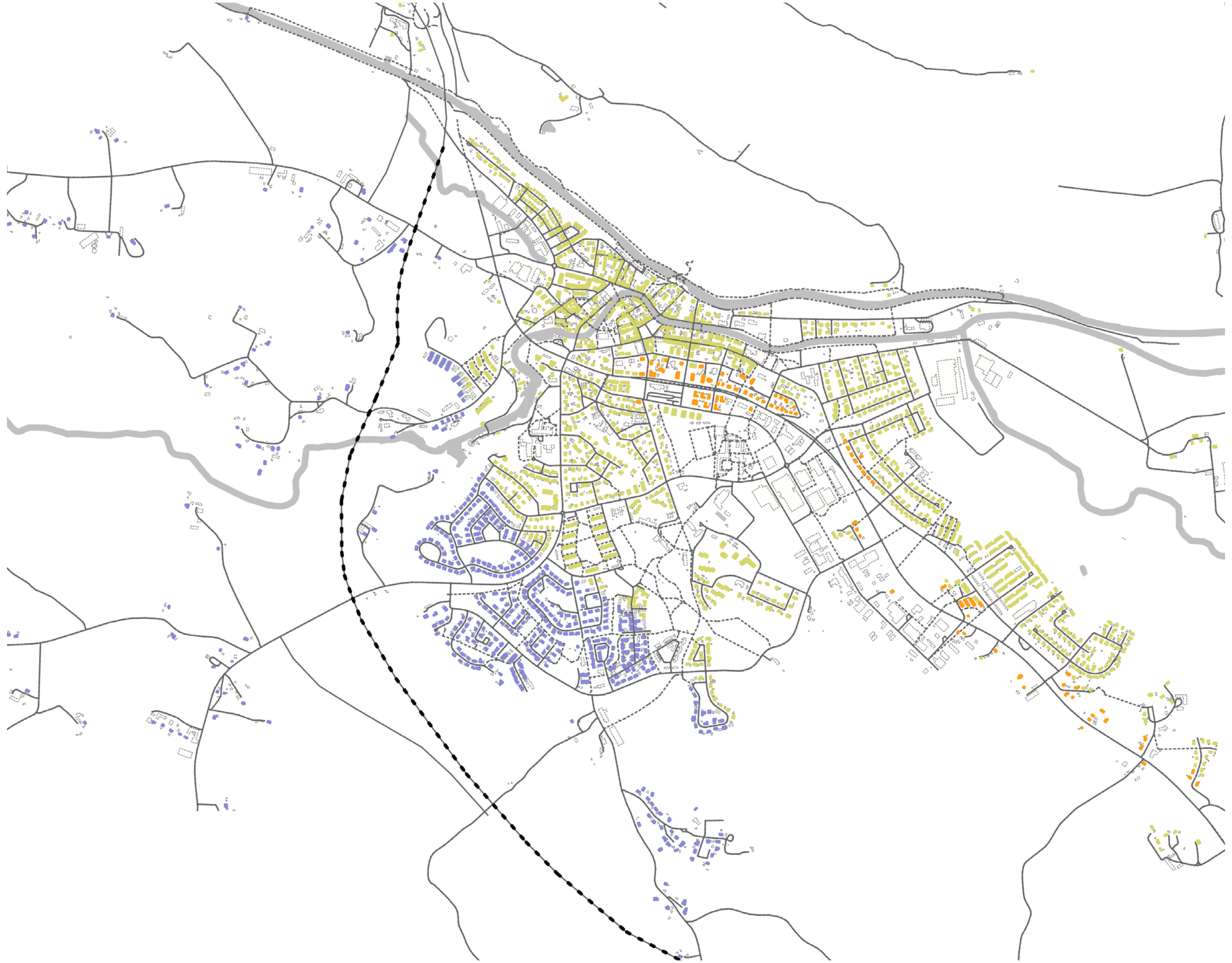

Figure 37.
Change in direct infrastructure exposure residential buildings

CASE STUDY: SÖDERKÖPING

Figure 38.
Direct infrastructure exposure
schools before (left)
and after (right)

Besides proximity to residential buildings, it is also important to address proximity to schools because children are an extra vulnerable group and proximity to green areas that can affect the attractiveness of these areas as recreational areas. The before-after analysis of the direct exposure to schools shows a negative effect for two schools but also, a positive effect for almost all other schools (Figure 38). The exposure in green areas decreases in the central green areas while many green areas in the southern parts of the town are negatively affected. This can have negative consequences for recreation in these areas (Figure 39).

- **<100m**
- **100 to 500m**
- **500 to 1000m**
- **>1000m**

Figure 39.
Direct infrastructure exposure
green areas before (left)
and after (right)

Societal consequences

The societal consequences are described by weighing the size of the cumulative effects with the value of the environmental aspect that is assessed and is decided by the project team (Checkpoint 3 in figure 7). To be able to link the different effect analyses to the environmental interests highlighted in the Environmental Assessment method (Miljö Konsekvens Bedömning (MKB) in Swedish) used by the Swedish Transport Administration, the consequences are grouped accordingly: natural environment, cultural environment and human health (in Swedish: naturmiljö, kulturmiljö, befolkning och hälsa).

Socioeconomic and social-ecological consequences (linked to human health in MKB)
The number of residential buildings that is directly exposed to air- and noise pollution decreases to almost zero. For schools the overall picture is also positive with most schools improving significantly in terms of disturbances by noise- air pollution. However, there are two schools that are negatively affected and here mitigation measures should be considered. Air- and noise pollution increases in green areas in the southern parts of the town which might have negative consequences for recreation.

Accessibility to important services is not negatively affected except for the distance from the bus stops for fast regional public transport to Söderköping's high school. The distance from the current bus stop to the school is almost 500 meters and the move of the stop to new highway exits will more than double this distance. The willingness to walk is known to decrease rapidly above 500 meters and this change can thus have severe consequences for Söderköping. If students from towns south of Söderköping decide to continue the bus into Norrköping, 17km north of Söderköping, the school in Söderköping might lose many students which on the long term can jeopardized the school's survival.

The commercial center located East of Söderköping (Fixområdet) shows a decreasing centrality on the regional scale, and the distance to the nearest exit increases, while the local centrality and catchment increases. In other words, this eastern commercial center loses its regional function and will become more of a local hub. This might have large negative consequences for the businesses located here today and in turn, affect local inhabitants that risk losing some of their nearby services. The Western commercial center shows an opposite trend and will become more important regionally. One can imagine that a relocation of some of the businesses from the Eastern center to the Westerns center will take place on the long term.

Overall, we see positive health consequences of the bypass related to reduction of pollution where many people are daily (dwellings and schools), but negative socioeconomic consequences related to commercial functions located at the eastside of town, which loses regional centrality. Furthermore, the upper secondary school risks losing students due to changes in public transport that can be linked to the new bypass.

Cultural-historical consequences (linked to cultural environment in MKB)
The cumulative effects in relation to the Medieval town center are that centrality extends east and the new boulevard becomes a very central street at the cost of Skönbergagatan that historically has been one of the main roads. This has consequences for the flow of people on these streets and Skönbergagatan may in the long run become less attractive for commercial activities. Overall, we see medium negative consequences for especially this former main street and positive consequences for the new boulevard. The rest of the medieval town is not negatively affected.

Ecological consequences (linked to natural environment in MKB)
The consequences of the fragmentation of habitats for the smooth snake (hasselsnok in Swedish) are severe in the northern part of the infrastructure and should be mitigated by added compensating habitats.

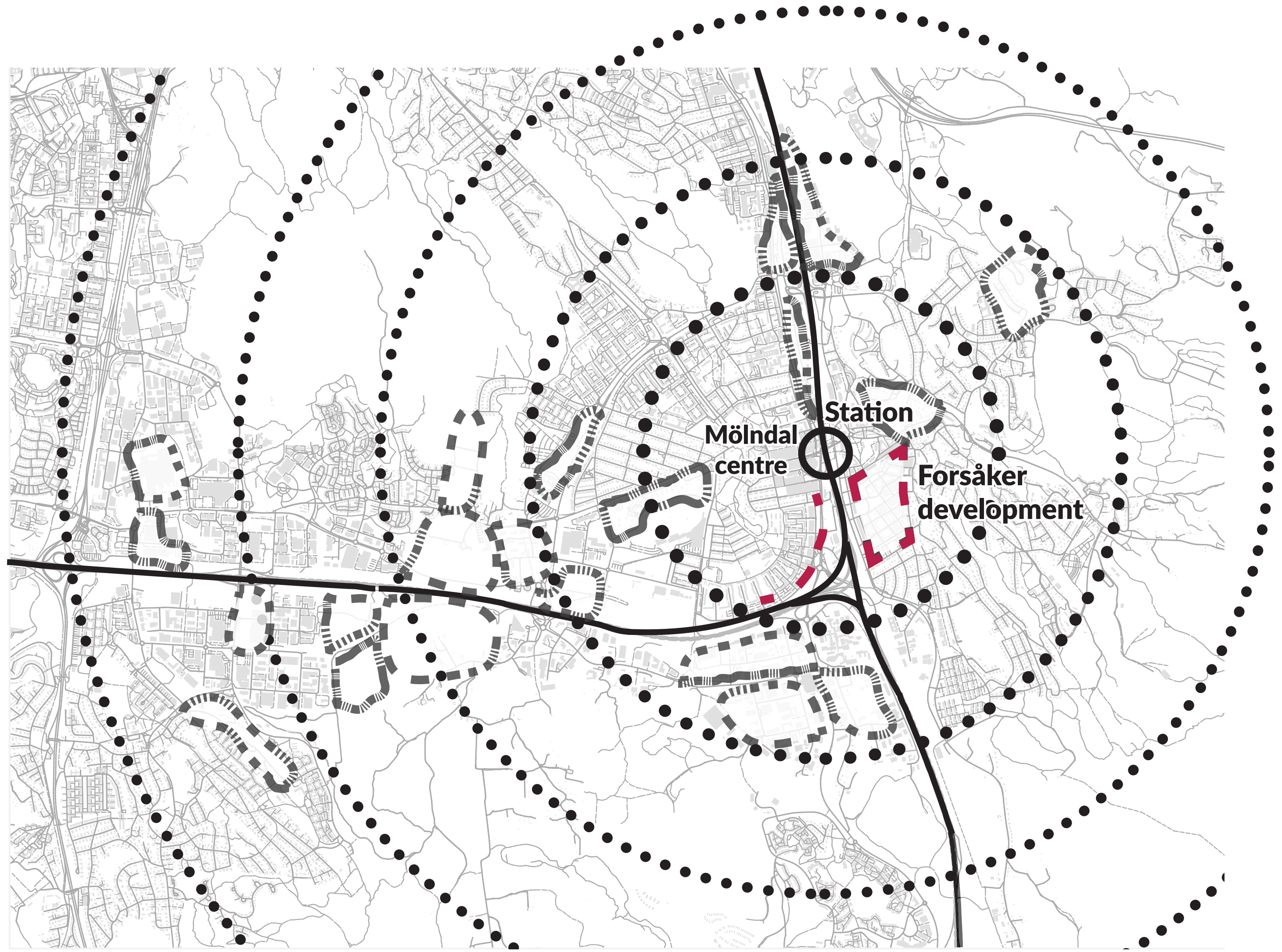

Figure 40.
Schematic mapping of the development plans in the area surrounding the station in Mölndal with the area Forsåker highlighted, where a mixed-use area is planned with 3 000 new dwellings. In red the densification areas included in the before-after analysis.

Mölndal

The planned Götalandsbanan that connects Gothenburg to Jönköping with a fast train stop in Mölndal center will change the position of Mölndal in the region. This will provide new opportunities for urban development that are at the same time dependent on how the station is integrated in the local urban environment. Besides the rail tracks that will be expanded and create a wider barrier, the area suffers from the barrier effect of the highway E20 that runs parallel to the rail tracks but is planned to go underground where the station will be located. East of the tracks, a large new mixed-use area is planned (Forsåker) with 3 000 new dwellings (Figure 40).

On the next pages, we will discuss step by step the method for 'Integrated impact assessment of infrastructure transformations in urban environments' for the case study Mölndal.

In the first step, the character of the built environment is identified as well as sensitivities and opportunities in the built environment related to the planned infrastructure transformation. The second step in the workflow focuses on how the built environment works today and how it affects people, other species, habitats, ecosystems and cultural-historical resources. In the third step, before-after analyses are used to compare various scenarios to cross the tracks and connect the new area Forsåker with Mölndal centre.

STEP 1. Inventory of the character of the built environment

The project starts with the identification the character of the built environment as well as sensitivities and opportunities in the built environment related to the planned infrastructure transformation. Depending on the project's requirements, this can entail one or more meetings with the project group including at least one representative from the Swedish Traffic Administration, one from each municipality that is affected (in this case Mölndal), and one or more consultants with socio-economic, ecological and cultural-historical expertise linked to infrastructural projects.

During project group meetings, sensitivities and opportunities are identified using the layers approach. The list of layers of the built environment can be used to structure this inventory and can be formulated as questions that sometimes can be answered without further analysis and can thus be described directly by the experts involved, but sometimes need additional analyses to be conducted in step 2 and 3. In table 6, questions that require further analyses are highlighted in bold text. This list is the result of step 1 which the project team decides on (Checkpoint 1 in figure 7) and defines the basis for the analyzes in step 2.

	LAYER	EXPECTED SENSITIVITIES AND OPPORTUNITIES	QUESTIONS (INPUT FOR STEP 2)		
			SOCIO-ECONOMIC	CULTURAL - HISTORIC	ECOLOGICAL
1	**SUBSTRATUM**	Height differences in the surroundings affect accessibility (independent of the infrastructure transformation)			
2	**NETWORKS**	New rail tracks create a wider barrier	How does the width of the barrier impact safety?		
		Proposed bridges over the new rail tracks	**How do the new bridges affect centrality and accessibility to services?**		
		Habitat network			**Does the infrastructure transformation cause fragmentation of important habitats (bats)?**
3A	**LAND OWNERSHIP**				
3B	**PUBLIC SPACE**	Kvarnbyn is important for cultural heritage and tourism		**Does position of kvarnbygatan and the old square change in relation to the town as a whole?**	
		Important natural areas east and west of the town (important recreational areas)	**Will accessibility of the important recreational areas change?**		

	LAYER	EXPECTED SENSITIVITIES AND OPPORTUNITIES	QUESTIONS (INPUT FOR STEP 2)		
			SOCIO-ECONOMIC	CULTURAL - HISTORIC	ECOLOGICAL
3C	**BUILDINGS**	Buildings along the highway and tracks	**How many buildings are directly exposed to infrastructure?**		
3D	**USE**	Schools and sport facilities (Solängen)	**Will accessibility of schools and sport facilities change?**		
		Important target points in the areas are the hospital, Ericsson and AstraZeneca	**Will accessibility of these target points change?**		
3E	**USERS**				

Table 6.
Checklist that can be used in step 1 (the list is decided at checkpoint 1 and defines the basis for the analyses in step 2)

STEP 2. Analysis of the functioning of the built environment

The questions that are identified in relation to sensitivities and opportunities in the area (Table 6) are investigated further in step 2 of the workflow.

First, the relevant analyses are identified based on the prioritized questions. For instance, the first question 'How do the new bridges affect centrality and accessibility to services?' can be addressed with closeness and betweenness centrality analysis to give insight if the proposed bridges over the tracks will change the movement flows of pedestrians and, in turn, the locations for commercial activities in the new area. Overlaying this analysis with the streets and buildings with cultural-historical value will help to answer the fourth question 'Does position of kvarnbygatan and the old square change in relation to the town as a whole?'.

A summary of the prioritized questions, analysis to investigate these, estimation of sensitivities and opportunities and recommended before-after analyses is given in table 7. This list is the result of step 2 which the project team decides on (Checkpoint 2 in figure 7) and defines the basis for the analyzes in step 3.

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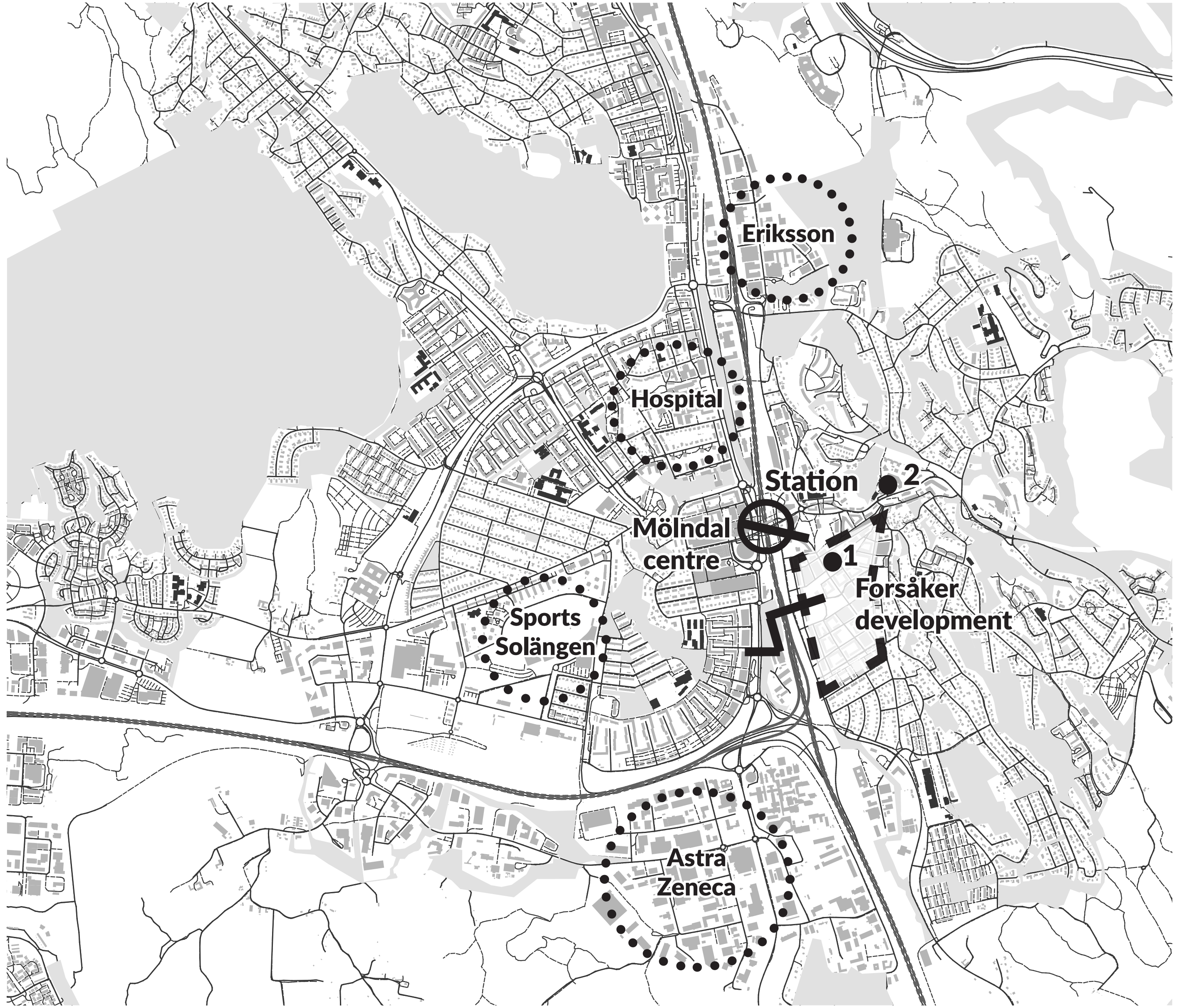


Figure 41.
Map with important locations and services in Mölndal
(based on table 6).

QUESTIONS STEP 1	DESCRIPTION OF ANALYSES (STEP 2)	EXPECTED SENSITIVITIES AND OPPORTUNITIES	BEFORE-AFTER ANALYSIS (STEP 3)
How do the new bridges affect centrality and accessibility to services?	Closeness centrality Betweenness centrality	It can be expected that the centrality will change with consequences for the new development Forsåker and kvarnbygatan and the old square	Recommended for all scenarios
Does position of kvarnbygatan and the old square change in relation to the town as a whole?	Overlaying centrality analyses with kvarnbygatan and the old square	See above	Recommended for all scenarios
Does the infrastructure transformation cause fragmentation of important habitats (bats)?	Habitat connectivity	Because the infrastructure is not changed, no impact is expected (harm is already done)	No priority
Will accessibility of the important recreational areas change?	Distance from buildings to access points parks		
How many buildings are directly exposed to infrastructure?	Distance from infrastructure to buildings, residential buildings, schools, green areas	Because buildings are already exposed to the infrastructure, no changes are expected	No priority
Will accessibility of schools and sport facilities change?	Distance from buildings to schools		
Will accessibility of the target points (hospital, Eriksson, Astra Zeneka) change?	Distance from buildings to target points (hospital, Eriksson, Astra Zeneka)		

Table 7.
Checklist that can be used in step 2

CASE STUDY: MÖLNDAL

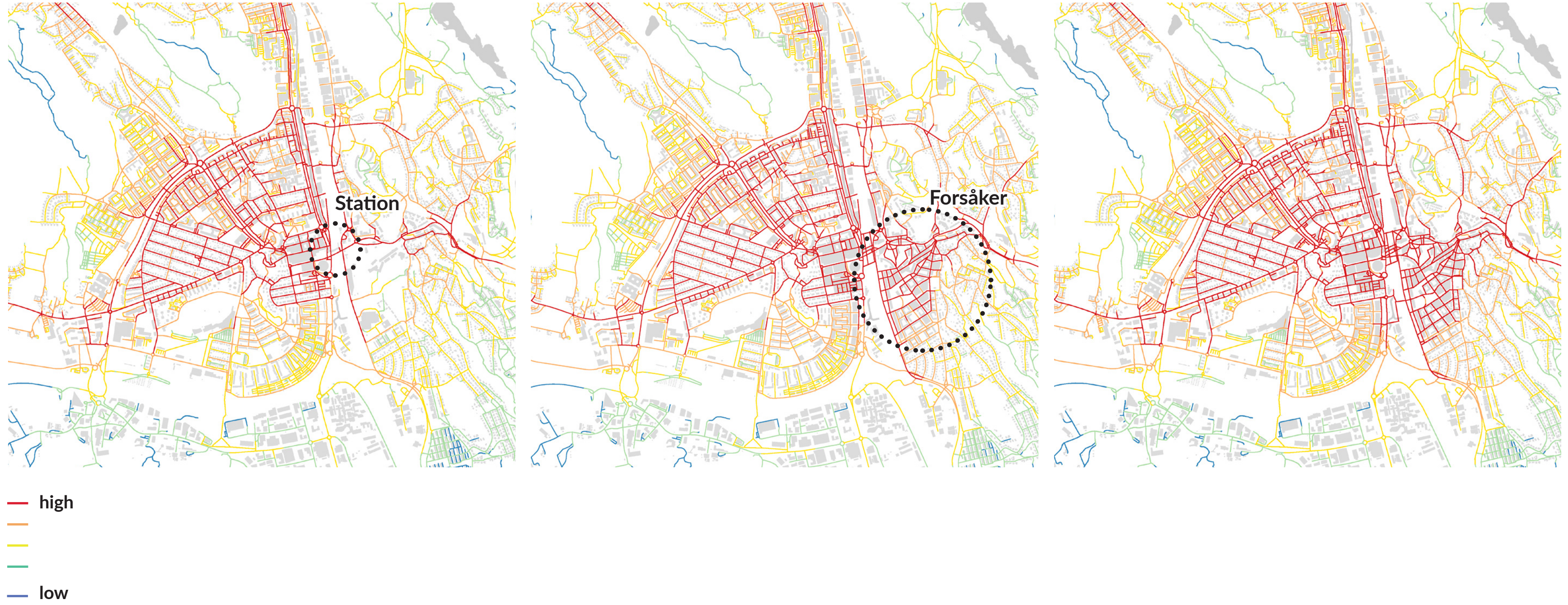


Figure 42.
Closeness centrality 2km current situation (left), new development Forsåker (middle) and two new bridges crossing the tracks (right)

STEP 3. Before-after analysis to reveal direct and indirect effects

Based on the inventory of questions and priorities above, we have grouped the analyses in two sets that will be presented below in combination with the results of the before-after analyses:

1. Centrality analyses that provide insight in how the bridge to cross the rail tracks affects movement patterns in Mölndal. This in turn is important to understand the impact of the bridges for the new development Forsåker as well as the areas and buildings with cultural historical value.

2. Habitat fragmentation that provides insight in how the infrastructure affects bats.

3. Accessibility to service with focus on schools, sport facilities, recreational areas and target points (work related)

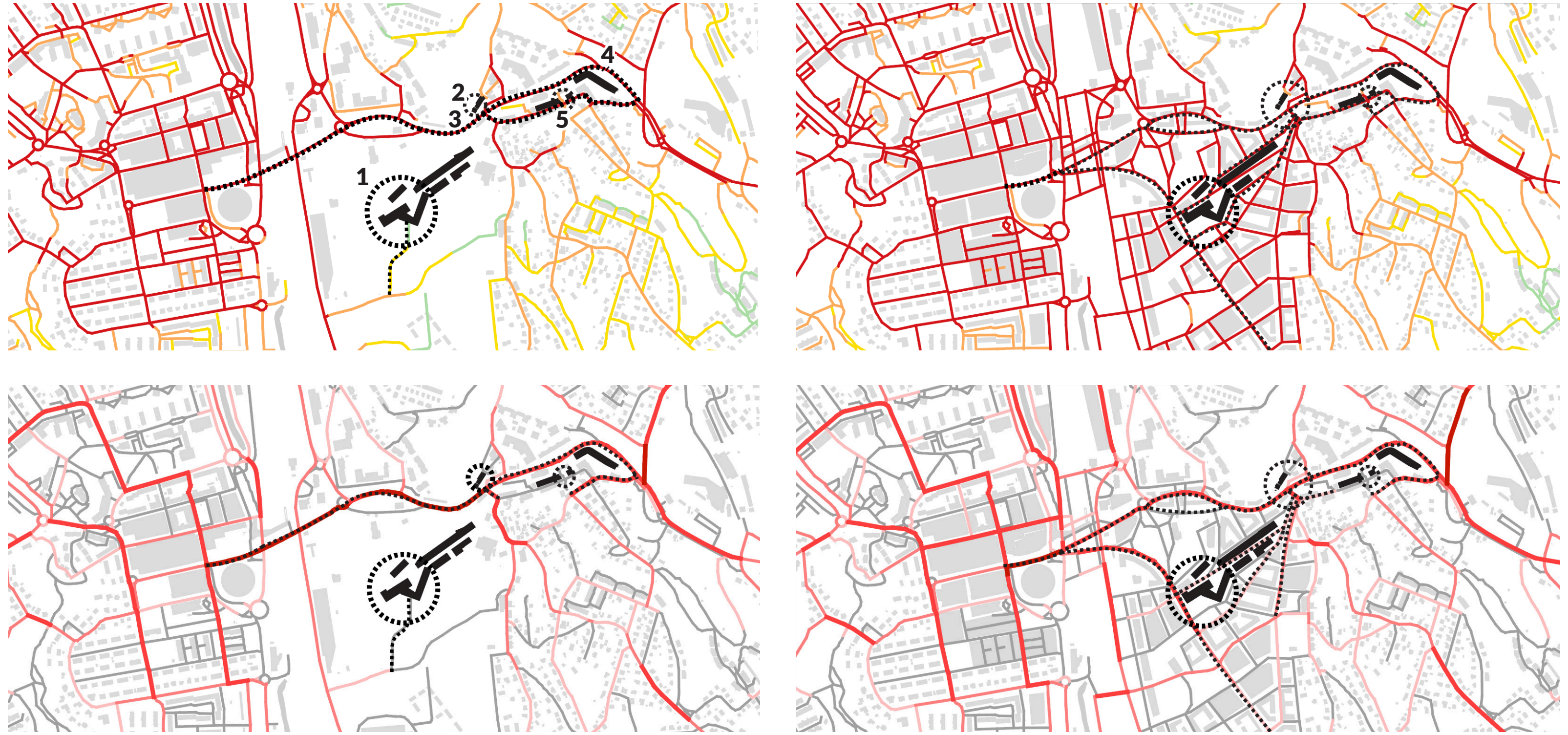
Centrality analysis

To answer the question how the infrastructure transformation might impact accessibility and local movement patterns, centrality analyses are conducted. The results show that the area east of the station has a higher centrality and the bridge crossing the tracks at the height of the station is the street with highest centrality (figure 42 and 43). The new development Forsåker shifts centrality towards the east, meaning that this area will become more of a destination in the local movement patterns.

However, the two new bridges crossing the tracks are needed for a shift in betweenness centrality, meaning that without these new bridges no large number of people passing through can be expected in Forsåker. This might have impact on the possibilities to establish commercial functions along this new axis.

The increased centrality recontextualizes also some important cultural-historical features such as Kvarnbygatan, gamla torget and Papyrus (Figure 44). With the new bridges and the developments in Forsåker, a new high street might develop that changes connections and characters of especially gamla torget and Papyrus.

Figure 43.
Betweenness centrality 2km
current situation (left), new
development Forsåker (middle)
and two new bridges crossing the
tracks (right)



Buildings of cultural-historical importance

1. **Papyrus**
2. **Gamla torget**
3. **Kvarbygatan**
4. **City museum**
5. **Mölndals Kvarnby Industrial museum**

Figure 44.
Recontextualization of important
features in relation to the new
centrality areas and paths. Current
situation (left), new development
Forsåker with two new bridges
crossing the tracks (right)

Habitat fragmentation

The question about fragmentation focuses on the habitats that are of importance for bats. Neither habitat networks and habitat patches are expected to be impacted by the changes in infrastructure because the area is already fragmented and no new risks for habitat loss and habitat fragmentation are added (figure 45). Therefore, a before-after analysis is not needed.

- Nesting sites
- Dispersal area, min50% probability
- Dispersal area, min25% probability
- Dispersal area

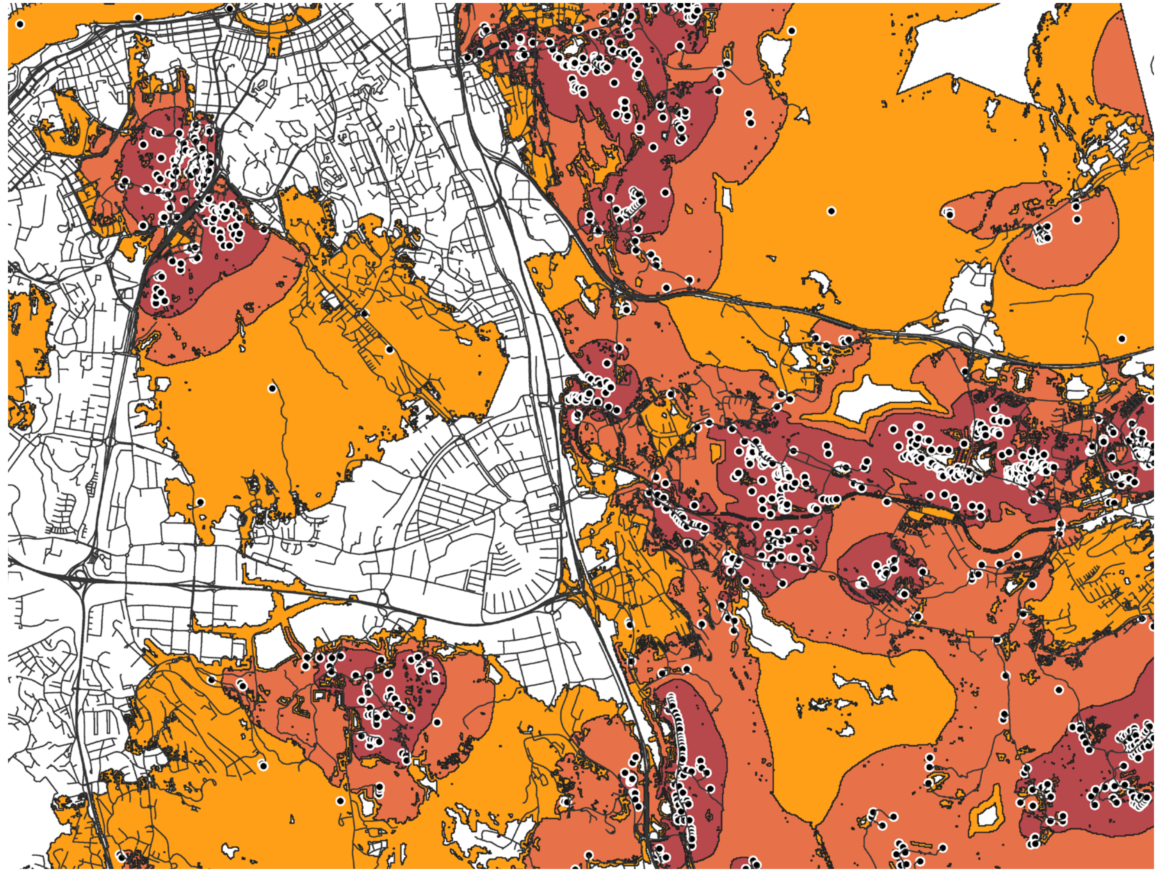
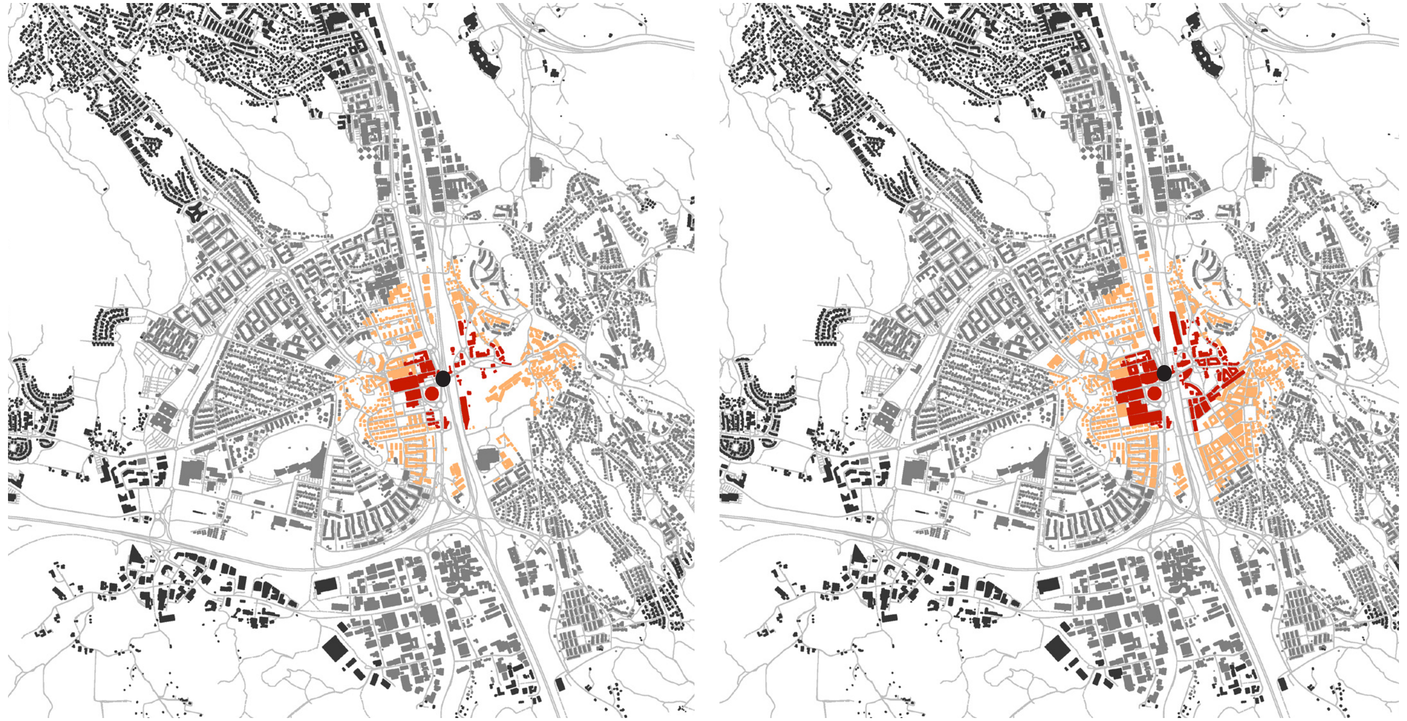


Figure 45.
Potential habitats and dispersal areas for forest-dwelling bats, Current situation

Accessibility analysis

The biggest change in the area is related to the added dwellings and other functions in Forsåker and not to changes in the infrastructure. This does mean that more people are living and working within a 500-meter threshold from the station and Mölndal centre (increase of 50% within 500 meter and 15% within 1km), which is positive for the investments in the station (figure 46). The analyses of accessibility of schools, recreational areas and target points all show that the infrastructure transformations do not increase nor decrease accessibility.



Before	After
0- 500m (80 build.)	0- 500m (114 build.)
500-1000 (607build.)	500-1000 (696 build.)
1000-2500	1000-2500
>2500	>2500

Figure 46.
Proximity to station (i.e. catchment) from all buildings before (left) and after (right)

Societal consequences

The societal consequences are described by the project team by weighing the size of the effects with the value of the environmental aspect that is assessed (Checkpoint 3 in figure X). To be able to link the different effect analyses to the environmental interests highlighted in the Environmental Assessment method (Miljö Konsekvens Bedömning (MKB) in Swedish) used by the Swedish Transport Administration, the consequences are grouped accordingly: natural environment, cultural environment and human health (in Swedish: naturmiljö, kulturmiljö, befolkning och hälsa).

Socioeconomic and social-ecological consequences (linked to human health in MKB)
Accessibility to important services such as schools, sport facilities, recreational areas and target points related to workplaces are not affected, except for the station itself and Mölndal centre that are reached by 50% more people within a 500-meter distance threshold. The positive impact deceases at larger distances.
A potential new high street crossing the new area Forsåker is highly dependent on the new bridges crossing the tracks. If these are not realized, the risk is the street loses through movement and will become less attractive for commercial activities. Because no businesses are located here today, the risk is mainly that the willingness to establish new businesses is low.

Overall, we see positive consequences of the new development Forsåker in relation to the station development. To secure establishment of businesses and commercial activities in the new area, it is important that new bridges are developed that cross the tracks. Whether the same results can be reached with only one bridge should be investigated further.

Cultural-historical consequences (linked to cultural environment in MKB)
The developments have no negative effects in relation to the cultural-historical value of Kvarnbygatan and positive effects for gamla torget and Papyrus where increased centrality improves the connection to and character of these features. Overall, we see positive consequences for the cultural environment, especially gamla torget and Papyrus.

Ecological consequences (linked to natural environment in MKB)
Partly because fragmentation has taken place in the past, there are no further negative consequences of the new infrastructural changes.

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APPENDIX 1

STEP 1

LAYER	MAP	DESCRIPTION OF LAYER	QUESTIONS		
			SOCIO-ECONOMIC	CULTURAL - HISTORIC	ECOLOGICAL
SUBSTRATUM					
NETWORKS					
LAND OWNERSHIP					
PUBLIC SPACE					
BUILDINGS					
USE					
USERS					

STEP 2

LIST OF ANALYSES	DESCRIPTIONS			THRESHOLD VALUES
	SOCIO-ECONOMIC	CULTURAL - HISTORIC	ECOLOGICAL	
CENTRALITY				
Closeness centrality				Relative (ranges, %)
Betweenness centrality				Relative (ranges, %)
Attraction betweenness				Expert knowledge
CONNECTIVITY				
Ecological connnectivity				Expert knowledge
Physical connnectivity				Expert knowledge
Visuall connnectivity				Expert knowledge
ACCESSIBILITY				
Proximity				Absolute numerical
Density				Expert knowledge
Diversity				Expert knowledge
INFRASTRUCTURE EXPOSURE				
Direct exposure				Absolute numerical
Indirect exposure				Expert knowledge

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APPENDIX 3. DATA SOURCES

> Blockdatabasen, Jordbruksverket.se

> Ång och bete, TUVA databasen, Jordbruksverket.se

> Habitat patches and networks (species: smooth snake, Coronella austriaca), Söderköping, Calluna AB

> Habitat patches and networks (species: bats), Mölndal, Calluna AB

> Motorised street network, Spatial Morphology Group (SMoG), Chalmers University of Technology, https://doi.org/10.5878/06c6-aw77

> Non-motorised street network, Spatial Morphology Group (SMoG), Chalmers University of Technology, https://doi.org/10.5878/x49h-pv07

>GSD-Översiktskartan, Lantmäteriet (zeus.slu.se)

> Open Street Maps, OSM, Points of Interest (POIs), geofabrik.de

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