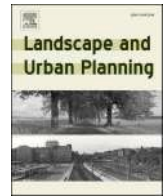


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## Planning for transformative change with nature-based solutions: A geodesign application in Stockholm

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### HIGHLIGHTS

- Geodesign is key for crafting innovative plans, managing trade-offs, and involving stakeholders.
- A geodesign process was implemented in Stockholm, involving fourteen stakeholders.
- Participants drafted transformative plans addressing local housing needs and promoting biodiversity and ecosystem services.
- Participants found proposed transformative change desirable but were skeptical about its plausibility and probability.
- It is crucial to strategically engage stakeholders, prioritize user-friendly tools, and explore web-based applications.

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### ABSTRACT

Advancing towards urban futures in which both human communities and ecosystems can thrive requires transformative change (TC). Spatial planning can serve as a backbone for inspiring and fostering the desired transformation of cities. However, to support this transformation, the challenge for spatial planning is to create unconventional plans that account for the complex trade-offs and interactions of different scenarios through participatory procedures. A promising approach for addressing this challenge is geodesign, since it couples spatial co-design with impact simulations. This paper aims to explore how, and with what effects, a geodesign process can support the co-creation of transformative urban plans that enhance biodiversity and ecosystem services while meeting urban development goals. A geodesign process was developed and deployed for a case study neighborhood in Stockholm, Sweden. Two scenario storylines were developed: one that follows the current city plan, and another one where the most transformative elements of the plan are further emphasized. Fourteen planning stakeholders divided into three groups translated the storylines into actual land use changes and explored the impacts of the two scenarios. The study findings indicate that the geodesign process enabled participants to develop transformative plans that address housing needs while also promoting biodiversity and ecosystem services through nature-based solutions. Participants showed high perceived desirability of TC scenarios in Skarpnäck but were mostly sceptical regarding the plausibility and probability of future implementation. Changes in perceived plausibility, desirability and probability comparing before and after the geodesign process were minor, with some inter-group variation. We recommend practical applications of geodesign to strategically involve key stakeholders throughout study conceptualization, scenario development, and model generation for better consideration of context. Enhancing geodesign tools for user-friendliness is also crucial. We suggest geodesign research to focus more on understanding its impacts on participants as well as scaling up for addressing complex challenges in metropolitan and landscape planning.

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## 1. Introduction

Advancing towards urban futures in which both human communities and ecosystems can thrive requires transformative change (Diaz et al., 2019; Elmquist et al., 2019; Wyborn et al., 2020). According to IPBES, transformative change (TC) can be defined as a “fundamental, system-wide reorganization across technological, economic, and social aspects, encompassing paradigms, objectives, and values” (Diaz et al., 2019). TC in cities and metropolitan regions is crucial in addressing environmental crises and social challenges of today (Hodson & Marvin, 2009, 2010; Scoones et al., 2020). Ongoing global urbanization processes have far-reaching effects on resource and energy consumption and related socio-economic processes, resulting in significant pressure on biodiversity and ecosystem services (Díaz et al., 2019; Oke et al., 2021). At the same time, cities and metropolitan regions provide dynamic environments to experiment with new and more sustainable configurations of socio-ecological and technological systems (Markolf et al., 2018; McPhearson et al., 2023; Pereira et al., 2020). Although there is an increasing recognition of the need for TC, there is less consensus on the nature of TC, how to facilitate it and whether it invariably produces positive outcomes for all (Blythe et al., 2018; Feola, 2015; Newell & Simms, 2020; Salomaa & Juhola, 2020). Disagreements concern the modes, methods, and speed of transformation, the magnitude of the change, and the scale of the reconfigured system (Bulkeley et al., 2020; B. O. Linnér & Wibeck, 2020; B.-O. Linnér & Wibeck, 2019; Salomaa & Juhola, 2020). Empirical research is lacking on how to incorporate and operationalize TC through planning in the context of cities and metropolitan regions (Mansur et al., 2022).

Spatial planning can serve as a backbone for inspiring and fostering the ‘desired’ TC of cities and metropolitan regions. However, its potential to address urgent environmental issues in a transformative way has yet to be fully exploited. Spatial planning, including urban and landscape planning, seeks to guide spatial development in cities and metropolitan regions (Hersperger et al., 2019). By outlining scenarios for future development, providing insights on their respective impacts, and enabling participatory planning procedures (Albert et al., 2019; Bateman et al., 2013), spatial planning can effectively guide urban development towards sustainable outcomes. Approaches to spatial planning vary from traditional positivist perspectives, where planners act as external experts detached from political influences (Davoudi, 2012; Healey, 2013), to more contemporary reflexive and relational approaches that challenge the fundamental nature of planning (Rydin, 2007). Regardless of the approach and despite its potential, spatial planning has only been partially successful in addressing the pressing problems of biodiversity loss and environmental degradation (Albert et al., 2020). Many cities have developed ambitious strategies and comprehensive plans. However, these plans often fail to be truly transformative, as they tend to reflect and reinforce existing development trends (Cortinovis & Geneletti, 2018). To push these plans in a more transformative direction, it is essential to promote collaboration between different stakeholders and perspectives (McPhearson et al., 2021), especially at the local level where actual implementation takes place.

At least three key challenges exist for spatial planning to support TC. *First*, planning processes need to promote and support the formulation of unconventional plans that substantially deviate from previous visions (Albrechts et al., 2020). *Second*, planning for TC needs to consider the complex trade-offs and interactions of different scenarios, for example on biodiversity, ecosystem, services, human wellbeing, and different socio-economic variables. And *third*, planning needs to find new ways for facilitating participatory procedures that allow for not only well-informed debates and negotiations, but also for the actual co-creation and co-exploration of scenarios. Achieving TC requires radical narratives (Kueffer et al., 2019; McPhearson et al., 2021) but the envisioned TC scenarios must at the same time be perceived as sufficiently plausible to achieve stakeholder buy-in (Shipley & Michela, 2006). Plausibility is

particularly important in a context in which the perceived probability of a future is low – a likely circumstance for plans that diverge substantially from the status quo. Transformative futures can be made more tangible through design and visualization that convey landscape implications (e.g. MacEachren et al., 2004; Thorn et al., 2020). However, participatory processes can also potentially dilute transformative ideas to make them more mainstream (Giusti et al., 2018; Wen et al., 2018; Winge & Lamm, 2019). Understanding how design and visualization may influence stakeholders’ perceived plausibility (possibility under stated assumptions), and desirability of transformative scenarios therefore has important implications for their future realization. Additionally, understanding perceived probability (likelihood given current trends) allows for gauging the degree of perceived difficulty of achieving TC, as well as the relative divergence from current trends.

Geodesign is a promising methodological approach to overcoming the challenges of spatial planning for TC (Steiner & Shearer, 2016). It is defined as ‘a design and planning method which tightly couples the creation of design proposals with impact simulations informed by geographic contexts, systems thinking and digital technology’ (Steinitz, 2012). Previous applications revealed its high potential to bridge social perspectives and interests and resolve conflicts over the use of space. Moreover, by facilitating collaborative processes, geodesign can support better decisions as well as foster transformative learning (Forester, 1999; Moura & Freitas, 2021a). Hence, the expected benefits of a geodesign process should be reflected both in its substantive outputs, such as maps and documents that embody better decisions, and in its broader outcomes in terms of participants’ awareness, perceptions and capacities. However, there are still significant gaps in our understanding of how geodesign can facilitate TC in contested urban settings. To advance the field, it is necessary to gain a deeper understanding of how geodesign processes can aid in co-creating spatially explicit plans for TC and support positive perceptions of TC among participants. Additionally, it is important to identify the benefits and practicality of geodesign in improving spatial planning processes, as well as the willingness of practitioners to use such tools (Hooper et al., 2021).

The planning of nature-based solutions (NBS) provides a useful testbed to assess the potential of geodesign approaches to support transformative spatial planning. NBS are defined as ‘actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges (e.g. climate change, food and water security or natural disasters) effectively and adaptively, simultaneously providing human well-being and biodiversity benefits’ (Cohen-Shacham et al., 2016). In urban policy and planning discourses, NBS play a significant role in re-defining people-nature relations in urban environments and thus accelerating urban sustainability transitions (Adams et al., 2023). NBS offer significant opportunities for collaborative design practices aimed at benefiting both people and the environment (Anderson & Renaud, 2021; Frantzeskaki, 2019; McPhearson et al., 2023; Raymond et al., 2017). For instance, nature-inspired regenerative projects (Zari, 2014) in metropolitan regions have proven their effectiveness in curbing pollution (Martínez-Bravo et al., 2019) and mitigating biodiversity loss.

Geodesign has been increasingly applied in collaborative spatial planning involving NBS across various socio-ecological contexts. For example, in Brazil, Moura and colleagues have conducted several geodesign studies using the GISColab platform to inform sustainable development pathways (Moura et al., 2022), and assess the scalability of their approach in 13 metropolitan regions (Moura & Freitas, 2021b). Campagna and colleagues applied geodesign, supported by the Geodesign Hub platform, to develop future scenarios for the Pampulha region in Brazil (Campagna et al., 2016) and to integrate green infrastructure into strategic spatial planning in the Metropolitan City of Cagliari, Italy (Campagna et al., 2020). In Germany, Gottwald et al. (2021) applied geodesign to river landscape planning and found it geodesign effective in supporting negotiation on NBS interventions. Similarly, Schröter et al. (2023) evaluated the use of geodesign tools for virtual participatory mapping of NBS in Costa Rica’s Grande de Tárcoles River basin and reported their

value in engaging local stakeholders. While these studies highlight the potential of geodesign, none of them explicitly adopt a transformative change lens. This represents a gap in existing research, as the transformative potential of geodesign for addressing systemic challenges and fostering sustainability transitions remains underexplored.

The aim of this paper is to explore how, and with what effects, a geodesign process can support the co-creation of transformative urban plans that address the need for new housing development while at the same time safeguarding and enhancing biodiversity and ecosystem services through NBS. To this end, we developed and deployed a geodesign process for a case study neighbourhood in Stockholm, Sweden, during which several groups of stakeholders each developed and explored the impacts of two scenario. The first scenario assumes the current spatial development strategy for Stockholm City is implemented. The second assumes a TC scenario much more radical in terms of the integration of NBS for urban transformation. The research questions are: *i) To what degree does a geodesign process enable participants to design TC scenario that meets housing development needs while enhancing biodiversity and ecosystem services? ii) to what extent does the geodesign process alter participants' perceptions of plausibility, desirability, and probability of TC?*

The Stockholm City was chosen as the research site of due to its relevance in addressing urban transformation challenges including population growth, limited land resources, climate change, and biodiversity loss (Adem Esmail et al., 2022; Brokking et al., 2021). The Skarpnäck district was specifically selected for its representation of cross-scalar planning issues, ongoing formal planning processes, and the willingness of stakeholders to explore alternative scenarios collaboratively. A key planning challenge in this district is integrating new housing and NBS within specific neighbourhoods while considering their broader impact on regional green infrastructure and associated biodiversity and ecosystem services. This necessitates the use of effective planning tools for the exploration, co-design, and negotiation of solutions.

## 2. Research design, materials, and methods

Geodesign is a novel but increasingly popular approach that

enhances traditional spatial planning and design by harnessing the capabilities of geographic information systems (GIS) coupled with modelling tools for rapid suitability and impact assessment. It integrates scientific knowledge and societal values into alternative scenarios through on-demand simulations and impact analyses (Ervin, 2012). Implemented in scenario-based workshops using GIS interfaces, geodesign fosters anticipatory knowledge by creating coherent visions of the future (Iwaniec et al., 2020).

This study follows a structured research design with three phases: preparation, implementation, and evaluation. These phases encompass six core steps of a scenario-based geodesign process, involving stakeholder engagement and data collection for crafting scenario storylines and a workshop using a customized GIS interface connected to a large touch-enabled screen (or touchable) (Fig. 1). Although a workshop is suitable also for the crafting of scenario storylines, we relied on iterative collaborative drafting between researchers and practice partners – drawing on their expertise and conversations with local stakeholders.

In the preparation phase, the study area's setting and challenges were co-defined through transdisciplinary interactions and a review of planning documents (Step 1). Subsequently, two scenario storylines for urban futures were co-developed – one following the existing Stockholm City Plan (SCP) (City of Stockholm, 2018) and another with more transformative goals for NBS adoption (Step 2). Key informants participated in this step to ensure correct interpretation of the SCP and inclusion of all relevant aspects in the scenario storylines. A customized GIS interface was created using ArcGIS 10.8.1, integrated with the CommunityViz V2 Scenario 360 extension.

During the implementation phase, a GIS-assisted workshop spanned two half-day sessions. Using the GIS interface, stakeholders conducted a suitability analysis to identify optimal areas for achieving goals, including new housing and NBS provision (Step 3). Subsequently, participants defined land use changes (Step 4) and assessed their impacts (Step 5) using the same interface.

In the evaluation phase, feedback surveys and reflective discussions were conducted on the geodesign process (Step 6). Additionally, outputs such as land use designs and the assessment of their impacts on selected ecosystem services were compared to identify similarities and

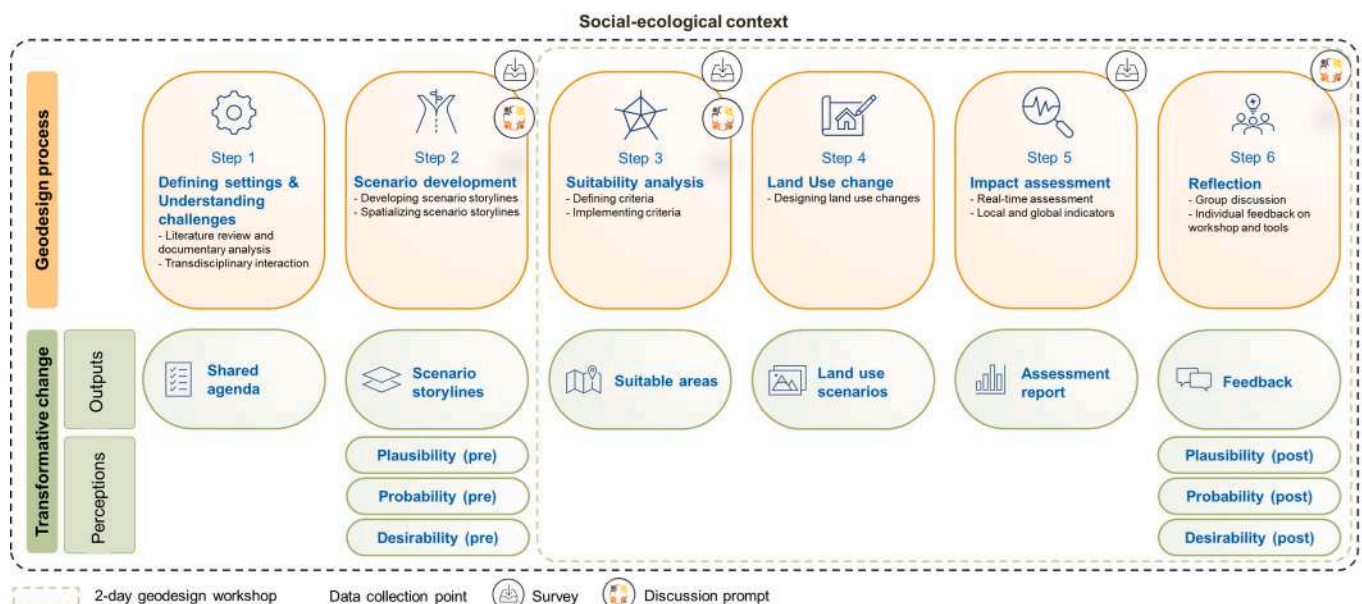


Fig. 1. Conceptual framework of the 6-step Geodesign process, expanding upon previous research (Gottwald et al. 2021; Albert et al., 2021). The framework involves discussions (e.g. in the form of a workshop) for crafting scenario storylines (step 2) and a workshop using a GIS interface with a touch-enabled screen (steps 3–6). In this study, steps 1–2 were conducted based on document analysis and consultation of key informants who contributed to develop and reviewed the scenario storylines, while steps 3–6 were empirically tested with the involvement of fourteen experts in a two-days digital workshop. (Adapted from Adem Esmail et al. (2024)).

differences across groups.

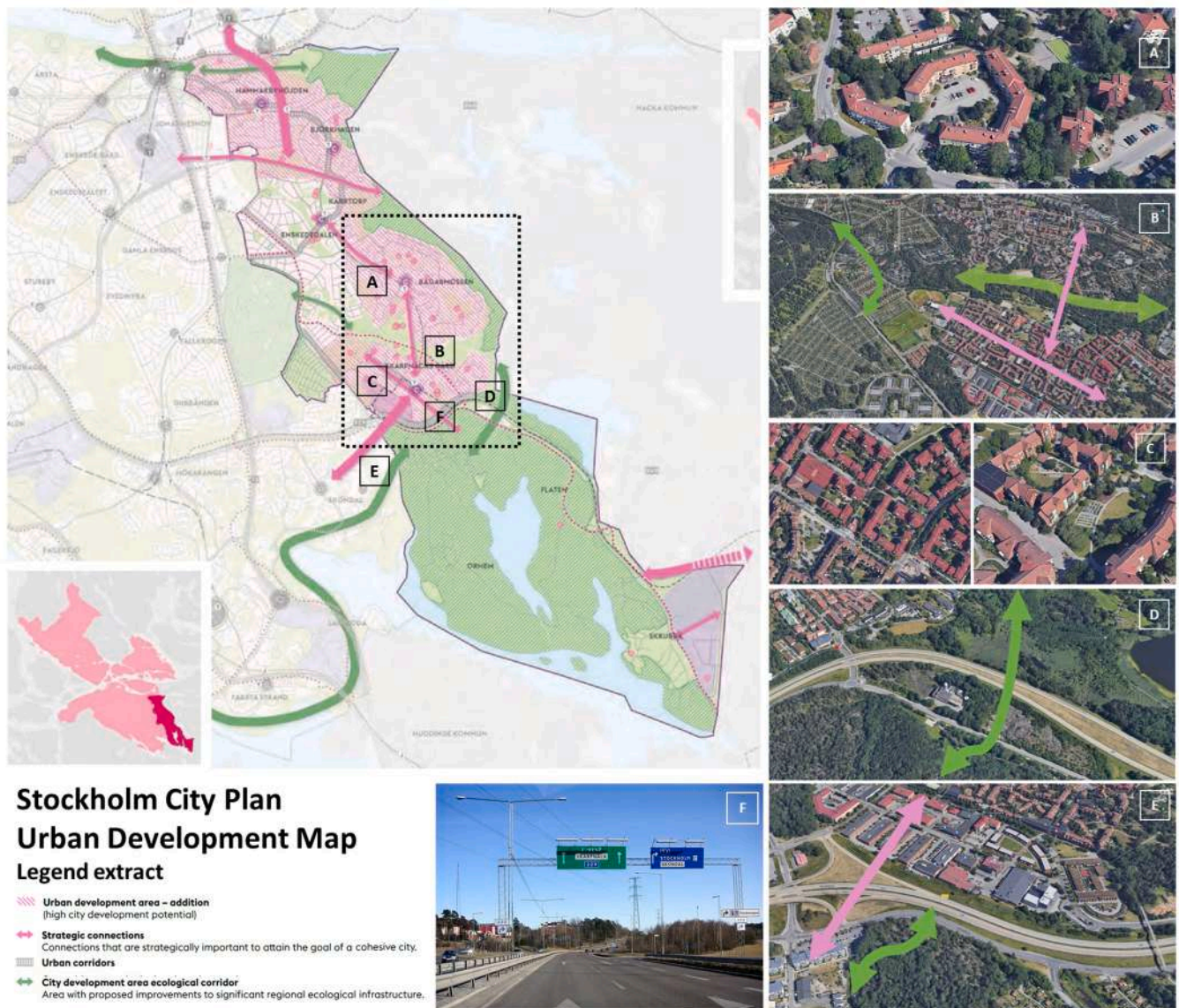
### 2.1. Geodesign process preparation

#### 2.1.1. Co-defining settings and understanding challenges

The Skarpnäck district provides an informative case study due to diverse but typical changes in the context of the SCP of 2018 (Fig. 2). It is situated in southern Stockholm and known for its diverse urban environment and robust transportation. The district is expected to experience a population growth from 46,145 in 2016 to an estimated 64,574 by 2040 (City of Stockholm, 2018). The advantages of the district include access to the Nacka and Flaten nature reserves, as well as the ongoing extension of the metro line that offers prospects for densification. This study focuses on the neighbourhoods of Bagarmossen and Skarpnäck Gård, separated by a ‘central green strip’. Bagarmossen, predominantly developed in the 1950s, features semi-open blocks

integrated with the terrain and a compact local centre. In contrast, Skarpnäck Gård has a grid layout with varied-scale buildings while maintaining consistent character. Of note, the SCP highlights development opportunities along Tyresövägen (a highway traversing the district), to mitigate its barrier effect and better connect Skarpnäck to the Sköndal and Flaten nature reserves.

For the geodesign process, we selected a 750-hectare study area within the Skarpnäck district, focusing on the Bagarmossen and Skarpnäck Gård neighbourhoods (Fig. 3). This selection was done in consultation with a contact person from the Stockholm City. Within the study area, eight sub-areas have been identified as ‘opportunity spaces’ for potential development, including housing and/or NBS. To enhance communication and facilitate local impact assessments, the sub-areas were further subdivided into twenty-seven smaller units by overlaying a 750-meter grid. The grid size was selected following an evaluation of alternative scales, including 500 m and 1,000 m (as exemplified by



**Fig. 2.** The challenges and local development opportunities in the Skarpnäck District study area, as outlined in the 2018 Stockholm City Plan (City of Stockholm., 2018). A) Bagarmossen neighbourhood developed in the 1950 s, with semi-open blocks adapted to the terrain and a small local centre. B) Central green strip between Bagarmossen and Skarpnäck; local ecological corridor between Bagarmossenskogen and Skogskyrkogården (green arrows), local connection between metro stations and urban corridor along Skarpnäck Allé (pink arrows). C) Skarpnäck Gård neighbourhood laid out on a grid with buildings varying in scale but with a uniform character. D) Ecological corridor part of regional ecological infrastructure (Flaten to Nacka nature reserve), and recreational asset to the immediate environment. E) Strategic connection for the goal of a cohesive city (connection to Sköndal waterfront urban development area – transformation). F) Tyresövägen highway barrier effect that could be mitigated to better link Skarpnäck to Sköndal and the Flaten nature reserve.

Gottwald et al. (2021), who partitioned their Lahn River case study into 1-kilometer reaches). This grid size was identified as an optimal balance between detail and practicality.

Through document analysis and engagement with local experts, we identified several primary challenges and co-decided on climate adaptation addressing urban heat and flood risk, biodiversity conservation, and social values, including nature-based recreation. Accordingly, we selected four key ecosystem services related to these challenges: ES1 Local climate regulation, ES2 Stormwater retention, ES3 Habitat (focused on oak trees), and ES4 Nature-based recreation. In subsequent steps, these four ecosystem services were measured as indicators of the impact of the various scenarios.

2.1.2. Scenario development

The scenario storylines were developed in line with the SCP of 2018, through collaborative iterations involving the research team and a contact person from the city. Two scenario storylines were created: the current *SCP Scenario* and the *TC Scenario*. The *SCP Scenario* follows the existing plan, while the *TC Scenario* takes a more radical approach, focusing on NBS to enhance ecosystem services and biodiversity. Going beyond the already progressive SCP, the *TC scenario* adopts a more nature-oriented and forward-thinking perspective that embraces a broader set of nature’s values (IPBES, 2022), emphasizing the stewardship role of humans in conserving biodiversity and ES. The two scenario storylines were articulated around four key aspects: A) *Urban development*, B) *Regional green infrastructure*, C) *Central “green strip”*

between the neighbourhoods of Bagarmossen and Skarpnäcks Gard, and D) *Tyresövägen*, a major highway that crosses the study area and plays a significant role in shaping both the movement of people and ecological connectivity (Table 1). They formed the basis for discussions and activities during the GIS-assisted workshop, including suitability analysis and impact assessment. Participants received the scenarios storylines and a pre-workshop questionnaire (Q1) before the workshop which were discussed during the workshop (D1).

2.1.3. Customized database and GIS interface

A customized database and GIS interface were developed and tested iteratively for the case study area using ArcGIS 10.8.1 and the CommunityViz V2 Scenario 360 extension. This GIS interface incorporated spatial data, geographic calculation tools, assessment models, and an indicator dashboard. Data included background spatial information, such as biotope and sociotope maps, protection statuses, green infrastructure, settlements, and ecosystem service maps (Table 2). An adjusted version of the Biotope SE map (Skånes 2022), based on discussion with local experts, served as the land use land cover map of the area (for detailed information, see Table S2 in Supplementary Material).

The GIS interface provided a suite of tools for conducting suitability analysis (Step 3), land use change design (Step 4), and impact assessment (Step 5). An essential feature was the indicator dashboard that displayed information to track progress toward planning objectives. This included metrics such as additional high- and low-density housing units, ecosystem changes (e.g., oak forest expansion), and ecosystem services

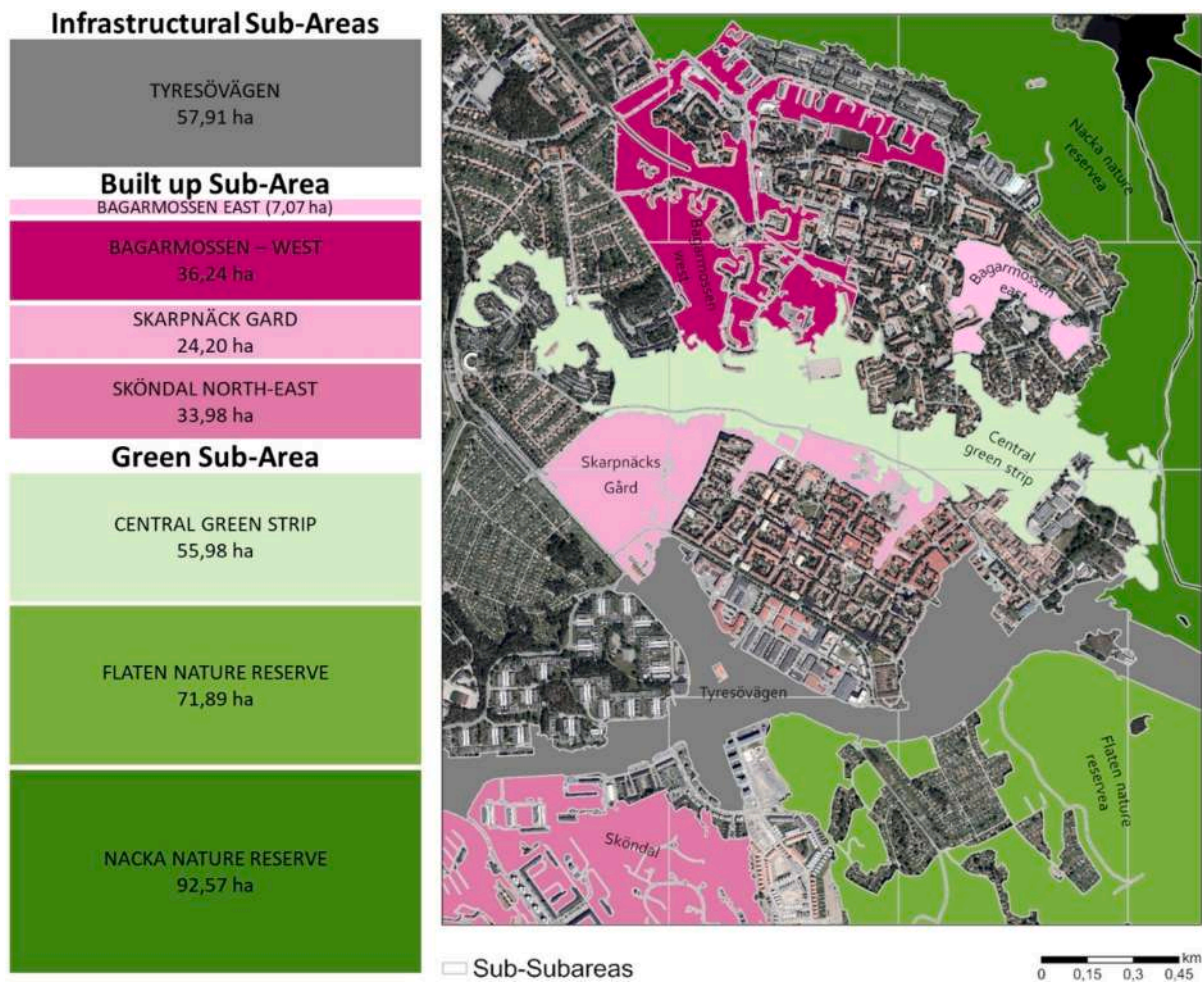


Fig. 3. The study area in the Skarpnäck district, comprising eight sub-areas identified as ‘opportunity spaces’ according to the Stockholm City Plan. These sub-areas vary in sizes and their degrees of disturbance and/or naturalness. Tyresövägen, a major connecting highway, runs through the study area and serves as an important element in the analysis (Adapted from Adem Esmail et al. (2024)).

**Table 1**

Two scenario storylines developed through iterative discussions between researchers and contacts at the Stockholm City. Note the SCP of 2018 is already ambitious in its approach to biodiversity and ecosystem services. The TC Scenario was designed to push these ambitions even further. The two storylines reflect this progression, with a particular emphasis on enhancing biodiversity and ecosystem services.

Key aspects	SCP Scenario	TC Scenario
A) Urban development	Major local development opportunities for new housing, services, businesses, more public spaces are fully exploited.	Urban development is compact with extensive greenspaces to better protect and safeguard local biodiversity and ecosystem services.
B) Regional green infrastructure	The regional green infrastructure is improved, which also enriches the immediate surroundings with recreational values.	There is more space for nature, enabling ecological processes to operate with less human intervention. The vital role of Bagarmossen-Skarpnäck for the connectivity of the regional oak habitat network is restored: the available opportunity spaces for urban development are re-designed to accommodate dynamic natural processes, including habitat quality, quantity, and connectivity.
C) Central "green strip"	The central "green strip" between Bagarmossen & Skarpnåcks Gård is expanded with new activities and destinations to connect the two areas. Existing corridors and social connections both within the areas themselves and to neighbouring municipality and districts are encouraged, as is the potential ecological corridor between Bagarmossenskogen and Skogskyrkogården.	The "green strip" between Bagarmossen and Skarpnåcks Gård is protected, and new forests and parks are created/restored and sustained with native species, strengthening habitat networks and nature-based recreation.
D) Tyresövägen	Tyresövägen maintains its important traffic function, but the barrier effect of the main road is partially alleviated by the development of a busy urban corridor to better connect Skarpnäck with Sköndal and the Flaten nature reserve.	Tyresövägen and the power line are hardly noticeable; this east-west axis is radically transformed to allow enhanced connectivity for both people and nature.

impacts, presented in both aggregated and disaggregated forms using a traffic light scale for intuitive interpretation (Gottwald et al., 2021). The GIS interface facilitated visualization and comparative analysis of the two scenarios in relation to the current state.

## 2.2. Geodesign process implementation

### 2.2.1. Geodesign participants

The participant recruitment process was a collaborative effort between the research team and a contact person from the Stockholm City, aiming to gather a diverse group of participants representing various planning levels and possessing expertise in climate change adaptation, biodiversity, and urban development. Stakeholders with a deep understanding of the Swedish planning system and societal challenges facing Stockholm were targeted. Fourteen experts participated in the geodesign workshop over two half-days, who were divided into three groups (labelled A, B, and C) to ensure active participation. Each group had access to a touch table with the same geodesign interface and was prompted to create two plans. These plans were based on the two scenario storylines developed for the study: the SCP scenario and the TC scenario. Both plans had to meet the requirement for 3,500 additional housing units while integrating NBS in the urban development as they saw fit.

The geodesign workshop participants represented different spatial scales of work (from local to regional), competencies and responsibilities (planning, planning support, and decision-making), and thematic

interests related to social values, climate adaptation, and biodiversity protection. Other characteristics include diverse educational backgrounds, with most holding master's degrees in fields such as urban planning and design, environmental sciences, and architecture, and varying levels of professional experience, ranging from 1 to 27 years (See Table S1 in SM).

### 2.2.2. Structure of the GIS-assisted workshop

The workshop spanned two half-days and comprised eight sessions of different types, including introduction, working, and evaluation (Table 3). On the first day, sessions included setting the stage (20 min), discussing proposed scenario storylines (60 min), and conducting suitability analyses for housing and NBS using the GIS interface (80 min). On the second day, sessions focused on co-designing land use changes and assessing impacts on ecosystem services and biodiversity in the study area, based on the two proposed scenarios (70 and 90 min). The workshop concluded with participants evaluating the effectiveness of the geodesign process in supporting the TC in Skarpnäck and more broadly in Stockholm.

## 2.3. Geodesign process evaluation

### 2.3.1. Evaluating the substantive outputs of the geodesign process

The land use designs co-created during the geodesign workshop are described in terms of the differences between scenarios (SCP Scenario vs. TC Scenario), and participant groups (A, B, C). The amount, size,

**Table 2**

Overview of spatial data implemented in the geodesign tool.

Name	Note	Source
Biotope map	56 biotope classes in the study area	(Skånes, 2022)
Sociotope map	Sociotopes that are important from a nature-based recreation perspective (e.g. nature playground, place of tranquillity, and allotment garden)	(Stähle, 2003)
Orthophoto 2012, 2017	–	(Lantmäteriet, 2019)
Protected areas	4 types of protected areas including Area of national interest for recreation, nature reserves, protected NR, world heritage site, Protected SCI	(SEPA, 2022)
Green Infrastructure (GI) habitats	GI oak forest* habitat, GI coniferous forest* habitat, pine forest* habitat, wetlands habitat	(CAB, 2019)
GI links	GI links of oak forest and of coniferous forest	(CAB, 2019)
GI corridors	GI oak forest corridor 1500 and 2500 m, GI coniferous forest corridor	(CAB, 2019)
Streams	Stream network	(Lantmäteriet, 2022b)
RUFS 2050 greenstructure	Greenstructure according to RUFS 2050 (regional development plan)	(Stockholm County Council, 2018)
ESBO GS	ESBO Stockholm city greenstructure	(City of Stockholm, 2014)
Tree canopy cover	–	City of Stockholm, 2022)
Buildings, roads	–	(Lantmäteriet, 2022b)
Topography	Digital elevation model with 2-m resolution	(Lantmäteriet., 2022a)

\*Including single large trees.

**Table 3**

The design of the two-day workshop, comprising eight sessions and an overview of the surveys and focus group discussion (FGD) prompts in relation to the distinct stages of the geodesign process (see Fig. 1) from a transformative change (TC) perspective. (Adapted from Adem Esmail et al. (2024).

Workshop session	Activities	Geodesign step	Questionnaire (Q) and FGD prompt
Pre-workshop	Define setting and draft scenarios	Step 1, 2	Q1. Pre-workshop survey
Session 1 (20 min)	Introduction		
Session 2 (60 min)	Discussing scenarios	Step 2	FGD1. Discussion prompt
Session 3 (80 min)	Suitability Analysis task: housing and need for NBS	Step 3	Q2. Survey
Session 4 (50 min)	Plenary discussion	Step 3	FGD2. Discussion prompt
Session 5 (20 min)	Recap	Step 1, 2, 3	Discussion
Session 6 (70 min)	Land Use Change and Impact Assessment tasks (Current STCP Scenario)	Step 4, 5	
Session 7 (90 min)	Land Use Change and Impact Assessment tasks (Transformative Change Scenario)	Step 4, 5	Q3. Survey
Session 8 (50 min)	Reflections	All steps	FGD3. Discussion prompt

distribution, and type of land use changes are compared, as well as the related impact on ES. Both qualitative and quantitative comparisons are made at aggregated as well as subarea level to identify emerging patterns.

### 2.3.2. Evaluating the perceptions of participants

To assess changes in perception of the participants, we used a mixed-methods approach consisting of qualitative/narrative data (observations, focus group discussions and evaluation exercise) and pre- and post-workshop quantitative data (short paper-based questionnaires) completed by the geodesign workshop participants (Table 3). Observations were noted during the workshop by at least one researcher and a master's student per group, including audio recording. Researchers observed participants' interactions within groups and with the tool to develop scenarios. Furthermore, all researchers were prompted to reflect on their observations during and after the workshop.

The surveys asked participants to rate their degree of disagreement with statements using a 9-point Likert range (9-point range used to improve differentiation among respondents within the small sample). Items we focus on here assessed the perceived need for TC in the study area and its plausibility, desirability, and probability. Plausibility is important to assess as an indicator of whether scenarios are anchored in reality and can achieve stakeholder involvement while desirability signals the degree to which the stakeholders share preferences and future goals. Plausibility and desirability thus allow for balancing the realistic with the aspirational. We assess *perceived* probability, on the other hand, to indicate how transformative a scenario might be, i.e., considering how current trajectories may or may not lead to future states (Ramírez & Selin, 2014). This is particularly important in the case of Stockholm, where the SCP is more transformative than many other cities. Two out of three surveys administered are relevant to this study, and the full surveys, along with discussion prompts, can be found in Supplementary Material. The first survey was administered electronically 7 days prior to the start of the workshop to establish baseline perceptions of participants regarding their understanding of TC in Stockholm and specifically in the study area. Another survey with TC items was administered at the end of the workshop before the final discussion. The final survey duplicated items from the initial survey to assess changes in perceived plausibility, desirability, and probability of the TC scenario.

Two separate group discussion activities took place at distinct stages of the geodesign process. The first focused on participant perceptions of the TC scenario, also in relation to the SCP and mirrored the quantitative survey items along with general impressions to gain any further qualitative insight from the participants. The final discussion focused on general feedback on each of the tools, allowing participants to provide positive and negative comments, as well as ask questions regarding the workshop content and design.

## 3. Results

During the focus group discussion at the beginning of the geodesign

workshop, participants shared interpretations and potential implications of the scenarios (SCP and TC), discussing the four main aspects characterizing each of them. Overall, the discussions showed the participants' good understanding of the scenarios and initial ideas for the sessions that followed (Table 3).

### 3.1. Substantive outputs

#### 3.1.1. Land use change maps in the SCP and TC scenarios

During the workshop, six different land use designs were created for Skarpnäck, reflecting various perspectives from the three groups under the two scenarios. Significant differences were observed between the proposed land use changes in the two scenarios (Fig. 4 and Fig. 5). In the SCP Scenario, groups primarily concentrated their design efforts on the Skarpnäcks Gård neighbourhood near Tyresövägen. It is notable that all three groups altered the same five sites, likely under consideration for actual development by the city. Conversely, in the TC Scenario, changes were more evenly distributed throughout the eight sub areas, with a particular emphasis on redesigning the region surrounding Tyresövägen and Skarpnäcks Gård. The nature reserves in the eastern part of the study area remained largely untouched, indicating a conservation-focused strategy. Only one group (A) proposed changes in the Nacka Nature Reserve in the TC Scenario. Regarding the type of changes proposed, in the SCP Scenario, groups primarily focused on adding new high-density housing without fully integrating NBS such as oak forests and wetlands. Conversely, in the TC Scenario, groups prioritized the adoption of NBS to address societal challenges while meeting housing demand in the area (see Supplementary Material for land use changes per group and scenario).

#### 3.1.2. Quantitative overview of the co-produced land use designs

All groups successfully achieved the assigned target of 3500 new housing units in the study area for both scenarios, averaging 3503 for the SCP Scenario and 3569 for the TC Scenario (Fig. 6). While Group C prioritized a higher share of medium–low density housing, followed by Group A, Group B decreased the number of medium–low density housing units in both scenarios, displaying a distinct vision from the other groups. The lower graph in Fig. 7 illustrates the varying land use design strategies between groups and scenarios. Notably, the design for the TC Scenario exhibits a consistent increase in oak forest compared to both the SCP scenario and the status quo maps.

#### 3.1.3. Example of substantive planning outputs in Tyresövägen and Skarpnäcks Gård

The geodesign outputs showed how groups approached new housing and NBS under the two scenarios. As examples, we compare design choices in Tyresövägen and Skarpnäcks Gård (Fig. 7). In the SCP scenario, groups pursued distinct strategies. Group A added high-density housing (13.41 ha), converting various areas. Group B added high-density housing (7.36 ha) and green recreation areas (1.37 ha), mainly converting green spaces. Group C introduced high-density (8.67 ha) and medium–low-density housing (0.87 ha), along with recreation

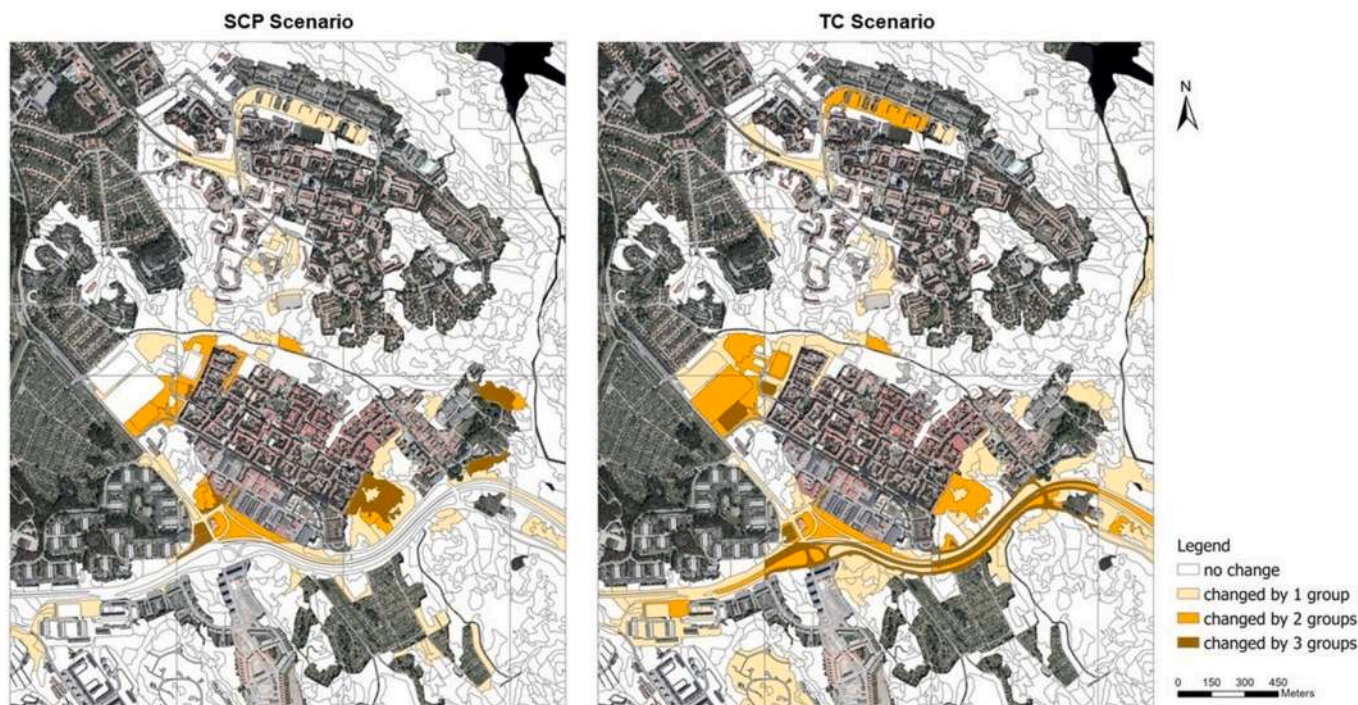


Fig. 4. Comparison of overall land use change maps co-created by the three groups for the two scenarios.

areas. In the TC Scenario, groups made more changes. Group A prioritized medium–low (9.56 ha) and high-density housing (4.33 ha) and recreation areas. Group B added more high-density housing (8.57 ha) and NBS, reducing green spaces. Group C significantly increased medium–low-density housing (12.02 ha) and NBS, with reductions in infrastructure and green spaces.

Similarly, in both scenarios, Groups A, B, and C pursued different strategies in Skarpnäck's Gård. In the SCP Scenario, Group A prioritized high-density housing (+2.76 ha) and urban structure (0.27 ha), reducing green spaces and lawns (−2.33 ha). Group B's high-density housing expansion led to significant losses of green spaces and structure. Group C adopted a mix of housing, mainly impacting green areas. In contrast, in the TC Scenario, all groups followed environmentally conscious approaches by integrating NBS. Groups A, B, and C added blue space/infrastructure (5.41 ha, 0.69 ha, and 7.26 ha respectively), while Group A included oak forest (1.55 ha).

#### 3.1.4. Impacts on ES: Current scenario vs TC scenario for Skarpnäck

During the geodesign process, the land use designs' impact on ecosystem service provision was assessed in real-time to aid participants' negotiations and decisions. Fig. 8 compares land use designs of the three groups for both scenarios, showing the TC Scenario outperforming the SCP Scenario in enhancing ecosystem services potential. The SCP Scenario generally has a negative impact on ecosystem services potential, except for a few cases. Tyresövägen and Skarpnäck's Gård, the focus areas, experienced the highest impacts. Group A had the most positive impacts in the TC Scenario, while Group C had the highest negative impacts in the SCP Scenario, particularly in Tyresövägen. Similar patterns were observed at the local level (see Supplementary Material).

### 3.2. Change in the participants' perception of TC

#### 3.2.1. Pre-workshop perception of need and potential for TC in Stockholm and Skarpnäck

Participants generally exhibited high familiarity with planning in Stockholm (7.45) and just a slightly lower familiarity with the local area

(6.36) (Fig. 9). Only two respondents were highly familiar with Stockholm planning but had limited experience in the local area. Group A participants consider themselves very familiar with the SCP and planning in the Skarpnäck district (8.25/7.8), followed by Group B (7.3/7.3) and Group C (6.7/6).

Participants widely perceived a high need for TC in the study area (average 7.3, minimum 5). Groups B and C strongly agreed (mean 8 and 7.7) that there is need for TC in Skarpnäck, followed by Group A, which agreed to a lesser extent. During the focus group discussions, participant B1 emphasized TC's necessity for enhancing and maintaining urban biodiversity, citing instances of housing developments encroaching upon green spaces in southern Stockholm. A3 highlighted the high value of green spaces in Stockholm, mentioning the absence of forestry, but also the need to utilize them alongside urban areas for new housing. B3 stressed Stockholm's significant natural forested areas, emphasizing the moral obligation to preserve them. A2 acknowledged challenges in urban planning, emphasizing collaborative efforts, integration of regulations, and the need for effective tools to prioritize conflicting ecological and social aspects, such as the 'green' and 'pink' arrows in the SCP (Fig. 2).

There was also a consensus that the current SCP does not go far enough in terms of using NBS to integrate biodiversity and ecosystem services goals (with an average score of 3.5; only one respondent rating above the midpoint at 7). During the focus group discussion, participants expressed varying perspectives on how the current plans utilize NBS for these goals. A2 noted 'greening' is currently used as a 'restriction', calling for strategic guidance and resolution of conflicting city perceptions. C3 highlighted the trade-off between nature protection and development, urging clear expressions in the plan to address this. A3 recognized political progress in including NBS but stressed the need for awareness and practical implementation. Overall, while there is acknowledgment of improvement in the current plan, concerns persist regarding strategic guidance and NBS implementation for enhancing ecosystem services and biodiversity.

These concerns were reflected in the survey item assessing perceived probability of the TC scenario (mean 4.3 with min = 2; max 9). During the focus group discussion, perspectives from A3 and B1 conveyed

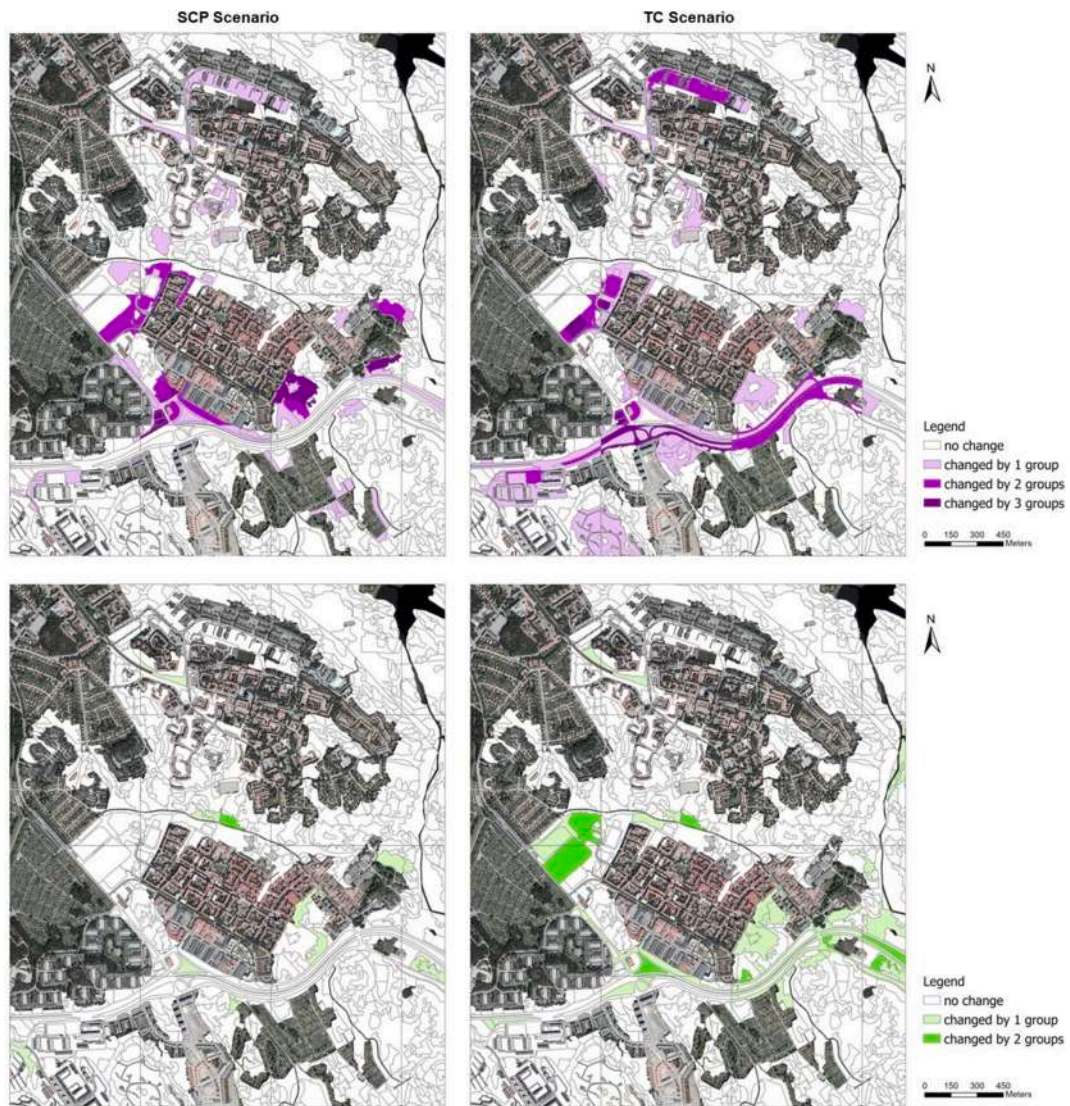


Fig. 5. Comparison of land use change maps co-created by the three groups for the two scenarios: upper panel changes to housing and lower panel changes to NBS.

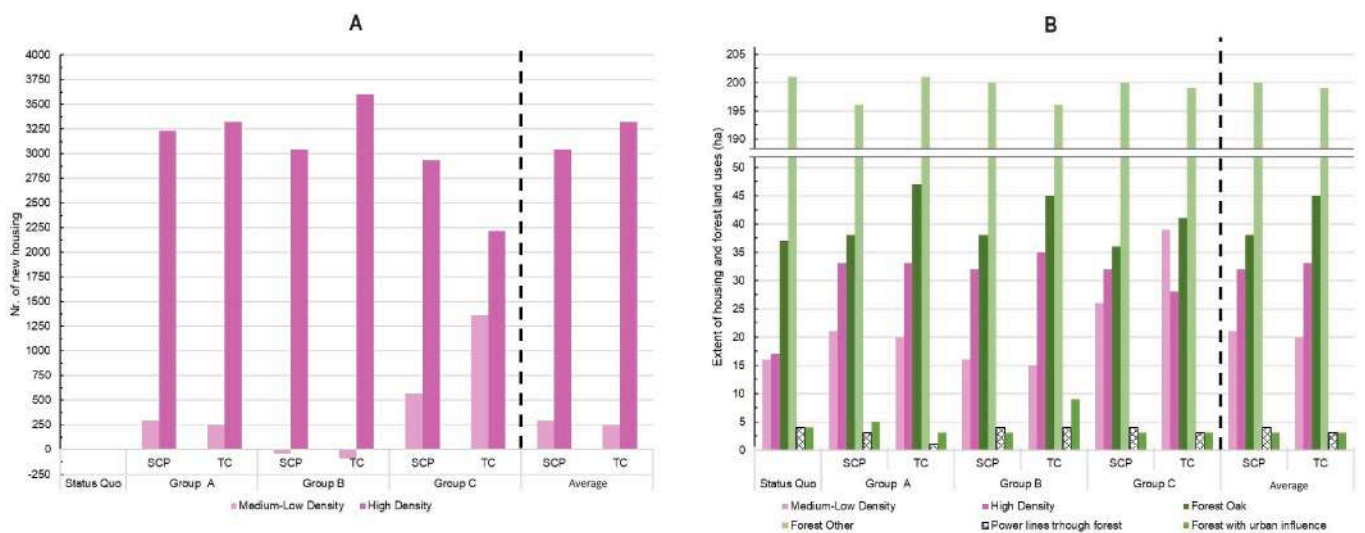


Fig. 6. Illustrative comparison of the proposals of the three groups for the two scenarios in terms of the number of new housing units (A) and the extent of land use for housing and forests (B), relative to the status quo.

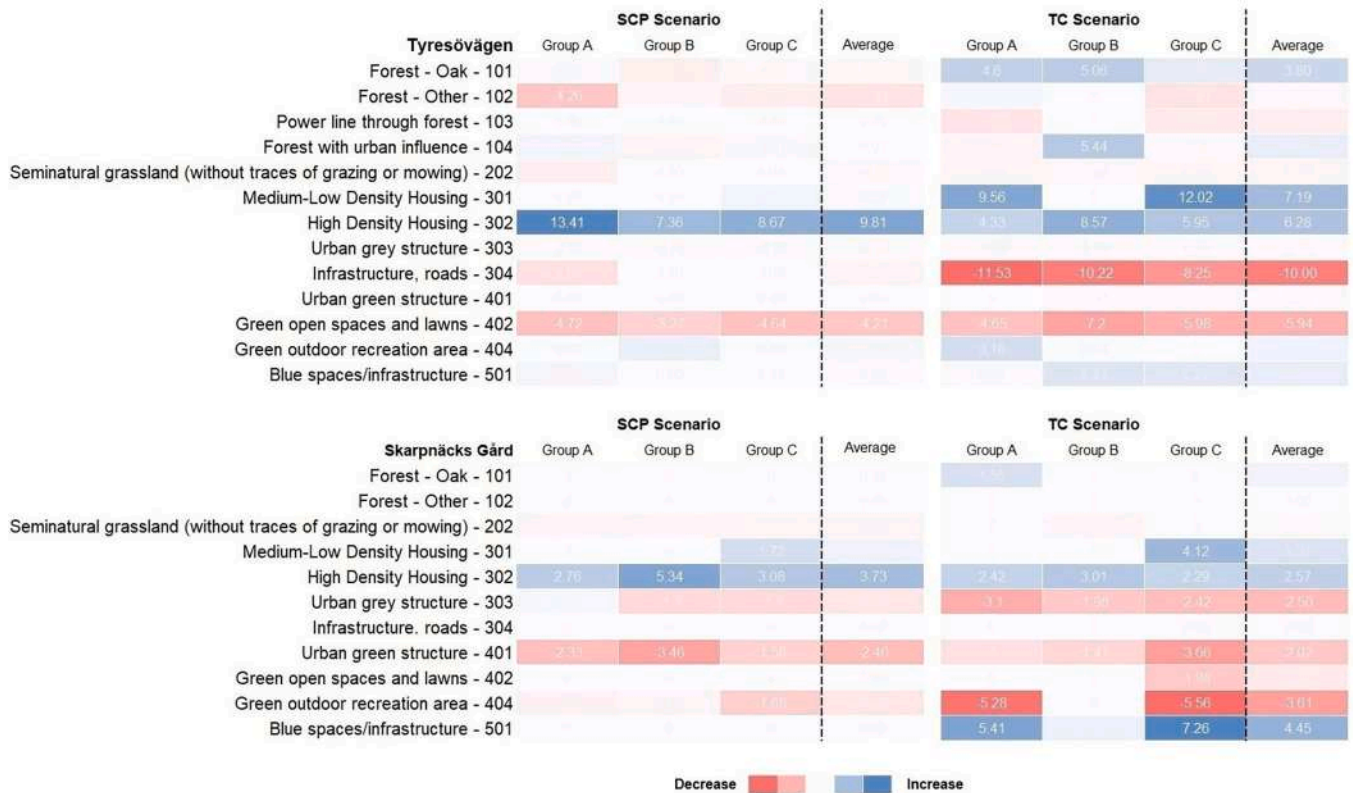


Fig. 7. Illustrative comparison of the proposals of the three groups for the two scenarios in terms of the extent of land use changes (ha) in the Tyresövågen (upper panel) and Skarpnäcks Gård (lower panel) sub-area, relative to the status quo.

uncertainty and scepticism regarding the probability of the TC scenario for Skarpnäck. A3 cautiously expressed optimism, but this was found to not necessarily related to the current trajectory but rather due to potential solutions from the geodesign process and the workshop. B1 voiced concern about the lack of observed progress on the ground, particularly regarding diminishing green space and ongoing developments favouring cars over TC towards sustainability. While participants were also dubious about the plausibility of the TC Scenario (mean 5.6 with min 1.0; max 9.0), they strongly agreed about its desirability for the future of Skarpnäck (7.8 with a min of 7).

3.2.2. Changes in perceived plausibility, desirability, and probability of TC

Participants' perceptions of the TC Scenario for Skarpnäck underwent subtle changes pre- and post-workshop (Fig. 10). Before the workshop, plausibility ranged from 1 to 9, with a mean of 5.6. After the workshop, plausibility slightly increased, ranging from 3 to 9, with a mean of 6. Regarding desirability, pre-workshop perception ranged from 7 to 9, with a mean of 7.8. After the workshop, it ranged from 6 to 9, with a mean of 8, indicating a slight increase. We did not expect any changes in probability, since the workshop only presents a TC scenario but had no relevance to the many external variables related to likelihood of achieving it. Perceived probability slightly decreased, ranging from 2 to 6, with a mean of 3.8.

As shown in Fig. 11, Group A experienced a moderate increase in perceived plausibility of the TC Scenario for Skarpnäck and Group B saw a decrease, reflecting varied responses within participant groups. Desirability perceptions showed mixed patterns, with Group A perceiving a decrease, Group B maintaining consistency, and Group C expressing an increase in desirability. These nuanced shifts highlight the complexity of participant perspectives, reflecting both optimism and caution in evaluating transformative possibilities for Skarpnäck.

Individual responses to the TC Scenario for Skarpnäck revealed a nuanced spectrum of perceptions. A1 and C1 showed a positive shift,

reporting increased plausibility, desirability, and probability. Conversely, B2 expressed scepticism, showing decreases in all aspects. A4, B1, and B4 maintained consistent viewpoints. B3, A3, C4, and C2 presented mixed evaluations, with increases in one aspect and decreases in others. A2's unwillingness to respond and C3's absence led to their exclusion from analysis. These diverse responses underscore the complexity of participants' perspectives that need further investigation.

4. Discussion

Reflecting on three key topics supports in-depth discussion on how geodesign can support the co-generation of transformative urban plans with NBS. The first topic pertains to the substantive outputs of the geodesign processes and their effectiveness in operationalizing TC in an urban planning context. The second topic focuses on the impact of the Geodesign process on participants' perceptions of the plausibility, desirability, and probability of TC. The third topic concerns the overall implications for planning practice.

4.1. Geodesign processes for facilitating co-design of alternative futures for TC

As the results reveal, the applied geodesign process promises substantial potential and can, in principle, encourage the processes and practices of transformations towards urban sustainability. Geodesign can be used to inspire and support participants, think 'outside the box' or 'think the unthinkable', co-produce different land use planning scenarios while being able to compare them, and assess the environmental and ecological impacts of the planned land use changes. The co-generated knowledge from the geodesign process can, in turn, support the generation of plans that meet the city's needs and targets for population growth while improving biodiversity and ecosystem services. Stimulated by the narrative of the TC Scenario for Skarpnäck, all groups

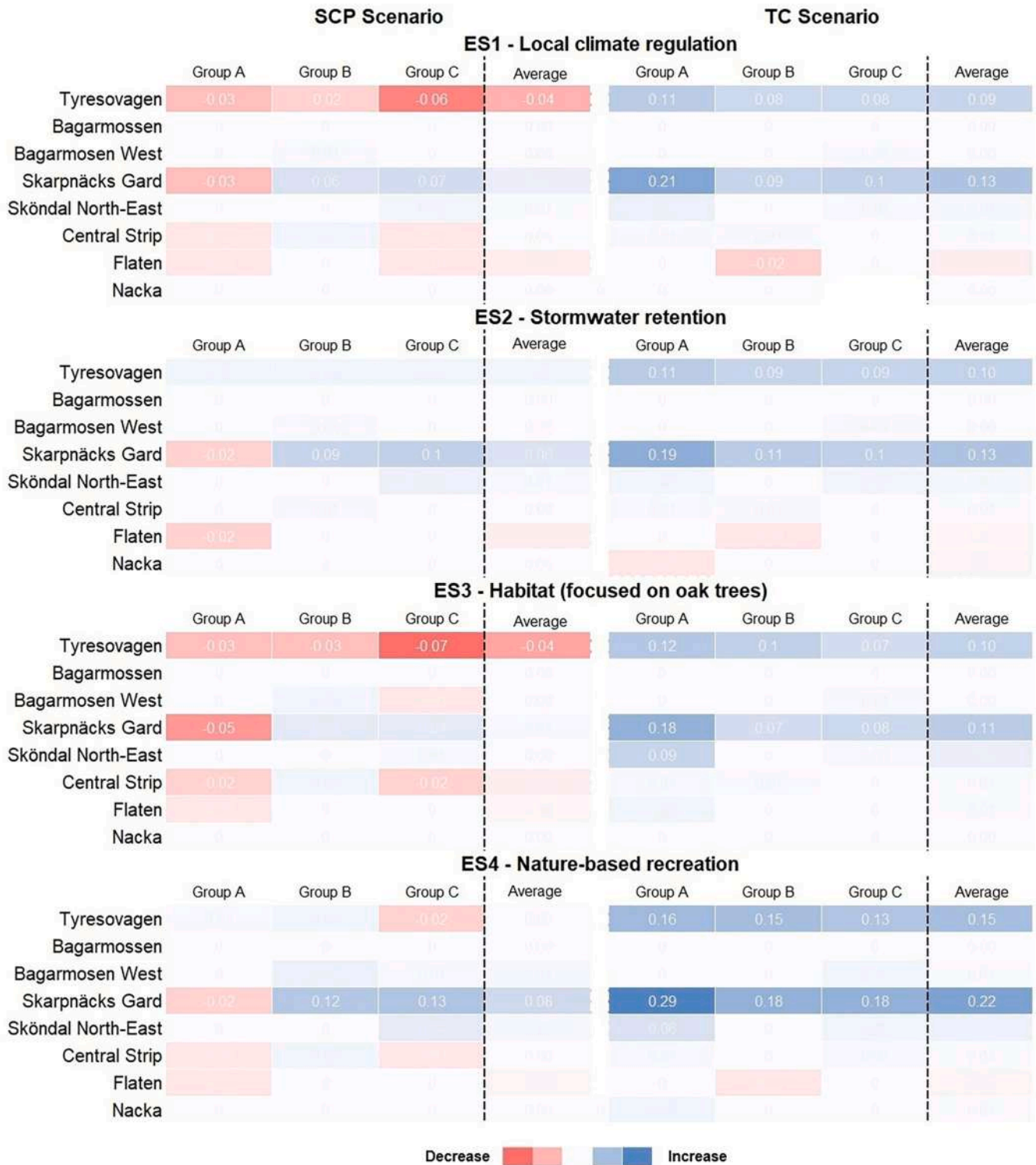


Fig. 8. Comparison across scenarios, and groups of the proposed land use changes based on their impact on selected ES. The values represent changes in terms of average ecosystem service values (0–3) with respect to the status quo.

were successful in envisioning more transformative alternative futures, despite the already-advanced approach promoted by the SCP Scenario. 'Transformative' features recognized in the maps produced for the TC scenarios as compared to those of the SCP scenario refer both to more extensive interventions in terms of the area involved and to a broader range of land uses deployed. Interestingly, all three groups included some blue (water) areas among the NBS proposed in the TC Scenario,

something not considered in the SCP scenario and never explicitly mentioned in the narratives. Often, these proposed blue areas correspond to spaces currently dedicated to infrastructure, including Tyresövågen and surrounding areas. This highlights that the geodesign process stimulated creative thinking and effectively supported the identification of more ambitious alternatives compared to the most obvious and familiar ones.

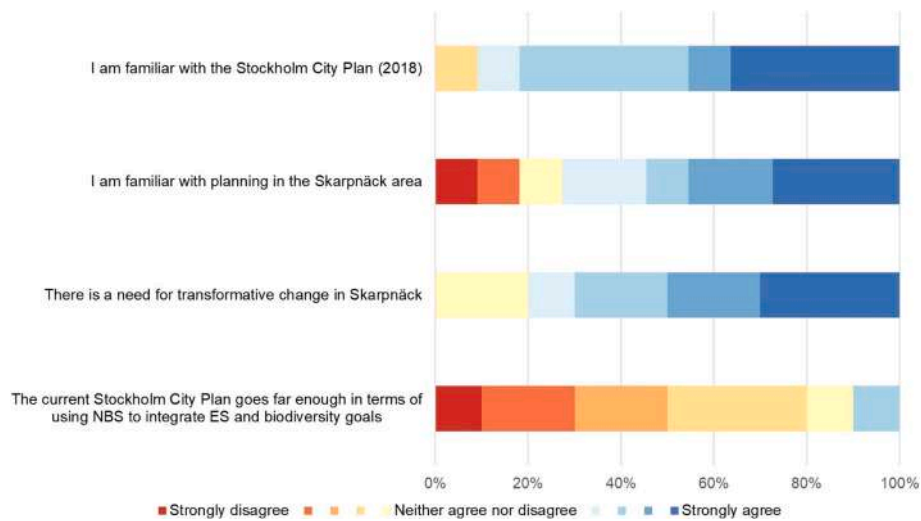


Fig. 9. Illustrative background information of geodesign workshop participants: (i) familiarity with SCP and specifically planning in Skarpnäck, (ii) the transformative potential of SCP, and the (i) need for TC in Skarpnäck. Total number of completed questionnaires (N = 13).

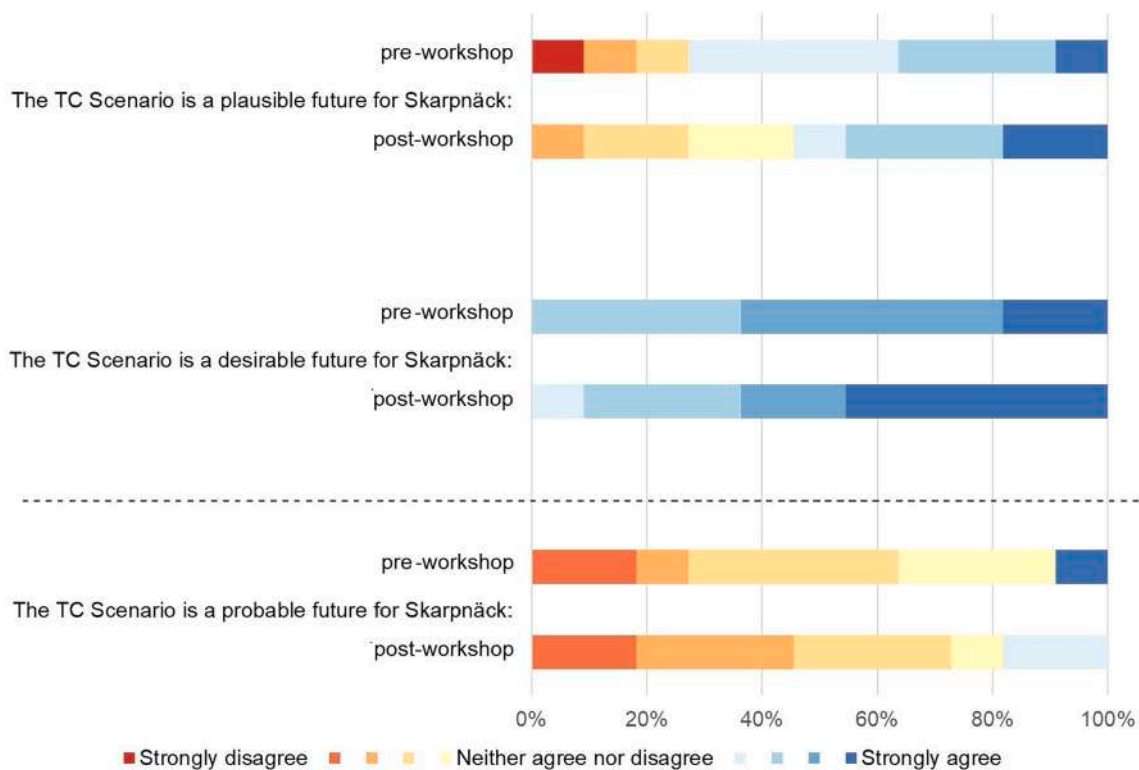


Fig. 10. Changes in the pre- and post geodesign workshop perception of the proposed TC Scenario as plausible (possible under the stated assumptions), desirable future for Skarpnäck, and probable (given current trends/under the stated assumptions). Total number of completed questionnaires (N = 12).

All teams successfully met the set goals and targets, including the provision of 3500 housing units in both scenarios. They achieved this by using different proportions of low and high-density housing and integrating different land use design strategies that included NBS such as oak forests and blue spaces. A key finding was that, across all six alternative futures developed by the three teams, only the TC Scenario spurred the improvement of habitat for biodiversity and ecosystem services compared to the current condition. This result was achieved despite the higher number of housing units accommodated in the maps produced for the TC Scenario compared to the SCP Scenario. It could be argued that the collaborative planning process supported by geodesign empowered practitioners in considering the most excluded interests and

values (Bentz et al., 2022; O'Brien, 2018), leading to reducing the trade-offs between housing and NBS that emerge in the SCP Scenario.

Participants acknowledged the usefulness of geodesign as an effective communication tool between the planning stakeholders involved. They particularly noted its potential to engage and inform both policy makers and citizens about planning alternatives, thereby supporting sustainable urban planning decisions (Adem Esmail et al., 2024). These findings seem to suggest that a scenario-based geodesign approach can effectively support urban planning for transformation through NBS, resulting in a more sustainable and ecologically sensitive plan. This finding aligns with previous studies that have highlighted the significant role of geodesign in facilitating collaborative planning processes for

	Plausibility	Desirability	Probability
Group A*	Moderate increase +0.75 (5.75→6.50)	Decrease -0.75 (7.25→6.50)	Slight increase +0.25 (4.25→4.50)
Group B	Decrease -0.25 (7.0→6.75)	Stable +0.00 (7.75)	Slight decrease -0.25 (3.75→3.50)
Group C*	Increase +1.83 (3.67→5.50)	Moderate increase +0.50 (8.00→8.50)	Decrease -1.27 (6.00→4.73)

Fig. 11. Group-based changes in the pre- and post geodesign workshop perception of the proposed TC scenarios as plausible (possible under the stated assumptions), desirable, and probable (given current trends/under the stated assumptions), and future for Skarpnäck. The thresholds are defined in a context-specific manner, based on the calculated maximum delta of + 1.83 and minimum delta of -1.25. The following scale is used to indicate changes: decrease (delta < -1.00); moderate decrease (-1 < delta < -0.5); slight decrease (-0.5 < delta < 0); stable + 0.00; slight increase (0 < delta < 0.5); moderate increase (0.5 < delta < 1); increase (delta > 1.00). Total number of completed questionnaires (N = 12).

urban transformation and improving the sustainability of land use planning and ecology (Gu et al., 2018; Huang et al., 2019; Wissen Hayek et al., 2016) and particularly focusing on NBS (Gottwald et al., 2021; Gottwald et al., 2021; Schröter et al., 2023).

However, we recognize that the trade-off between urbanization and ecological and environmental planning cannot be simply resolved by applying geodesign processes. Planning processes are far more complex in terms of involved interests and goals than what can be simulated in a geodesign process. Spatial planning for TC faces structural challenges, in addition to the complexity of considering the trade-offs of different interests and interactions of different scenarios and in prioritizing economic interests rather than ecological values (Beveridge et al., 2024) in the design process.

#### 4.2. Impacts of the geodesign process on participants' perceptions

At the start of the geodesign process, participants' perceived desirability of TC was high across groups (mean of 7.8 on the 9-point Likert range). Perceived plausibility (5.6) was just above the mid-point of the range (5), and perceived probability below the mid-point (4.3). Overall, the desirability-plausibility gap indicates practical challenges beyond the context of the geodesign workshop. The relatively low probability (also when compared to plausibility) may indicate the extent to which participants see the TC scenario in Skarpnäck as "transformative" relative to current trajectories. This aligns with our intention that the TC Scenario substantially diverges from the assumed current trajectory, helping to validate the geodesign process.

The geodesign process mostly led to minor and inconsistent changes in perceptions of TC among the participants, assessed using our before-after survey design. Looking across groups, there was a slight increase in desirability and plausibility, with Group B as the outlier that remained stable and showed a decrease in means (pre: 7; post: 5.8, respectively). Group B started with a remarkably high perceived plausibility (7), and a 'regression to the mean' may have been the result of grounding ideas in a more complex reality with a range of indicators. The general increase in plausibility is a promising result since the geodesign process, as a 'future visioning exercise', was designed to take a transformative idea and visualize its potential implementation. Our study thus provides some limited evidence that visualization and participatory modelling may nudge TC from a desirable idea to a more plausible future. We did not hypothesize changes in probability, but the slight decrease may be due to an increased appreciation of the complexity of the system and decision-making trade-offs, as evidenced by participants' comments and reflections.

Differences across the groups point towards an opportunity for further research on the group negotiation process that occurs during

geodesign workshops. An in-depth qualitative method based more firmly on transcript coding and evaluation within such a context, for example, could focus on how individual perceptions change in real-time and how consensus is reached (or not) in relation to TC planning. This could be supported by dividing participants into pre-identified groups of 'TC optimists' and 'TC pessimists'. Further research to build on our study could ideally also use larger samples and perform validity tests on survey scales used to assess perceptions of desirability, plausibility, and probability.

#### 4.3. Challenges and opportunities for geodesign to support planning for TC

Based on the participants feedback, Table 5 presents a summary of challenges and opportunities for geodesign to support planning for TC. Their critical reflections shed light on the limitations of the applied geodesign process that affected both the substantive outputs and perceptions. Critique can be organized along two main categories: 1) the lack of involvement of all participants in the first two steps of the geodesign process (co-defining settings and understanding challenges, and scenarios development), and 2) technical issues related to the geodesign tool and technology.

The lack of participant involvement in co-defining settings and understanding challenges of the study area resulted in a list of indicators and criteria that participants interpreted as insufficient. During the discussions within the groups, numerous suggestions on potential additional indicators emerged. However, although the lack of involvement affected the ownership by the participants, it should be noted that including all the suggested indicators would not have been possible and that focusing on a shortlist would have been needed in any case to reduce complexity. While not possible within the scope of this study, future efforts should aim to directly involve the participants also in co-identifying the most important data and indicators necessary to answer the study-relevant questions, thus increasing their ownership of the entire process (Campagna, 2022).

Similarly, time and resource limitations precluded a stronger involvement of participants in developing the scenarios storylines. The entire geodesign process relied heavily on two scenario storylines for Skarpnäck taking the SCP as a starting point, which were developed iteratively by the research team and local key informants. To overcome this limitation, a focus group discussion was conducted to help the participants gain an adequate understanding of the scenario storylines. The discussions revealed that the participants understood the two scenarios well and had some initial ideas on how to implement them in the subsequent geodesign sessions (see Table 4). Given the relatively minor changes in participants' perceptions between pre- and post-workshop surveys, it remains unclear to what extent the participants' adherence to 'instructions' versus their enthusiasm for the actual TC influenced the geodesign outcomes. However, participants' demand for TC remained consistently high, with even a slight increase on average after the geodesign workshop.

In turn, the lack of early direct participant involvement may explain participants' critique regarding the kinds of data and knowledge considered and the chosen scale of planning (which implies whose knowledge/data is involved). The type of knowledge, its configuration, and the inclusion of various ecological, social and economic interests and values across multiple spatial and temporal scales are emphasized by other studies focusing on urban sustainability and transformation (Adams et al., 2023). Furthermore, the results suggest that the geodesign tool could be technically advanced to strongly encourage creativity and the consideration of inherent uncertainties in planning.

#### 5. Conclusions

The application and evaluation of geodesign in planning for transformative change in the Skarpnäck district case study successfully

**Table 4**

Participants' reflection on the two scenarios during the focus group discussion (D1), which aimed at enhancing their relevance to the group and the task at hand.

Key aspect	Participants Feedback/comments
A) Urban development	Most participants expressed support for the transformative scenario. Participants A3 and A2 emphasized the transformation of unused buildings, densification through infill and building up stories, and the potential change in land use, including a decrease in areas designated for cars to be converted into housing. They highlighted practical approaches to achieve the envisioned transformation in urban development and biodiversity conservation.
B) Regional green infrastructure	Practical measures to achieve this include creating and connecting nature reserves, transforming urban infrastructure like Tyresövägen, and caring for oak trees, as emphasized by A3. Additionally, enhancing recreational use can be achieved through the creation of local park playgrounds (A3). B2 suggested that densification in urban areas can contribute to restoring ecological values. However, C4 raised concerns about financial constraints, highlighting the need to make choices between investing in parks for recreational purposes and preserving the forest due to limited resources.
C) Central "green strip"	The discussion on the "green strip" in Skarpnäck reflected a range of perspectives, underscoring the complexity of balancing ecological and social values, considering historical plans, and seeking solutions that cater to diverse preferences and needs in urban green spaces. There was widespread recognition of the importance of protecting the green area. A3 highlighted successful examples of connecting ecological and social values and suggested enhancing recreational values in green areas. Concerns about potential segregation due to green wedges were raised, but A3 emphasized the need to make green areas more exciting and liveable. Various viewpoints on the values of green areas were presented, with an emphasis on balancing diverse needs (B1) and considering public health through economic valuation (B3). Historical context was discussed by A2, noting the initial enclave planning of Skarpnäck areas and the evolution of ideas about connectivity. The importance of finding win-win solutions and being open to different perspectives was emphasized (A3 and B2).
D) Tyresövägen	The discussion centred around the development of an urban corridor along Tyresövägen and underscored its multidimensional nature, including considerations of traffic, feasibility, economic factors, and broader societal impacts in urban planning decisions. A3, B and C4 highlighted that Tyresövägen has less traffic compared to other areas (Sveavägen), making an urban corridor feasible. A2 emphasized the goal of making Tyresövägen less of a barrier and considers infrastructural aspects beyond the physical barrier. B3 and A2 proposed practical measures like reducing speed limits and creating tree alleys to save green spaces as done in other parts of Stockholm (Örbyleden). A3 suggested expanding the concept to include parks along the road. B4 acknowledged impressive ideas but raised concerns about feasibility and the cost of building roads. To this B3 raised political questions about how cities calculate costs, advocating for the inclusion of broader societal impacts in economic calculations.

**Table 5**

Summary of challenges and opportunities for geodesign to support planning for TC emerging from the discussion with the participants during the final reflection.

Challenges: What are the greatest challenges, beyond the specific case study, for the tool to be useful in planning?	Opportunities: What are the greatest opportunities, beyond the specific case study, for the tool to be useful in planning?
<ul style="list-style-type: none"> <li>• The inability to draw polygons freely constrains creativity and limits the expression of ideas during the planning process.</li> <li>• Technical limitations, such as difficulties in navigation and the absence of an undo button, reduce the tool's usability and dynamic nature.</li> <li>• The absence of essential data layers, including topography and geological information, diminishes the tool's effectiveness in assessing land suitability.</li> <li>• Insufficient communication about the model's precision and inherent uncertainties affects user confidence and decision-making.</li> <li>• The lack of transparency in the indicators and criteria used within the tool challenges its applicability to real-life planning processes.</li> <li>• Concerns about the tool's value stem from scepticism that it might compete with existing knowledge and tools, particularly in well-studied regions like Stockholm.</li> <li>• The tool's limitations in managing group dynamics necessitate measures to ensure inclusive participation and address differing values among stakeholders.</li> </ul>	<ul style="list-style-type: none"> <li>• The tool's ability to enable real-time comparisons of scenarios provides a dynamic and efficient platform for decision-making.</li> <li>• Its accessibility to diverse stakeholder groups, including politicians and residents, highlights its potential to foster inclusive dialogues and enhance understanding of complex planning processes.</li> <li>• By simplifying complex layers and data, the tool empowers stakeholders less familiar with planning to participate in more informed decision-making.</li> <li>• Its modelling capabilities support the exploration of multifunctional solutions, offering a nuanced perspective on their broader impacts.</li> <li>• The integration of a transformative approach promotes out-of-the-box thinking and facilitates role-playing discussions, enriching the planning process.</li> </ul>

facilitated creative planning and the development of alternative futures with varying degrees of transformative change. These aims were met despite the two primary limitations of our study – low in-depth participation in indicator and scenario development and technical issues. The scenario designs created by the three groups differed across the conventional and the TC scenarios. This suggests that geodesign can play a role in engaging diverse stakeholders and encouraging them to explore how TC can be locally incorporated and operationalized within urban and metropolitan planning contexts, despite the inherent challenges.

The evaluation revealed that participants found the TC scenario highly desirable but questioned its plausibility and probability. Potential reasons for this hesitation could be participants' awareness of the complexity of planning processes in a real-life context and other structural challenges that go beyond the planning control and positional power.

Future applications of geodesign should aim to involve key stakeholder informants in the entire process – from study conceptualization to scenario preparation and model generation – to ensure the definition of a common goal, shared language, and joint commitment, in addition to considering the best available data and knowledge. Furthermore, the technical capabilities of the geodesign tools need to be enhanced, making interfaces more intuitive and user-friendly. Future experiments could incorporate geodesign analytics to offer a more nuanced comprehension of group dynamics throughout the design process.

Further research could focus on how the advantages of collaborative

geodesign could be leveraged by addressing the shortcoming in our local case study. Beyond this, the approach could be upscaled to planning at the metropolitan and landscapes levels – i.e. scales where the challenges of TC are more complex, but the opportunities of identifying substantially different pathways for spatial development are even greater. Finally, future scholarship could investigate how the in-depth collaboration and negotiation among key stakeholders in an in-person geodesign process can be amended by the involvement of the larger public through web-based applications.

#### CRediT authorship contribution statement

**Blal Adem Esmail:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Chiara Cortinovis:** Methodology, Investigation, Writing – review & editing, Funding acquisition. **Sigvard Bast:** Conceptualization, Methodology, Software, Investigation, Data curation, Writing – review & editing. **Carl C. Anderson:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualization. **Lina Suleiman:** Investigation, Writing – original draft, Writing – review & editing, Funding acquisition. **Gustavo Arciniegas:** Software, Data curation, Writing – review & editing. **Davide Geneletti:** Methodology, Writing – review & editing, Funding acquisition. **Ulla Mörtberg:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision, Funding

acquisition, Project administration. **Christian Albert:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition.

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## Declaration of Competing Interest

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

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.landurbplan.2025.105303>.

## Data availability

Data will be made available on request.

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