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Envisioning the future—Creating sustainable, healthy and resilient BioCities

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ABSTRACT

Numerous challenges – from population increase to climate change – threaten the sustainable development of cities and call for a fundamental change of urban development and green-blue resource management. Urban forests are vital in this transition, as they provide various ecosystem services and allow to re-shape and re-think cities. Based on a Europe-wide community effort with diverse experts centered around urban forests and urban greening, we propose five key research fields to generate the knowledge required to unlock fundamental changes in urban development and green-blue resource management: circular bioeconomy, climate resilience, governance, social and human environment, and biodiversity. To support the design of greener, cooler, more inclusive and resilient cities, all these research fields require inter- and transdisciplinary collaboration, engaging stakeholders in transforming urban engagement and functioning. We summarise main inter-, trans- und multidisciplinary research paths for each field and the cross-cutting knowledge areas that can help to address the challenges many cities face (e.g., modelling and assessment of the urban microclimate). For transforming cities further knowledge is needed on e.g., urban innovation, transition, participation, and more. Finally, we address how the identified research gaps can be implemented (e.g., international coordinated research effort, interdisciplinary networks).

1. Introduction

Cities are growing rapidly and are challenged by climate change, social inequalities, and growing populations. Today, urban areas have become home to the vast majority of the European population (United Nations, 2018). This situation is reflected across the globe, the result of a combination of migration from rural areas and world population growth (United Nations, 2018). As a result, an expected 68% of the world population will be living in urbanised environments by 2050 (United Nations, 2018). Migration to cities and continued population growth

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will have a matching effect on patterns and processes of urbanisation globally. Depending on the location and context, existing cities will expand and transform, smaller towns and cities will grow, and new cities will appear. The impact of a burgeoning world population concentrated in more numerous and larger cities on global environmental problems, is becoming increasingly clear and urgent (Seto et al., 2014; Kennedy et al., 2015; Concepción et al., 2015). That cities are traditional catalysts for economic activity, and that associated patterns of production and consumption have reached many of the limits the planet can sustain (ONeil et al., 2018), presents a real and present challenge for the built environment. To complicate matters, increasing urbanisation presents challenges in matters of human health and well-being, community interaction and social justice. Compounding this task is the fact that cities are inherently complex and that urban issues are multifaceted (Batty, 2009; Batty, 2018), with solutions demanding inter- and trans-disciplinary attention – a situation which hints at an increasing number of urban challenges and of an increasing diversity which will need addressing.

In this frame, initiatives such as the United Nations Sustainable Development Goals (SDGs) present valuable and useful frameworks for actors from research, government, industry, and society variously involved in urban futures. Whether these frameworks are focussed enough to guide urban development towards meeting these multiple challenges remains a question. For cities to become greener, cooler, and resilient it is necessary to quickly move beyond current paradigms and practices via an innovative, accelerated response encapsulated in a grand narrative (Wilkes-Allemann et al., 2022). The BioCity manifesto constitutes such a step. It puts natural elements, such as forests and green spaces, and processes in the centre and makes them a guiding component in a paradigm shift in understanding, ordering and acting in the city of the future. The BioCity manifesto as presented in the green book of BioCities (Scarascia-Mugnozza et al., 2023) resonates with similar initiatives such as nature-based solutions (Eggermont et al., 2015), and biophilic cities (Beatley and Newman, 2013), and eco-cities (Suzuki et al., 2010), and healthy cities (Ashton et al., 1986). However, instead of offering another single-issue approach, it aims to encompass these concepts into a holistic vision for sustainable and socially just human-nature relations in cities. Therefore, it critically extends and enlarges on these concepts through the involvement of more diverse branches of research and practice (e.g., social sciences, forestry), their effective integration and contextualization, and through the exploration of novel cross-cutting perspectives, as well as providing conceptual clarity. Thus, it goes beyond silo thinking and requires an interdisciplinary tackling and implementation. To enable BioCities the current body of knowledge needs to be expanded with new and context-specific knowledge on urban transformations and sustainable solutions. The aim of this paper is to identify relevant research gaps within the model of BioCities, to enable action and reflection on BioCities, and to propose research paths for exploration of the BioCities manifesto. Additionally, we aim to propose pathways for reaching the paradigm shift and to pursue a BioCity by rethinking current cities in a holistic manner, taking a inter-, trans- and multi-disciplinary approach and going beyond administrative boundaries. Thus, this paper lists a number of future topics rather than it identifies examples of possible solutions, which we see as a task of future publications. In this paper we present a holistic perspective that takes into account ecosystem services and disservices and is crucial in the development of future cities. Economic, ecological, and societal perspectives need to be integrated to identify synergies and let the cities thrive. Simultaneously, innovative ways of integrating and transferring existing knowledge into practice are needed.

1.1. The BioCity manifesto

Definition and conceptualisation of what BioCities should be is described in detail in the work of Guallart et al. (2023) which was the output of the European Forest Institute funded project "Green Book of BioCities" (Scarascia-Mugnozza et al., 2023). This project served as a base for our work of exploring research gaps and possible future paths for implementing this manifesto. The definition of BioCity is elaborated via a set of functional traits which consider the manifesto from various operative perspectives as shown in Table 1. These functional traits proceed from the stance that natural systems form a normative basis for the BioCity, and that specific elaborations and iterations of natural systems emerge in cities, in response to various political, economic, social, technological, legal and environmental conditions. Each trait builds on key findings from relevant disciplinary fields.

2. Methods

To identify research paths guiding future BioCity development, we used methodological triangulation, including desk research, foresight scenario building, and focus groups with experts from science and practice. Thereby, we aimed at (1) scoping definitions, drivers, and critical variables of BioCity development, (2) identifying major research paths for implementing the concept of BioCities, (3) identifying trade-offs and synergies between these, and (4) validating the results through the analysis and consultation of other urban initiatives.

2.1. Scoping of definitions, drivers and critical variables

Implementing the BioCities manifesto brings along a wide range of issues and challenges that will be faced in the future and that need to be considered while developing the concept. To this end we applied foresight scenario building, a method used for future research (European Foresight Platform EFP, 2010; Government Office for Science, 2017; Shell, 2008). Thus, to build the future in the short, medium and long term. The scenarios built through this method can provide a wide range of perspectives on what might happen "like a set of maps describing different aspects of a landscape" (Shell, 2008). It can deepen the understanding of the driving forces affecting future development of e.g., BioCities, and thereby contribute to identify research paths required to better understand driving forces (Government for Science, 2017). For this purpose, we conducted three online workshops with experts from science and practice working in the field of architecture, urban planning, urban forestry, urban governance, urban policy, and landscape planning. In the first workshop we identified visions and narratives and initial knowledge gaps. To understand the dynamics of change, the experts were asked in a second workshop to identify driving forces that influence the trends of contemporary urban development, based on the PESTLE[1] (political, economic, social, technological, legal, and environmental) structure. In a third workshop assumptions and scenarios for future BioCities were formulated and further research paths were identified. These online workshops ran between November 2020 and April 2021 and each one lasted for two to three hours.

2.2. Identifying major research paths for implementing the BioCities manifesto

To assess research paths for implementing the BioCities manifesto, we conducted a series of online focus group discussions. To do so we first reviewed current concepts to have an overview of related research areas.

[1] https://pestleanalysis.com/what-is-pestle-analysis/

Table 1
The ten key functional traits of the BioCity manifesto as defined by Guallart et al., (2023).

Functional trait	Description
1 The BioCity as a Carbon Sink	The BioCity does not emit carbon dioxide (CO_2) and other greenhouse gasses (GHGs) which trap heat in the earth's atmosphere, but rather absorbs them, as forests do (US EPA 2021). The BioCity interacts intentionally with trees and forests within and without the urban boundary to benefit from the goods and services they sustainably provide.
2 The Self-Sufficient BioCity	The BioCity produces locally the derivative resources it needs for its operation. It produces energy through its own renewable systems, extracts water from its own natural basins or subsoils, and grows food and biomass (in the BioCity or the associated BioRegion) for its own population (Guallart, 2014).
3 The Multi-Layered BioCity	The BioCity must be organised such that each of its levels, from the subsoil to the ground, the central body and the roofs can develop different, mutually reinforcing functions and provide resources using elements of green, blue, brown and grey infrastructure to service the BioCity as a whole (Silva et al., 2020).
4 The Healthy Living BioCity	The BioCity exceeds characterisation as a collection of human settlements, instead people are understood to be part of an ecosystem. Since BioCities are necessarily urban areas that promote a wide spectrum of life (bios); human well-being and biodiversity are fostered by the same multi-scalar strategies as in natural ecosystems. This is achieved by using biodiversity to aid the provision of ecosystem services (ESS), demonstrated by how forests reach equilibrium (Brockerhoff et al., 2017).
5 The Circular Bioeconomy BioCity	Circular and evolutionary bioeconomies make the BioCity a vibrant, regenerative system featuring dynamic governance approaches which enhance interlinked hierarchies of activity. These are in constant reinvention, and spawn ample aligned job opportunities through the use and development of local bio-based materials and recycled materials to manufacture, maintain and improve the products required for the proper functioning of the BioCity (Silliman and Angelini, 2012).
6 The Low-Mobility Connected BioCity	The low-mobility BioCity promotes changes in the habits of its population. Through functional reorganisation of an urban area, within the radius of a fifteen-minute walk or cycle all basic services necessary to live are made readily available (Moreno et al., 2021). The connected BioCity enables individuals to exchange goods and information in such a way that it enables society to function, flow and progress together in the most sustainable, efficient and ecological manner (Simard et al., 2012).
7 The Urban-Rural Balanced BioCity	Just as soft, blurred, gradated, fluid, and reciprocal boundaries between discrete natural ecosystems (ecotones) optimise health and function, unbiased symbioses and dialogues between the urban BioCity and its corresponding rural Bioregion enable urban systems to work in harmony with the natural systems of their territorial environments. This balance thus fuels both the urban and rural economies, through the growth of thriving, regional bio-based value chains (Yahner 1988).
8 The Participatory Local Culture BioCity	The BioCity is not only adapted to its local climate and environment, but also promotes a material, cultural and social identity based on its unique local history and traditions via continuous exchange with the broader world through physical and information networks. Through an integrated governance ecosystem incorporating top-down and bottom-up decision making with communal rights, local residents and communities are proactively engaged in self-determining the realities and networks of influence of their BioCity.
9 The Resilient BioCity	In a mature BioCity, publicly accessible urban blue and green nature in the forms of forests, meadows etc. provide a diverse population of citizens with opportunities for their lives. Such public and accessible places provide democratic spaces in accordance with the justice perceptions of all affected stakeholders and globally accepted standards for human rights. In doing so, they perpetuate the value of past human and natural heritage, as well as secure the infrastructures which will be required to meet the challenges of tomorrow.
10 BioCities for All	Within the BioCity, biodiversity is prioritized not only in terms of sheltering a variety of species, but also in terms of maximising accessibility for all citizens, regardless of ability, age, race, ethnicity, religion, occupation, gender, income or education, whilst undermining forced displacement from gentrification, with commensurate variation in tailored niches of the built environment. The involvement of citizens is natural at all levels. Ultimately, the universal BioCity will eliminate systemic and structural environmental inequalities and injustices.

Based on these results we clustered major research fields resulting in five major clusters as shown in Fig. 1. These five topic areas are: Biodiversity,[2] Circular Bioeconomy,[3] Climate Resilience,[4] Governance[5] and Social and Human Environment.[6] For each one of these research fields, we conducted a focus group with experts from different regions and professional backgrounds, as well as with experts involved in the project Green Book of BioCities (Annex 1). Both types of experts had the necessary skills and expertise to cover all of the research fields that were deemed important. The experts from the project Green Book of BioCities were included in these workshops so that they could add missing research paths based on the literature review they conducted in order to write the Green Book of BioCities. However, it is important to note that the discussions and results of the focus groups are limited and influenced by the perspectives and preferences of the experts involved. The focus groups were structured in three main parts. The first one addressed the challenges in relation to the implementation of the BioCities manifesto, the second one discussed the knowledge gaps and the last one the priority research topics (cf. Annex 4). At the end of each part experts were encouraged to nominate the three most important research questions for the topic. The focus group discussions were carried out online between May and June 2021 and lasted for three hours. The discussions were recorded, transcribed and analysed using Mayring and Fenzl, 2019 qualitative content analysis. Based on the analysis a white paper per

[2] **Biodiversity** includes: Urban Ecology, Environmental Sciences, Biology, Landscape Ecology, Biodiversity & Conservation, Sustainable Development, Urban Planning, Urban Forestry and Forest Genetic Resources

[3] **Circular Bioeconomy** includes: Urban Planning, Urban Design, Architecture, Materials Sciences, Forestry, Environmental Engineering, Industrial Ecology, Ecological Economics, Econometrics, Sustainability Impact Assessment, Vocational Education, Innovation Management, Transition Research and Municipal Governance.

[4] **Climate Resilience** includes**:** Climate Research, Urban Climatology, Environmental Sciences, Urban Hydrology, Urban Water Resources, Physical Geography, Greenspace Planning & Management, Landscape Architecture, Urban Design, Architecture & Built Environment, Forestry, Biology, Ecology, Biogeography, Transition Design, Resilience, Social Sciences and Humanities.

[5] **Governance** includes**:** Environmental Sciences, Greenspace Planning & Management, Greenspace Planning and Design, Urban Planning, Forestry, Urban Forestry, Urban Greening, Green space Governance and Policy, Forest and green Space Goods and Services, Public Involvement, Social Sciences and Humanities.

[6] **Social and Human Environment** includes**:** Spatial planning, Forest economy and health, Sociology, Forest Administration, Architecture, Urban Planning, Forest Planning and Environmental Economics.

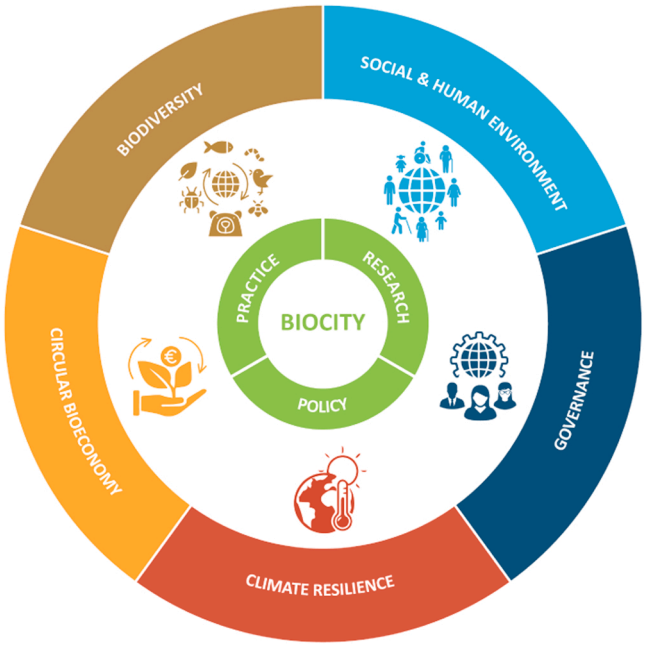


Fig. 1. Major research fields for identifying the research paths for implementing the BioCities manifesto.
Source: Own representation based on Wilkes-Allemann et al., 2022.

research field was written. In order to thoroughly analyse the results of the focus groups discussions, as well as to expand and cross-validate the results of the focus group discussions a landscape of arguments was created for each topic area based on the transcript of the discussions (cf. Annex 5). Thereafter, the arguments were clustered based on how often these were mentioned in each research field (cf. Annex 6).

2.3. Trade-offs and synergies between the research fields

We then reviewed the white papers to identify synergies and trade-offs between the research fields. They provided inputs to the responsible of this process and gave feedback. Thereafter, an online workshop with all project participants on identifying synergies and trade-offs was carried out in July 2021. Finally, the draft research path proposal was amended with these new insights.

2.4. Validation of the research paths

To validate our results with other urban initiatives, we reviewed our results through an online expert workshop with practitioners and scientists representing architecture, urban planning, urban forestry, urban governance, urban policy, and landscape planning. The workshop was conducted in September 2022. It was recorded, transcribed and analysed using Mayring and Fenzl (2019) qualitative content analysis. Additionally, an overview of relevant political agendas such as UN-Habitat New Urban Agenda, research agendas such as Wolfram and Franzeskaki (2016), reports such as the OECD Resilient Cities report, and initiatives such as EU Green City Accord and EU New European Bauhaus was prepared (cf. Annex 2). These documents were then reviewed to identify e.g., driving forces, critical variables and overarching themes, or other research paths proposed by these initiatives and by doing so adapt our results (cf. Annex 3). Following these reviews, additions and amendments to the research fields were carried out, with the intention to be as comprehensive as possible with respect to the body of knowledge at the time of developing the research paths for implementing the BioCities manifesto.

3. Results

In view of climate change scenarios, planetary gentrification and other challenges facing cities, a paradigm change and the transition to BioCities as a model for adapted and resilient urban systems is urgent. Considering a time horizon of 2050, the current rate of transition appears slow, even maybe too slow. So how can a transition to BioCities be successful in a comparatively short time span? What can affect the transition process to BioCities? What are the success factors? What are the risks? In the following, we elaborate on critical variables as well as the major research paths required to guide the transition to BioCities.

3.1. Identified challenges and research paths for each research field

3.1.1. Circular bioeconomy

The hazardous effects of fossil-fuel driven climate change and the depletion of fossil resources have been recognized (IPCC, 2018; Meadows and Randers, 2004). This demands future cities to be based on renewable materials and renewable energies. To mitigate over-exploitation of bioresources, urban bioeconomy should be complemented with circular economy principles. In the debate about the integration of emerging circular and bioeconomy approaches in urban practice and research, the following perspectives reveal important challenges that demand further research:

From a life cycle management perspective on bio-based materials and products, the increasing importance of closing resource loops, slowing resource consumption, and enhancing the use of local bio-based materials is recognised to achieve a higher resource availability in cities and turn the built environment into a carbon storage facility. Challenging strategies that require further innovation and knowledge include the separation, consequent cascading, and recycling of organic waste fractions; business models and information systems to enhance the urban mining of biogenic materials; a reduction in food waste and the prolonging of building service lives through durable materials and maintenance; as well as the design of products for disassembly and a dematerialisation of construction with wood and other biomass-based materials.

A sustainable development perspective highlights the importance of identifying and promoting those strategies that maximise social, human, and environmental outcomes. Not all strategies associated with the circular and bioeconomy necessarily contribute to a sustainable urban development that supports a wide spectrum of life. Challenging from this perspective is the balancing of different capitals (e.g., natural, social, human) at different scales (e.g., urban, national, global) and the design of suitable guideposts.

From a cultural change perspective, habits and mindsets of citizens and public institutions are key factors to guide urban consumption patterns towards local produce. Simultaneously, cultural change in supply and manufacturing is necessary to establish circular design thinking and to ensure bioresource management aimed at maximising ecosystem services. Strategies that might catalyse such change, but require further investigation, include participatory planning, citizen science and engagement, communicating the everyday benefits of a circular bioeconomy at all levels, educating manufacturing professionals, setting standards, leveraging green public procurement, and showcasing full value chain processes in cities.

In terms of spatial sustainability, urban planning and design, architecture, urban agroforestry, and regional interconnectedness play a central role in implementing circular bioeconomy strategies such as greening cities, managing land use conflicts, and introducing local bio-based products into the market. Research from this perspective should adopt a holistic approach integrating a portfolio of strategies and effects across the urban-rural interface to unveil interconnections and to clearly define the boundaries of a BioCity.

3.1.2. Climate resilience

Recognition and action on planetary boundaries (Steffen et al., 2015) and the complex of challenges brought on by anthropogenic activity is the foundational driver of the field of climate resilience. The BioCity of the future is conceived as an accelerated response to this problematique, specifically the problem of climate change. In discussions about both the impact of climate change on cities, and the impact of cities on climate change, the following perspectives emerge as important threads for future research:

From a mitigation perspective, there is an acknowledged urgency to lower GHG emissions and energy consumption in cities, as well as for developing integrated carbon storage measures in and around urban centres (Kamal-Chaoui and Robert, 2009). In addressing these challenges, revisiting of approaches such as an Earth System Sciences[7] can be valuable, as well as the elaboration of further knowledge around strategies and measures such as developing greenspaces in and around urban centres to absorb much of the emissions a city produces, sourcing energy, water, food and building materials locally, and engendering modality shifts and mobility efficiencies which lead to critical reductions in GHG emissions. At the same time research efforts need to be focused on renewing human-environment and human-nature relationships, with the intention to aid climate change mitigation through awareness and behavioural change.

From an adaptation perspective, challenges revolve around physical measures to combat rising temperatures and heat stress, dealing with extremes in precipitation patterns causing droughts and flooding, and coping with sea level rise causing coastal erosion and flooding of low-lying areas. A guiding framework for adaptation measures span the range of urban infrastructures in which various climate change-related cycles play out (and can be influenced). These include (1) Green-Blue infrastructures: private and public greenspace - in particular the urban forest - and all natural and built environment water systems and features; (2) grey infrastructure, including transport systems and elements, but also structures and buildings; and (3) the social infrastructure of cities, understood as the intangible system of practices, cultures, relationships and networks (Meyer et al., 2006). Added examples of research attention in this perspective include strategies and measures linking built environment features both horizontally and vertically to optimize mitigation effects.

A resilience perspective highlights the need to help urban communities and their spaces, places and networks to co-exist with a natural environment undergoing radical change, assuming that change will occur even if the most optimistic scenario for reduction of emissions is achieved. Resilience is understood as the agility of (urban) communities and ecosystems to effectively adapt and evolve in response to calamities (Holling, 1973). In addressing these challenges, the BioCities outlook proposes the adoption of existing resilience perspectives as well as the notion of bio-resilience, to include the resilience of other species found in cities. Other themes emerging in this perspective deserving investigation include fostering health and well-being through multi-scalar strategies, linking urban and rural economies to enable shock-resistant and responsive bio-based value chains, integrated governance ecosystems enabling top-down and bottom-up decision-making which responds to change effectively and equitably, and accessible urban green-blue infrastructure building on existing green-blue networks particular to each city.

3.1.3. Governance

The holistic, transboundary nature of BioCities requires new forms of thinking about local governance, planning and participation. The need to go beyond silo thinking and to identify adaptable, resilient and co-creating modes of governance is driving research in this field, as well as the need to enhance cooperation between governments, private actors, planners, scientists and the civil society, and the capacity of all actors to reimagine the city. In discussions about a transition to BioCities, the following perspectives emerge as important threads for future research:

From a governance perspective, challenges revolve around integrating different disciplines and enhancing collaboration between different departments in a trans-disciplinary approach. In this context, the provision of capacity building at all levels – from institutional capacity to capacity of co-learning – deserves investigation. A further challenge is to ensure that the BioCities manifesto is conceived as a global cross-sectoral model and that it is applied considering all or at least most traits of the manifesto. Here, it is necessary to understand and to ensure inter-governmental cooperation enabling the implementation of the BioCities manifesto. Reforming current investment mechanisms and ensuring the maintenance of necessary capacities for the transition to BioCities is a further challenge. Thus, investigating ways of (re) funding providers of services such as green spaces will be relevant, as well as proposing simple frames to tackle the complexity of the urban social-ecological system.

A planning, design and management perspective highlights the need to rethink the way cities are planned beyond current practices so that resilience, sustainability and quality of life are the cornerstones of urban planning, design and management. Thus, understanding how to adapt regulations and how to allow interconnections between different disciplines (planning, design and management professionals) will be crucial. Additionally, proposing adequate capacity building possibilities to secure the proper implementation of the concept is necessary. A further challenge that deserves investigation is the need to secure land in order to allow for the implementation of the BioCity manifesto. Finally, proposing ways to avoid social inequalities at all levels of city planning, design and management in terms of technology use and access, and gentrification will be an important field of research.

From a participation perspective, challenges revolve around the best methods to involve a wide range of stakeholders and to integrate their perspectives and their expectations into the vision of BioCities and in the transition process. This requires a proper understanding of the role of these stakeholders in the governance process, and of the ways to raise their awareness about the BioCities manifesto, providing them with the necessary information and with financial and practical advice, and empowering them by supporting self-respect and self-reputation. Additionally, understanding the needs of all stakeholders and addressing the aspect of long-term thinking in terms of environmental justice, ethics, and the recognition of the long-term benefits of BioCities will be crucial. This necessitates the integration of minorities in the participation process in a fully inclusive process. A further challenge is ensuring collaboration between all stakeholders involved (e.g., consultants, experts and implementing partners) at the different levels of the transition. Finally, preventing organisations (e.g., enterprises, NGOs) from becoming dependent on local governments pursuing the transition to BioCities will be a challenge to be tackled.

3.1.4. Social and human environment

Governance, biodiversity, climate resilience and the circular bioeconomy are all embedded in the social and human environment, and thus the likelihood of the transition to a BioCity is bound to the successful change in the social system. The most important challenges of the transition to the BioCity are related to urban densification and risks of overcrowding, participation and involvement of the inhabitants in planning and decision-making, as well as human health and well-being.

From a socio-cultural environment perspective, challenges arise concerning the growing urbanisation and densification of cities that lead to a shortage of living and recreation space in and around cities. This has an effect on housing prices and consequently leads to segregation and increased inequalities (e.g., unequal access to different resources), deeper social and economic divide, and poverty. Further, current

[7] As for instance first proposed by de Humboldt in *Essai sur la géographie des plantes* in 1807.

consumption trends (e.g., veganism, consumption of local food, urban gardening) linked to urbanisation and to food security and food sovereignty in the context of densely populated cities lead to challenges in land use policy, urban planning and design. "Digitalisation" and digital innovation (e.g., advances in social media, AI, and digital connectivity) present both a challenge and an opportunity for the city of the future. Through migration and immigration caused by climate crisis, cities become drivers in terms of lifestyles, values, and attitudes. The spectrum of diversity is a challenge that cities have to tackle, as it needs adaptation of processes (e.g., translation of crucial document for migrants). Finally, uncertainties concerning future events have severe impacts on society at different levels, and this poses challenges to both policy makers and society in general. Understanding how societies can learn to cope with uncertainties would be necessary.

A participation and involvement perspective highlights the need of participatory approaches that are inclusive and methods that aim at proposing a comprehensive stakeholder analysis, as well as ways of establishing co-production and two-way communication. Additionally, it highlights the necessity of improved channels and tools of data collection aiming at higher representativity in terms of technology and digital innovation in participative processes (e.g., social media, participatory GIS, online surveys, etc.) to engage different stakeholders. Here, the challenge will be to determine the necessary level of participation for projects at different scales that are not costly, time-consuming, and that do not require special skills of planners.

From a health and well-being perspective, challenges revolve around the integration of more green infrastructure in cities (as a way to reduce CO_2 emissions as well as air and soil pollution, improve air quality and walkability, foster private gardens for healthy food), the quality of the available green areas and equal access to green space. Here, understanding how good transport infrastructure promotes physical activity for all types of citizens in terms of abilities and disabilities will be necessary. Finally, a further challenge is to integrate health and well-being in guidelines and regulations of city planning. Therefore, proposing innovative ways of how to integrate health in current policy instruments will play an important role. A further challenge is defining clear and legally binding indicators, as well as implementing more binding legal acts concerning the amount and quality of green spaces in cities necessary to foster health and well-being of all citizens, particularly children (e.g., with regard to air quality). In this context identifying relevant factors will set the base for implementation.

3.1.5. Biodiversity

Biodiversity is a key element of future BioCities. The need to conserve biodiversity is well recognised (CBD, 2021). However, there is no consensus concerning the level and type of biodiversity that is needed at the city level to improve the liveability of cities. In discussions about the importance of biodiversity for the transformation to BioCities, the following perspectives emerged as important threads for future research:

From a stakeholder's perspective, one main challenge is to reach consensus on the understanding of biodiversity in a city. Varying meanings of biodiversity make it difficult to reach a consensus about which biodiversity we want to preserve. Here, in particular, the awareness and understanding of biodiversity and its connection to ecosystem services by citizens play a major role. A challenge in this context is a non-biased understanding of biodiversity which does not prefer certain more benign species over others. Therefore, communication and knowledge transfer are key elements to raise awareness about how natural solutions work as a strategy for biodiversity conservation and how they can be improved. Therefore, citizen involvement and awareness building should start in the childhood, and not only focus on adults and public institutions with legislative power. Cultural influences on the understanding of nature and biodiversity in specific, levels of acceptance from citizens and how people appreciate nature-based solutions as a management approach to increase biodiversity need further investigation. In order to apply any actions to protect, manage, and restore natural or modified ecosystems, citizen science and transdisciplinary approaches are needed.

From a policy perspective, monitoring and measuring the effectiveness of nature-based solutions on biodiversity is crucial. However, conceptual clarity on nature-based solutions is still missing. Nature-based solutions could well be inspired by nature without benefiting biodiversity. For instance, a bioreactor based on algae is an effective carbon storage, but it is not directly improving local biodiversity. At the same time, one strategy could enhance biodiversity in one area (e.g., roof-top garden can increase flora and insect diversity) but simultaneously create disservices in another one (e.g., breeding problems of birds in roof-top gardens). Further, the impact of nature-based solutions on biodiversity and ecosystem services could not only be direct. For instance, while a bioreactor itself has no influence on local biodiversity, its function as a space-efficient carbon storage might save land for biodiversity conservation. Therefore, it is important to quantify both services and disservices from ecosystems while developing and implementing nature-based solutions. Overall, the application of nature-based solutions is not only influenced by their effectiveness but also by limitations such as acceptance by government and citizens, finance, scarcity of land and collaboration between stakeholders.

From an ecological perspective, it is important to preserve and improve connectivity between species within a cityscape to support ecological and genetic links between cities' flora and fauna. Biodiversity conservation strategies must ensure the continuity of species. It is not enough to create habitats, but also to monitor and manage them. Creating a stronger foundation for the ecosystem that supports biodiversity in general can foster functional connectivity between the city and the peri-urban and wider landscape in an urban-rural-nature continuum. Quantification of biodiversity and its habitat is not just a simple count of the richness of flora and fauna but must be considered in the urban context from a functional point of view that measures how different types of ecosystem services are linked to ecosystem structure and functions.

From an inter-disciplinary perspective, the interoperability between urban biodiversity, landscape ecology and urban planning at any governmental level is challenging. For instance, small municipalities usually lack ecology departments, but big cities have many different departments, which would need to collaborate to implement biodiversity strategies. Here, another big issue is how to homogenize interpretations from academia, practice, and administration about biodiversity. In addition to this, there is a lack of connection between researchers and practitioners, and there is a need to transfer scientific knowledge and insights into practice, which is often impacted by economic or legislative constraints.

3.2. Identified overarching themes and cross-cutting research needs

Some challenges appear cross-cutting to the research paths discussed above with respect to the research fields shown in Fig. 2. Examples of priority research needs touching at least two of the identified research fields are presented in Table 1. Overall, the following challenges may benefit from inter- and trans-disciplinary research across research fields:

3.2.1. Reconciling different perceptions

Different stakeholders such as academics, citizens, governments, and industry might have diverse and even contesting ideas, perceptions, and interests on the development of BioCities. The challenge is to integrate this diversity of stakeholder opinions into the BioCities vision. Therefore, it is necessary to set common grounds of understanding on the topics and concepts around BioCities and their implementation. Part of the difficulties in setting such common grounds, is the definition of the BioCity boundaries of influence. Such a definition is challenging as it might be thought in the administrative or systems-based perspective. Limits in the administrative realm are relevant in defining by whom and

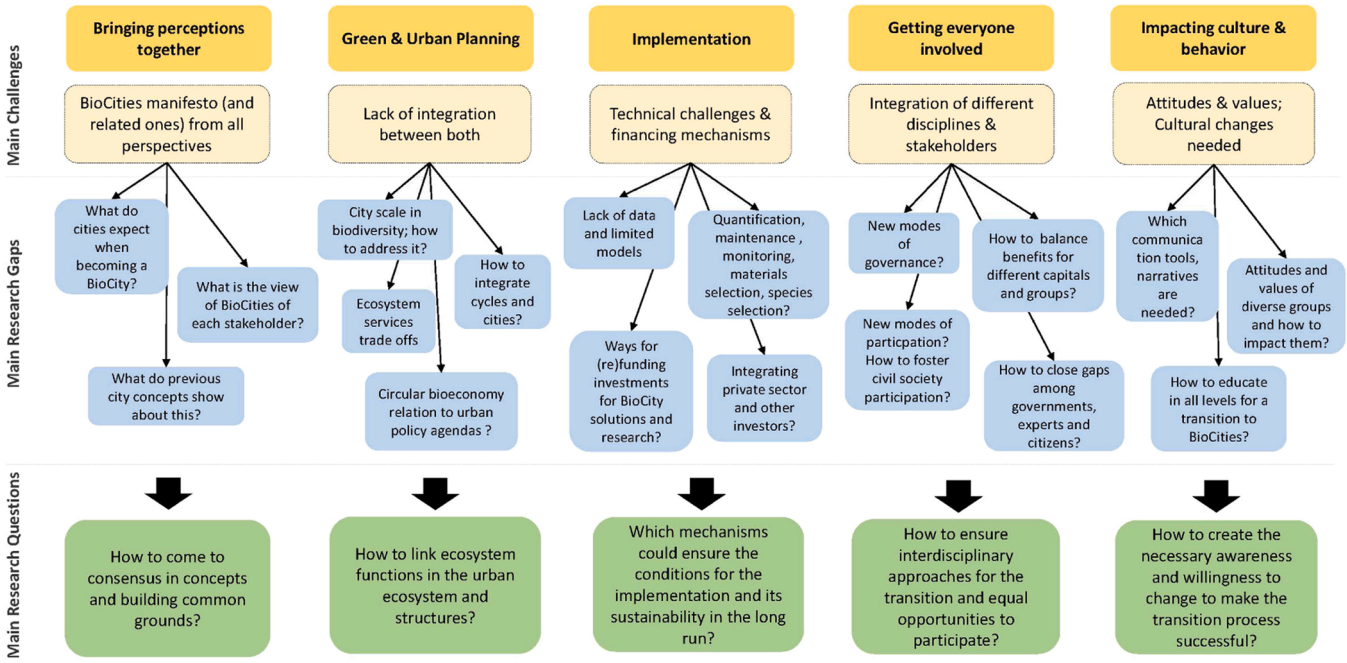


Fig. 2. Diagram of the synthesis of the five white papers to detect main challenges, major research gaps and critical research questions for overarching themes. Source: Compiled by authors based on Wilkes-Allemann et al., 2022.

how BioCities are governed and, therefore, who takes leadership in the transition and funding for it. Whereas from a system approach, the management of the urban-rural interface gains particular importance and does not necessarily coincide with the administrative limits. In order to implement the BioCities manifesto considering the different perceptions, it is necessary to collaborate with current (e.g., New European Bauhaus initiative) and emerging (e.g., One Health) initiatives that have at their core the same aim as the BioCity manifesto: to develop sustainable, resilient and liveable cities. Main questions to be investigated are: How and to what extent can BioCities contribute to reaching Sustainable Development Goals (SGDs), and conversely how will strategies and action plans for reaching SDGs affect BioCities? How does the BioCities manifesto relate to other sustainability models, and how does this contribute to identifying vulnerabilities in the transition to BioCities?

3.2.2. Interoperability between green space management and urban development

It is not an easy task to integrate the frameworks and conditions that must be considered and addressed from a green planning perspective in the traditional design and planning of cities. This includes the integration of systems and cycles at a city planning level. Moreover, the lack of interconnectivity or existing silo thinking, across stakeholders and disciplines, adds difficulty to the processes. Urban planning plays a central role in implementing strategies to support urban biodiversity, reduce natural resource use and mitigate climate change, such as greening cities and managing land-use conflicts. This is also related to the challenge of urbanisation processes generating shortage of land, segregation, as well as social inequalities in green space access and the related benefits for human well-being. The integration of green planning, green management, urban planning and urban design offers the opportunity that silo planning is changed to intersectoral planning, where different departments coordinate each other to reach the common objective of BioCities.

3.2.3. Funding and implementation

A number of challenges need to be addressed in order to secure funding for a transition to BioCities. Overcoming these challenges is seen as an important prerequisite for the implementation of the Biocites manifesto. These challenges include a lack of information, tools, and standards for quantifying, measuring, monitoring, and evaluating the diverse processes that lead to a transition at a city level. They also relate to the lack of understanding of benefits and conflicts that the use of a specific strategy might generate in diverse dimensions, such as the contrasting impacts of selected building materials on climate change, biodiversity, and the urban socio-spatial aspects. Further, the sources of investments into BioCity solutions are to be considered. A special challenge is how to involve the private sector. The use of modern technology in the transition to BioCities as well as its availability, accessibility and affordability as key elements of the manifesto pose many challenges that need to be addressed. Furthermore, challenges may vary and act differently across the different scales of cities. So, the question of how the BioCities manifesto can be applied at different scales of cities and within different geographical and socio-political contexts needs thorough investigation. By extension, two fundamental questions need to be answered: Can all cities become BioCities? Are there growth limits to BioCities?

3.2.4. Getting and keeping everyone involved

On the one hand, engagement and empowerment in terms of co-creation, co-production, co-planning and co-governance of different stakeholders and more precisely of citizens is needed at all dimensions and moments of the transition. Engagement and empowerment bring the challenge of thinking of different, more cooperative, and inclusive approaches of governance. On the other hand, there is a disconnection between researchers, practitioners, developers, and decision-makers, that results in a need for cooperation. The disconnection between departments and levels of government that need to work towards common goals adds difficulty to this issue. The challenge is the integration of different disciplines and their corresponding stakeholders from the beginning into the decision-making and planning processes and throughout its implementation and evaluation. Fostering participation as proactive engagement and empowerment of civil society represents the main challenge. This requires adequate information on the process, new creative participation methods and monitoring actions.

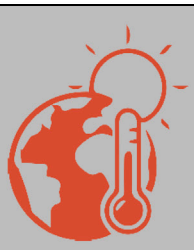
3.2.5. Impacting culture and behaviour towards transformation

Cultural and behavioural change towards values, mindsets, and attitudes that support the transition is needed. This needs to be considered in education at all levels and finding strategies and tools for adequate communication with diverse audiences. Clear communication with stakeholders is essential to bridge the information gap between experts and citizens, which might signify obstacles for fostering change. (Table 2).

4. Discussion and outlook

The aim of this research paper is to present research paths to critically and constructively accompany the implementation of the BioCities manifesto. This manifesto is framed by ten functional traits that need to be considered in cities to enable the transition to greener, cooler, inclusive and more resilient cities. Our results show that critical variables are assumed to impact future pathways towards BioCities, both as

Table 2
Selected priorities and cross-cutting research needs allowing the transition to BioCities.

	Governance	Circular bioeconomy	Climate Resilience	Social and Human environment	Biodiversity
Governance		Identifying sustainable practices, policies and SDG-action plans that effectively support the emergence of BioCities			
Circular Bioeconomy	Developing social innovations that support technical innovation and the transition to circularity		Understanding climate mitigation potential of circularity and technical innovation in engineering and building technology.	Identifying ways to make the urban circular bioeconomy truly inclusive and equitable in terms of social, economic and spatial aspects	Assessing the effects of circular strategies on biodiversity.
Climate Resilience	Identifying types of policies that are crucial to avoid catastrophic impacts of climate change.	Understanding the effect of climate change on bioeconomy resources.		Assessing the interlinkages between resilience, human health and biodiversity and identifying the levers to provoke sustaining loops.	Identifying strategies to mitigate the impact of urban climate on urban ecosystem.
Social and Human Environment	Identifying adaptive and co-creating governance models that promote inclusivity and social equity.	Developing social innovations and identifying drivers of cultural change to foster circular and sufficient practices.	Identifying soft infrastructures changing habits and practices in areas of mobility, consumption and circularity.		Identifying approaches to better assess services and disservices offered by biodiversity in urban ecosystems.
Biodiversity	Determining levers to raise the awareness of long-term benefits of biodiversity conservation among citizens and policymakers.	Balancing the impacts of circularity on biodiversity and other ecosystem services such as resource productivity.	Monitoring and assessing the impacts of climate change on the urban ecosystem.	Mapping and investigating the linkages between biodiversity and human well-being.	

Source:Source: own representation based on Wilkes-Allemann et al. (2022).

drivers and/or barriers in the transformation process. These variables point to new areas for further necessary action and research. Through the analysis of the initial BioCities manifesto based on the PESTLE framework, we have identified five major variables that are critical to consider when implementing it.

- First, 'degrees of political stability' is seen as crucial when implementing the BioCities manifesto. Here, understanding compatibility of political systems and political commitment to the BioCities traits will be crucial. Additionally, flexibility and adaptability of the current regulatory and legislative systems, as well as the degree of inclusion and participation of communities will further promote or hinder the implementation of the BioCities manifesto.
- Second, 'volatility of economic conditions internationally, nationally, and locally' will influence the applicability of the manifesto. In this context, the predisposition of communities (e.g., to volunteer in activities of common interest such as maintaining public space) and governments to expand value concepts beyond the monetary (such as bio-based value chains) will be of utmost importance. Furthermore, as economic instability prevents sustainable resource consumption, and the economic affluence leads to an increase in resource consumption. Both will strongly influence the implementation of the manifesto.
- Third, 'willingness and capacity of urban communities to adapt to systemic changes' will influence the implementation of the manifesto. In this context having awareness of motivations behind the transition, understanding migration patterns, having knowledge of the future of work, as well as identifying demographic trends, will help promoting the transition to BioCities.
- Fourth, 'developing necessary technological innovations' for relevant target groups is a necessary condition in order to fulfil the traits of the BioCities manifesto. In this context, the uptake of that technology will be crucial.
- Fifth, 'availability of natural resources' such as water, energy, timber and food and speed of anthropogenic impacts on planetary boundaries is seen as an important barrier and/or driver when implementing the BioCity manifesto. Cities will need to close cycles and take stock of existing resource flows. Additionally, protection and a holistic and integrative management of natural resources well need to be implemented. Having awareness of the consequences of climate change will drive to an increased protection of natural resources and will lead society and governmental behaviour towards sufficiency, reuse and measures for increasing green spaces.

Thus, enlarging current knowledge on this regard will be necessary.

The Biocity is also discussed in relation to related initiatives, concepts and manifestos. To begin with, the identified research paths differ from initiatives like 'Eco-cities', 'Climate-neutral cities', 'Sustainable Urban Development', 'New European Bauhaus, and 'Biocultural Diversity' in that the BioCity manifesto aims at a holistic perspective on urban planning, management and design which considers different disciplines such as governance, architecture, technology development, biodiversity to reach the transition. The New European Bauhaus initiative, for example, looks into just three dimensions (sustainability - including circularity -, quality of experience - including aesthetics - and inclusion - including affordability) to reach affordable, inclusive and attractive solutions for climate challenges in urban planning. In comparison to the Eco-cities initiative another main difference is that the BioCity manifesto does not only consider the economic and environmental pillars of sustainability, but also the social dimension. Further, in comparison to Climate-neutral cities, which only considers what is necessary to reduce GHG emissions in cities, the BioCities manifesto also addresses other planetary and social boundaries that need to be considered to transition to greener, cooler and more resilient cities. Concerning the biocultural diversity concept the main difference is that the proposed research paths do not only concentrate on the interrelatedness between people and their natural environment but go beyond by considering different perspectives addressing the same issue. Similar examples of new visions for future city developments are to be found outside of Europe, e.g., the Forest City concept in China (Boeri, 2016), however, these differ in terms of scope. While the BioCity is meant to be applied for transforming existing European cites, the Forest City concept of China is meant as a basis for new developments.

Our research shows that the research paths presented are crucial in order to allow the transformation of current cities into BioCities. Additionally, in order to reach the envisaged BioCities and tackle challenges identified in the described research paths, transnational and intersectoral coordination and cooperation are required, as well as willingness to integrate the research paths in ongoing policy processes (e.g., revisions of regulations such as Green Deal, Bioeconomy policy and/or upcoming regulations such as EU restoration Law). This assumes strong commitment from different stakeholders (from researchers to policy makers) at different levels (local to international) of implementation. To facilitate the implementation of the identified research needs, we propose the following five pathways.

First, a **coordinated effort** is needed between researchers at the international and national level to utilise in an efficient and effective way the international and national research funding resources available. To foster the coordinated effort, networks and committees integrating various stakeholders could be beneficial. At the same time, the funding resources need to be tailored to the specificities of BioCities research needs. Therefore, understanding and awareness of policy makers towards the topic is a pivotal prerequisite. Furthermore, coordinated efforts of researchers and interested organisations, and lobbying for creation of the financial means that would foster knowledge creation on the topic is needed.

Second, **networking activities at the local, national and international level** will be necessary between the different disciplines (from spatial planning, architecture, forestry to economy) contributing to the transition. A commonly built digital knowledge platform uniting the findings from different disciplines that address the research gaps outlined here could help to enhance and structure cross-disciplinary knowledge transfer and mutual learning.

Third, **inter- and trans-disciplinary research projects** involving adjacent and emerging disciplines are necessary and will be pivotal in promoting innovations to allow the transition to sustainable, resilient and liveable cities. The research needs identified here will facilitate finding interesting research topics to foster the transition and interdisciplinarity.

Fourth, **capacity building** at all levels and disciplines will be necessary to promote the concept of BioCities and to gain momentum in relation to this concept. Here, we see the need for building capacities from school levels to universities, but also in practical organisation and decision-making bodies organisations.

Finally, **coordinated efforts with other initiatives** at the local, national and international level as well as popularisation of the concept of BioCities will act as a catalyst. It is important to profit from these initiatives, as the BioCities concept only provides a frame that should be further co-developed over the years.

This paper represents just an initial step, where all important aspects in BioCity concepts are emphasised. Future research would explore specific examples and practices and elaborate more on their specificities.

Additionally, to raise awareness of the concept within the research community and interested stakeholders, the popularisation of the topic in the wide public through various means of communication (traditional and social media) must be advanced. In particular, the active engagement of journalists, using different communication platforms and tools from blogs, exhibitions to awards, could be utilized. This is especially important as we see possible limitation of the use "bio" in the concept name, which could be seen as propaganda of a uni-sectoral approach (green and nature), which our BioCities manifesto certainly is not.

There are some limitations that will constrain the application of the identified research needs. A first limitation is time. It will take some years, as well as personal and financial resources to fill some of the research gaps identified in this paper. Secondly, the BioCities concept is dynamic, and it will need to be revised in a couple of years. Lastly, innovative coordination, collaboration and funding mechanisms need to be developed in order to address all identified issues and fill existing gaps. There are also some limitations concerning the methodology used for the identification of research paths in the context of the BioCities. A main limitation is that the research paths identified have been developed from a European perspective considering mostly the challenges European cities are facing. For a wider application of the BioCities concept it may be necessary to apply other perspectives and adapt the concept to the local circumstances. In terms of experts involved in the development of the research paths it is necessary to mention that a broad range of disciplines were integrated in the development. However, experts working in the field of technological innovation (in the sense of what is possible) and scholars from the humanities have so far been underrepresented. Knowing their perspectives to the BioCity concept could also foster the transition.

Further complementary aspects of this work is that it is based on the expertise of a wide range of experts from science and practice, making it possible to develop a comprehensive research agenda that proposes research areas and knowledge gaps in the frame of the BioCities transition. In addition, identified research paths, as well as drivers and barriers of transformative processes, provide practitioners and decision-makers with guidelines on how to think of the cities of the future and what areas would need to be prioritised and further worked on to help transform their cities into BioCities. Furthermore, this manuscript offers clear framework and relevant research questions for both researchers to elaborate on within their fields of expertise. Finally, this joint effort and trans-disciplinary approach broadened perspectives of current research and highlighted the multitude of fields needed for future BioCities. Mowing away from sectoral toward more over-arching inter- and trans-disciplinary approaches are needed, as portrayed in this study.

CRediT authorship contribution statement

Jerylee Wilkes-Allemann – conceptualization of the manuscript, data collection, analysis and interpretation, drafting and revisions of the manuscript, final submission; Mira Kopp – data collection and analysis, drafting a first version of the manuscript, critical revision of the manuscript and final approval of the version to be published; Rene van der Velde - data collection and analysis, drafting a first version of the manuscript and critical revision of the manuscript, final approval of the version to be published; Andreas Bernasconi – data collection and analysis, critical revision of the manuscript, final approval of the version to be published; Elisabeth Karaca – data collection and analysis, critical revision of the manuscript, final approval of the version to be published; Slavica Čepić - data collection and analysis, critical revision of the manuscript, final approval of the version to be published, Jelena Tomićević-Dubljević - data collection and analysis, critical revision of the manuscript, final approval of the version to be published; Nicole Bauer - data collection and analysis, critical revision of the manuscript, final approval of the version to be published, Anna Petit-Boix – data collection and analysis, final approval of the version to be published; Evelyn Coleman Brantschen – data collection and analysis, critical revision of the manuscript, final approval of the version to be published; Jessica Cueva – data collection and analysis, critical revision of the article and final approval of the version to be published; Sina Leipold - critical revision of the article and final approval of the version to be published; Somidh Saha – data collection and analysis, critical revision of the article and final approval of the version to be published; Ivana Živojinović – data collection and analysis, critical revision of the article and final approval of the version to be published.

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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Annex 1 – Participants List

Annex 1 List of workshop participants. Participants marked in grey are part of the ReBio Consortium responsible for developing the research agenda heading towards the transformation to BioCities.

Participants	Country	Institution	Type of Stakeholder	Step	Research Field
Alberto Bezama	Germany, Chile	Helmholtz Centre for Environmental Research -UFZ	Research	2	Circular Bioeconomy
Andreas Bernasconi	Switzerland	PanBern	Practice	3,4	Governance
Ana Mitic-Radulovic	Serbia	Centre for Experiments in Urban Studies - CEUS	Practice	2	Social and Human Environment
Anna Petit-Boix	Germany	University of Freiburg	Research	1	Circular Bioeconomy
Arne Arnberger	Austria	University of Natural Resources and Applied Life Sciences	Research	2	Social and Human Environment
Bart Muys	Belgium	KU Leuven	Research	4	Biodiversity
Cecil Konijnendijk	Spain	Nature Based Solution Institute - NBSI	Research / Practice	2	Governance
Chantal van Ham	Belgium	IUCN	Research / Practice	2	Biodiversity
Clémence Dirac	Switzerland	Federal Office for the Environment	Practice	2	Social and Human Environment
Constanza Parra	Berlgium	KU Leuven	Research	4	Governance
Daniel Ibañez	Spain, US	Institute for Advanced Architecture of Catalonia -IAAC, Harvard Graduate School of Design	Research / Practice	2	Circular Bioeconomy
Diana Tuomasjukka	Finland	European Forest Institute - EFI	Research	2	Circular Bioeconomy
Dijana Vuletic	Croatia	Croatian Forest Research Institute	Research	4	Biodiversity
Divina Gracia P. Rodriguez	Norway	Norwegian Institute of Bioeconomy Research - NIBIO	Research	2	Social and Human Environment
Evelyn Coleman	Switzerland	Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences HAFL	Research	1	Governance
Elisabeth Karaca	Austria	University of Natural Resources and Life Sciences - BOKU	Practice	1,3	Governance
Fabio Salbitano	Italy	University of Florence	Research	1,4	Governance
Giovanna Ottaviani Aalmo	Norway, Kosovo[8]	Norwegian Institute of Bioeconomy Research - NIBIO	Research / Practice	1,2,4	Circular Bioeconomy
Giovanni Sanesi	Italy	University of Florence	Research	4	Governance
Giuseppe Scarascia	Italy	University of Rome	Research	1,4	Circular Bioeconomy
Irene Weinberger	Switzerland	Quadrapoda	Practice	2	Biodiversity
Ivana Zivojinovic	Austria	University of Natural Resources and Life Sciences - BOKU	Research	1,3	Governance
Jelena Tomićević Dubljević	Serbia	University of Belgrade	Research	1,3	Social and Human Environment
Jerylee Wilkes-Allemann	Switzerland	Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences HAFL	Research	1,3	Governance
Jessica Giron	Germany	Karlsruhe Institute of Technology - KIT	Research	3	Biodiversity
Lone Ross	Norway	Norwegian Institute of Bioeconomy Research - NIBIO	Research	4	Circular Bioeconomy
Lauren Cook	Switzerland	Swiss Federal Institute of Aquatic Science and Technology - EAWAG	Research	2	Climate Resilience

Liisa Tyraväinen	Finland	Natural Resources Institute Finland	Research	2	Social and Human Environment
Liz O´Brien	UK	Forest Research	Research	2	Social and Human Environment
Maria Chiara Pastore	Italy	Politecnico di Milano	Research / Practice	2,4	Circular Bioeconomy, Climate Resilience
Marie-Reine Fleisch	France	Agroparistech	Research / Practice	4	Biodiversity
Mario Köhler	Germany	Gartenbauamt Karlsruhe - GBA	Practice	2	Biodiversity
Michael Salka	Spain	Institute of Advances Architecture of Catalonia - IAAC	Research	1,4	
Mira Kopp	Germany	University of Freiburg	Research	1,3	Circular Bioeconomy
Mònica Ubalde	Spain	Institute for Global Health – ISGlobal	Research	4	Social and Human Environment
Nicolai Jacobi	Germany	ICLEI Europe	Practice	2	Circular Bioeconomy
Nicolas Picard	France	GIP Ecofor	Research	4	Biodiversity
Nicole Bauer	Switzerland	Swiss Federal Institute for Forest, Snow and Landscape Research WSL	Research	1,3	Social and Human Environment
Pedro Pinho	Portugal	Centre for Ecology, Evolution and Environmental Changes - cE3c	Research / Practice	2	Biodiversity
Raffaele Gorjux	Italy	Keios	Practice	2	Governance
Renate Späth	Germany	Ministry for Environment, Agriculture, Conservation and Consumer Protection of the State of North Rhine-Westphalia	Practice	2	Social and Human Environment
Rene van der Velde	Netherlands	Delft University of Technology	Research	1,3	Climate Resilience
Rik De Vreese	Belgium	European Forest Institute - EFI	Research / Practice	2	Governance
Robert Hostnik	Slovenia	Slovenia Forest Service - ZGS	Research	2	Social and Human Environment
Robert Mavsar	Finland	European Forest Institute - EFI	Research	4	Circular Bioeconomy
Roberto Tognetti	Italy	Universita degli Studi del Molise - UNIMOL	Research	4	Climate Resilience
Silvano Fares	Italy	Italian National Research Council - CNR	Research	2,4	Climate Resilience
Sina Leipold	Germany	University of Freiburg	Research	1	Circular Bioeconomy
Slavica Čepić	Serbia	University of Belgrade	Research	1,3	Social and Human Environment
Somidh Saha	Germany	Karlsruhe Institute of Technology - KIT	Research	1	Biodiversity
Thomas Randrup	Sweden	SLU	Research	2	Governance
Tobias Stern	Austria	University of Graz	Research	2	Circular Bioeconomy
Vanessa García Otero	Germany, Colombia	University of Stuttgart and Urbanic Group Bogota	Research / Practice	2	Governance
Vanessa Zeller	Germany	Technical University of Darmstadt	Research	2	Circular Bioeconomy
Vicente Guallart	Spain	Institute of Advances Architecture of Catalonia - IAAC	Research / Practice	4	Climate Resilience
Wenche Dramstad	Norway	Norwegian Institute of Bioeconomy Research - NIBIO	Research	2	Biodiversity

Annex 2: List of review agendas for validating our results

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Annex 3: Questions posed to review other agendas

1. What do other agendas/reports/initiatives observe in regard to driving forces, critical variables and overarching themes for the future development of conceptual perspectives such as ‘BioCity’?
2. What do other agendas/reports/initiatives see as challenges and perspectives in respect to various research fields identified and elaborated in step 2?
3. What do other agendas/reports/initiatives see as knowledge areas and research gaps in relation to the various research fields identified and elaborated in step 2?
4. Which keywords arise in other agendas/reports/initiatives which complement (or contradict) the keywords drawn from the ‘landscape of arguments’ prepared at the conclusion of step 2?
5. What are the main implementation challenges emerging in other agendas/reports/initiatives?

Annex 4: Protocol of focus groups by research fields

Each focus group discussion was structured in three parts. In each part specific questions related to the research field were discussed. These are as follows:

Circular Bioeconomy		
Part 1	Strategies for transitioning to more circular biobased cities	• Which is the most important strategy for a transition to a circular biobased city? Why? • Which strategy has the highest potential to be implemented in a successful way? Why? • Which of these is the most accepted by decision-makers? Why?
Part 2	Influencing factors for the success of circular biobased strategies	• What are the environmental, societal and economic impacts of scaling up the proposed strategies (e.g., to an entire city, region, country)? Are all strategies compatible with one another? • What are the environmental, societal and economic impacts of scaling up the proposed strategies (e.g., to an entire city, region, country)? Are all strategies compatible with one another? • What is required to minimize negative impacts? What kind of individual and societal change do we need? Which institutions and innovations?
Part 3	Research and knowledge gaps	• What (scientific and practical) knowledge is missing in order to overcome the challenges for the realization of the mentioned strategies? • Which are the three most pressing research questions regarding circular biobased cities?
Climate Resilience		
Part 1	Challenges	• What are the specific challenges around atmospheric cycles, hydrological cycles, heat cycles and pollution in the context of (bio)cities? • What inter-relationships (and trade-offs) exist between various biophysical & biogeochemical processes in the context of the (resilient) BioCity of the future? • Which areas of investigation and action are needed to developing responses to these challenges? (i.e. which are currently lacking or underdeveloped?
Part 2		• How do various biophysical & biogeochemical cycles (relating to urban climate) resonate in different forms of infrastructure? • How are the areas of investigation and action identified in part 1 specifically related to each spatial system, and what refinements can be made to these areas in light of these contexts? • How might social practices, cultures and networks further impact/refine these avenues of investigation and action? • Are there relevant questions/themes/avenues missing from this second session?
Part 3	Scales and stakeholders	• Are these the right scales (e.g., scales missing, different kinds of cities)? • How are the R&D areas identified in session 1 and refined in session 2 related to various scales, and what further refinements can be made to these areas in light of these scales? • Which stakeholders are involved in each scale, and what does this specifically mean for avenues of investigation, development and action? • Which kinds of interactions (between academia, government, industry and community/society) are necessary for investigation, development and action at each scale? • Which pathways for change can be identified for each scale
Governance		
Part 1	Governance for the transition to BioCities	• Which governmental and institutional forms contribute to the transition to BioCities and how can these be reached? • Are further processes involving society, science and decision-makers necessary for the transition to BioCities? • Which instruments/strategies/action programs – policies – are necessary for the transition to BioCities?
Part 2	Participation and networking as key elements for the transition to BioCities	• What are the potentials and limits of participation and networking in the transition to BioCities? • What are the challenges in integrating different stakeholders into the transition to BioCities? • What is the necessary framework to enable participation and networking?
Part 3	Planning and design as key elements for the transition to BioCities	• How can urban planning and design to implement the concept of Biocities be scaled up withhin the city and to a national level? • What are the challenges for spatial planning in applying such a concept? • How can trade-offs between different expectations towards realising BioCities be reduced at the various planning levels?
Social and Human Environment		
Part 1	Socio-cultural environment and challenges	• What are the trends and challenges in relation with the social environment in the city of today in the European context? • What changes are needed to happen to reach Biocity in 2050?
Part 2	Participation and involvement	• What is your experience with people's involvement in planning and decision-making in urban development and environmental issues? • What needs to be changed to get an individual involved in participation processes?
Part 3	Health and well-being	• How are the topics health and well-being integrated in the city of today? What role do they play? • If we consider health and well-being as most important factors, how would they frame/influence the BioCity?
Biodiversity		
Part 1	Biodiversity in the city: background, trends a challenges	• What does Biodiversity mean in the context of BioCities? • At which complexity levels (e.g., engineering, intervention, stakeholder) biodiversity in cities should be addressed? • What are the trends of biodiversity in the context of biocities? • What ecological economic, and social challenges do cities face in terms of Biodiversity and how can these be addressed?
Part 2	Nature- Based Solutions (NbS) for Biodiveristy conservation in a spatial, temporal and taxa scale	• What are the pros and cons of applying the concept of NbS to increase urban biodiversity (e.g., urban green spaces, green infrastructure)? • What is important to consider when applying the concept of NbS for biodiversity conservation in a spatial temporal and taxa scale? • How do NbS address and contribute to urban resilience by increasing biodiversity conversation in cities?
Part 3	Enhancement of ecological knowledge of biodiversity	• Which biodiversity in the cities we ought to preserve (terrestrial, aquatic, exotic, native, etc.)? • How can urban ecology be enhanced for promoting urban biodiversity conservation? • How to transfer landscape-scale urban biodiversity models into urban planning to foster biodiversity conservation and enhancement?

Annex 5 Landscape of arguments for each research field. Source: own representation based on focus group discussions

A: Biodiversity	B: Circ. Bioeconomy	C: Climate Change	D: Governance	E: Social Environmt.
Aesthetics	Business Innovation Hubs	Actions & Projects	Agenda linking	All peoples needs
Awareness raising	Citizen Engagement	Adaptative Approaches	Behavioural Change	Big Picture missing
Biodiversity & NBS	Clear definition	Citizens and Science	Bottom Up / Top Down	Change of minds & habits
Blue Infrastructure	Contextuality; city strat.	Data and Models	Capacity Building	Citizen Engagement
Citizen Engagement	Creativity	Durability	Changes	Co-Creation
Conflicts	Cutural Change	Environmental Justice	Communication	Digital Connectivity
Contact with nature	Feedback-Loops	Green Infrastructure	Contextuality	Diversity of Stakeholders
Common understanding	Five Capital Approach	Green Spaces	Decentralisation	Early Engagement
Communication	Greening the city	Green Roofs	Dependencies Prevention	Education & Skills
Connectivity	Holistic perspective	Holistic, integrative view	Donor Policies	Explaining the benefits
Economy / Costs	Innovation/new products	Inclusion	Form/Level Participation	Green Space for health
Education	Interconnectivity	Interdisciplinarity	Interdisciplinarity	Health in planning
Evaluation	Knowledge Transfer	Integration of data	Key Players	Innovation in Planning
Functional Approach	Mid-/Longterm Agenda	Lack of data	Knowledge Transfer	Knowledge-Transfer
Green Planning	Mindsets & habits	Learning and studying	Longterm Maintenance	Learning Process
Increasing Biodiversity	Monitoring local/systemic	Maintenance	Mindsetting	Monitoring
Knowledge Transfer	Narratives/trigger projects	Metabolic cycles	Mosaic Governance	Access to Nature
Integration into Planning	Networking	Multiple Benefits	New Business Models	Naturebased solutions
Legislation	Public Health	Naturebased solutions	Perception Collection	New Approaches
Local solutions	Recycling and Re-Use	New materials	Perimeter of Biocity	Participatory democracy
Multifunctionality	Re-Materialisation	Neighbourhood scale	Pilot Project as Starters	Pressure on decisions
Silo-Challenge	Social Inclusion	Participatory Approach	Political Discourse	Providing Spaces
Testing new solutions	Spatial planning	Re-Definition of a city	Political Leadership	Slow Mobility
Time needed	Streamlining strategies	Understandable goals	Private Landowner	Social Inclusion
Trade-Offs	Timber	Under and upper ground	Project Culture	Socio-ecological info.
Triggering	Urban Metabolism	Urban Science	Reimagening the City	Systematic integration
Valorisation	Waste Reduction	Variability of changes	Regulatory Framework	Time and resources
			Scaling up or down	Trade Offs

Annex 6 Cross validation of arguments. Source: own representation based on focus group discussions

Four (4) overall arguments (mentioned in all five focus group discussions)**:**
Re-Definition of a city, green planning, time and education.

A: Biodiversity	B: Circ. Bioeconomy	C: Climate Change	D: Governance	E: Social Environmt.
Common understanding	Clear definition	Re-Definition of a city; Understandable goals	Reimagening the City	Big Picture missing
Green Planning	Spatial planning	Under and upper ground	Perimeter of Biocity	Green Space for health
Time needed	Mid-/Longterm Agenda	Durability	Longterm Maintenance	Time and resources
Education	Feedback-Loops	Learning and studying	Capacity Building	Education & Skills; Learning Process

Six (6) key arguments (mentioned in 4 of 5 focus group discussions): citizen engagement, connectivity, knowledge transfer, streamlining strategies, new business models and greening the city.

A: Biodiversity	B: Circ. Bioeconomy	C: Climate Change	D: Governance	E: Social Environmt.
Citizen Engagement	Citizen Engagement	Actions & Projects		Citizen (early) Engagement
Connectivity	Interconnectivity		Interdependencies	Digital Connectivity
Economy / Costs	Business Innovation Hubs		Donor Policies; New Business Models	New Approaches
Knowledge Transfer	Knowledge Transfer		Knowledge Transfer	Knowledge-Transfer
Silo-Challenge	Streamlining strategies		Pol Discourse & leadership	Systematic integration
Biodiversity increasing	Greening the city	Green Spaces/gr. roofs		Socio-ecological info.

Eleven (11) sustaining arguments (mentioned in 3 of 5 focus group discussions):
Social inclusion, change of minds, contextuality, innovation, holistic perspective, regulatory framework, naturebased solutions, multi-functionality, participation, trigger projects and adaptive approaches.

A: Biodiversity	B: Circ. Bioeconomy	C: Climate Change	D: Governance	E: Social Environmt.
	Social Inclusion	Inclusion		Social Inclusion
	Cutural ch.; Mindset,habits		Behavioural Ch./Changes/mindsetting	Change of minds & habits
Local solutions	Contextuality; city strat.		Contextuality	
Testing new solutions	Innovation/new products; creativity			Innovation in Planning

(*continued on next page*)

(*continued*)

A: Biodiversity	B: Circ. Bioeconomy	C: Climate Change	D: Governance	E: Social Environmt.
	Holistic perspective	Holistic, integrative view	Perception Collection	
Legislation			Regulatory Framework	Pressure on decisions
NBS & Biodiversity		Naturebased solutions		Naturebased solutions
Multifunctionality		Multiple Benefits		Explaining the benefits
		Participatory Approach	Form/Level Participation	Participatory democracy; co-creation
Triggering	Narratives/trigger projects		Pilot Project as Starters	
Integration into Planning		Adaptive Approaches; Variability of changes	Scaling up or down; agenda linking; Bottom Up-top down	

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