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ORIGINAL PAPER

A conceptual model for a circular city: a case study of Maribor, Slovenia

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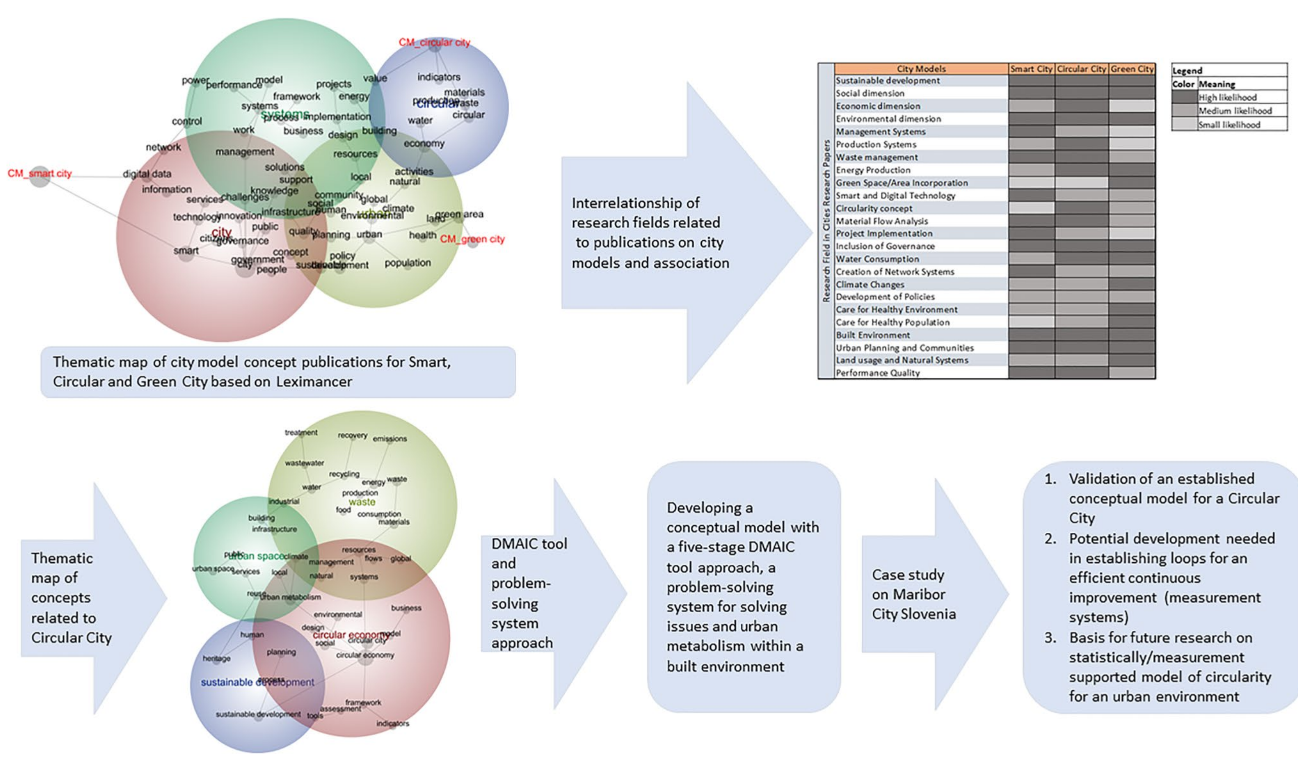
Abstract

Cities play a crucial role in achieving sustainable development. Decision-makers require assistance in developing city transformation plans amidst the emergence of various city models. A content analysis using concept mapping was conducted to examine smart, circular, and green city models. The analysis, supported by Leximancer, revealed that city models are evolving by adopting beneficial solutions from competitors, reflecting a strong focus on sustainable development. Additionally, twenty-four research areas essential for implementing a circular city were identified and validated. Furthermore, a conceptual model for a circular city was developed, incorporating the Define-Measure-Analyse-Improve-Control tool and a problem-solving system. Testing the model on Maribor highlighted challenges in monitoring the transition towards circularity. The study validates the established model but emphasises the need for further research and case studies to verify its practicality. This scientific research enhances the understanding of city models and their evolution towards sustainability, providing valuable insights for decision-makers and urban planners.

Graphical abstract



Keywords City models · Conceptual model · Define-Measure-Analyse-Improve-Control Process · Content analysis · Problem-solving structure

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Introduction

By 2019 over 55% of the global population resided in urban areas (United Nations 2019). With their hindsight areas, cities consume over 60% of global energy and over 75% of the planet's material resources (Dodman et al. 2017; World Economic Forum 2022). Such consumption rates generate an increased impact on the environment and society. Thus, cities are responsible for producing up to 50% of global solid waste and 70% of greenhouse emissions yearly (OECD 2021). Projections by Gao and O'Neill (2020) indicate an increase in urban areas by 1.8 to 3.6 by 2100 in comparison with the year 2000, with the residing population expected to rise by 15 per cent, according to United Nations (2019), while World Economic Forum (2022) projecting 80% of global population residing in urban areas by the year 2050. The increased growth of cities and their population presents a unique challenge for policymakers, researchers, experts, and society in achieving sustainable development in cities.

The importance of cities in combating rising economic, social, and environmental issues has not gone unnoticed. The United Nations emphasised the cities as an important area to be considered, thus including them under the 11th goal of Sustainable cities and communities (General Assembly UN 2015). European Union (EU) delivered a renewed Urban Agenda for the EU (Urban Agenda for the EU 2023), further supporting countries' dedication towards sustainable development in urban areas. Such directives have fostered the development of various city models (smart, green, sustainable cities), including circular cities, encompassing circular economy principles for urban areas. The circular city model was supported by the EU's "Circular cities and regions initiative" to reduce pressure on natural resource consumption and create sustainable and circular jobs (European Commission 2022). The initiative adopted the European Green Deal (European Commission 2021) and the Urban Agenda for the EU (Urban Agenda for the EU 2023).

The emergence of various city models for urban areas poses a challenge for decision-makers, experts, and researchers. However, there is a distinction in tackling acceleration towards a sustainable city for various city models. According to the existing literature review, we can perceive the prevalent features of the mentioned city's models. For example, smart cities employ smart and digital technologies (Moradi 2020; Tiware et al. 2021), circular cities introduce principles of circular economy from the strategic and practical perspectives (Crippa et al. 2022), while green cities focus on greening public spaces (Jia et al. 2021; Zhang et al. 2022). City models' reviews are beneficial for furthering the city's development. However, the rapid rise of publicised review papers presents an obstacle between discerning potential breakthroughs or rewriting published findings (Nature Sustainability 2021). Understanding city models' underlying fields and potential overlaps can forward implementing beneficial ideas in practice.

In recent years, there has been a tendency towards the circular economy and subsequent implementation in urban areas (European Commission 2015; European Commission 2019). The circular economy implementation within cities faced several barriers, as the circular economy was primarily developed for industry and services (Williams 2019), including product development (Boeri et al. 2019). The transition towards redefining the circular city model as a built or urban environment has begun with increased research and support by organisations such as the EU, Ellen MacArthur Foundation, and the UN (Murray et al. 2017). A transformation of the established circular economy approach to better accommodate the intricate systems presented by cities is needed (Prendeville et al. 2018). The increased interest in circular cities spurred the development of several research areas, such as building on resource efficiency (Ness and Xing 2017), circularity in port cities (Gravaguolo et al. 2019; Cerreta et al. 2020), establishing circular tools (Girard & Nocca 2019), nexus for energy, food and transport (Paiho et al. 2021). Cities are considered complex built systems, and defining circularity models should consider a systems approach (Wijkman et al. 2019). Systems approach in cities were perceived in the "ReSOLVE" approach (Prendeville et al. 2018), complex urban system structure (Rios et al. 2022), and inclusion of resilience hubs across urban systems (Boeri et al. 2019). However, these models focused more on various areas (*e.g.* energy, waste, food sector), not comprehending the entire system. Also, statistical validation and a transition measurement system are needed to provide adequate information for decision-makers. Inspired by the existing studies and research the main challenge is not a circular approach implementation but measuring acceleration towards circularity and providing continuous improvements backed with statistical and reliable data (Birgovan et al. 2022; Paoli et al. 2022). A solution can emphasise a circular city model based on the Define-Measure-Analyse-Implement-Control (DMAIC) tool and problem-solving system, represented within this paper. The DMAIC tool, as part of Six Sigma, is a data-driven technique that enables a project-based approach, providing an established five-phase structure, enabling the identification of possible solutions, their development and implementation (Jamil et al. 2020). Such an approach allows for semi- and final loops throughout the process (Sokovic et al. 2010) and allows continuous improvement to already implemented circular approaches while enabling a system perspective. As this approach is data and statistically-driven (Monday 2022), it enables management through measurement techniques. It allows the promotion of "state-of-the-art" maps before and after the implementation (de Mast and Lokkerbol 2012). Furthermore, it coincides with the need for measuring systems for transitioning from a linear to a circular economy (Birgovan et al. 2022; Paoli et al. 2022). The problem-solving structure enables one to focus on the roots of issues (Mingers and Brocklesby 1997). Engaging DMAIC and problem-solving into one model assures a systemic structure supported by measurement techniques and supports developing strategies for the transition towards circularity.

Thus, the research focus has been given to the three main areas. Firstly, to examine the extent of correlation in developing different city models, exploring their shared areas of interest and the advantages of adopting an integrated approach. This analysis has been conducted via a research papers' content analysis on circular, green, and smart cities. Then, to identify key research fields, crucial for the progression of circular cities and their transition from the current linear strategies. Understanding the existing research focus is essential in establishing a foundation for devising strategies and projects that can guide policymakers when incorporating circular activities. Third, to design and test a conceptual model based on the DMAIC (Define, Measure, Analyse, Improve, Control) tool and a problem-solving structure. This model incorporates the identified research fields that promote circular growth. Through a case study, strengths and potential shortcomings of the model are identified and addressed to enhance its effectiveness. This research is essential as it can guide policymakers in formulating strategies that facilitate continuous improvement of their cities and lay the groundwork for possible unified standards in the transformation towards a circular city.

Methods

This section represents a methodological approach and methods, comprehending details on literature review and content analysis, implementing and testing DMAIC process. A visual presentation of our research is seen in Fig. 1.

Content analysis

The search inquiry consisted of three separate searches focused on various city models. The inquiry was conducted in the Web of Science (WoS) Core Collection database, which is well-maintained, valid and suitable for bibliometric analysis (Pasko et al. 2021). The ten years were considered (from 1st January 2012 to 31st December 2022) as a content analysis requires at least three years (Bornmann and Leydesdorff 2014). Such a period also allows for examining the change in research trends along with strategic documents, such as the Agenda on Sustainable Development Goals (United Nations 2013). Boolean operators used in the inquiry are provided in Table 1. Furthermore, we have considered only articles, review articles and proceeding papers in English.

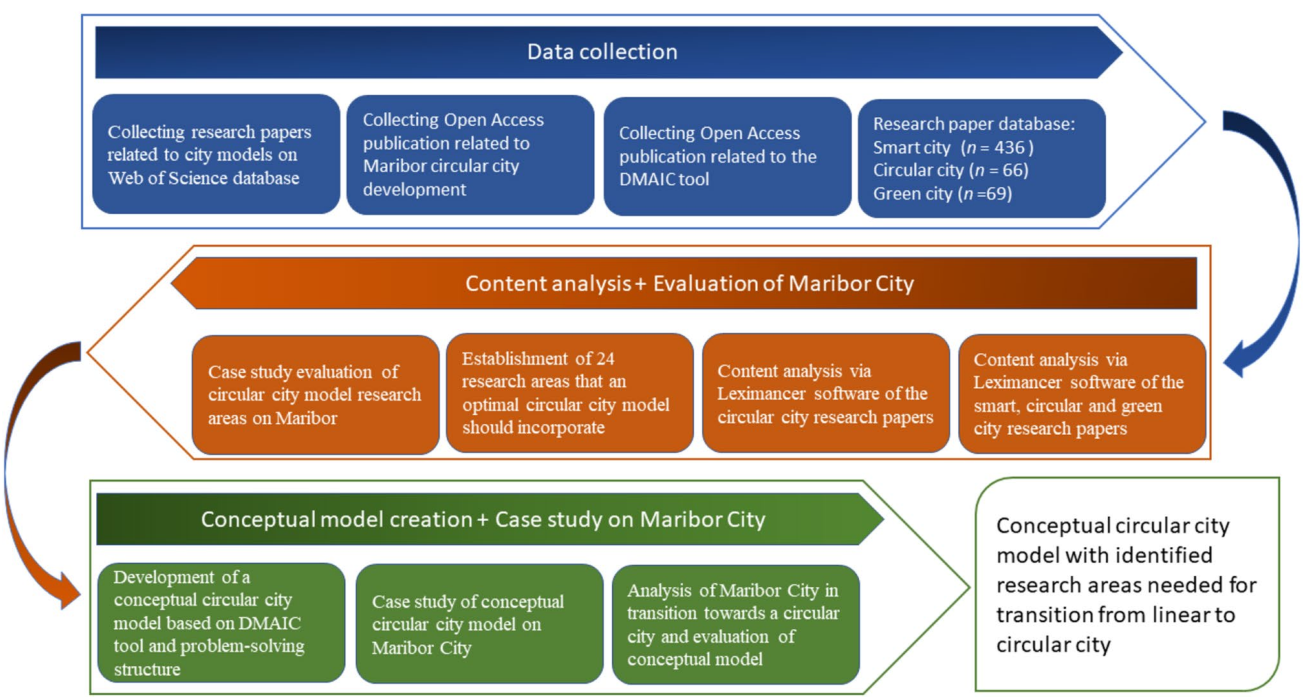

Fig. 1 A research methodology for designing and testing a conceptual model for circular cities

Table 1 Boolean operators used in the inquiry for city models

City model	Boolean operators
Circular city	1. (ALL = ("circular cit*" OR "circular town" OR "circular municipality" OR "circular metropolis" OR "circular cosmopolis")) AND ALL = (concept* OR defin* OR care OR model OR idea) 2. ((ALL = ("circular cit*" OR "circular town" OR "circular municipality" OR "circular metropolis" OR "circular cosmopolis"))) AND ALL = (indicat*)
Green city	1. ALL = ("green cit*") AND ALL = (review AND concept*) 2. ALL = ("green cit*") AND ALL = (definition OR concept*)
Smart city	1. ALL = ("smart city*") AND ALL = (review AND concept*) 2. ALL = ("smart city*") AND ALL = (definition OR concept*)

The identified papers for each inquiry were distributed into three groups aligned with city models (smart, circular, green). A two-step screening procedure was applied, enabling paper selection per a set of individual constraints (Padilla-Rivera et al. 2020). The first step comprehended an abstract and title overview, where we excluded papers with no content links to the city models. The second step comprised a content review, where at least one of the following factors had to be attained:

- the keywords needed to have a contextual meaning in the paper's content to the inquiry,
- the inclusion of other significant keywords closely related to city models (e.g. smart technology, big data for the smart city).

The initial inquiry and the two-step screening procedure results are shown in Table 2. The established database was a basis for additional content and statistical analyses.

The content analysis was implemented using Leximancer software. Leximancer is a tool which uses text mining to generate topic models or concepts based on high-frequency words garnered from the text materials (University of Surrey 2022). The software performs analysis using natural language text data (Biroscak et al. 2017) and applying the Bayesian-based algorithm (Smith and Humpreys 2006). Leximancer builds a concept system using thematic and semantic inquiries (Smith 2003), grouped into themes with associations and occurrences (Cretchley et al. 2010). Leximancer visualises concepts, providing additional information about interrelationships and the concept's strength (Cretchley et al. 2010; Angus et al. 2013). Such visualisation is achieved by representing themes as circles, with their colour differentiation building a heat map. The warmer colours (*e.g.* red, orange) are representative of prevalent themes, while the cooler colours (*e.g.* green, blue) mark less significant themes (Engstrom et al. 2022). The association by tags analysis enables additional data representation. Tags are not directly involved by identified themes or concepts but are searched directly in the provided publications, exploring existing data and analysis avenues (Wilk et al. 2021). The tag's positioning within the concept map, concerning the heat map, represents specified research areas of significance (Biesenthal and Wilden 2014), improving understanding regarding strong semantic connections and overlaps between tags, concepts and themes (Campbell et al. 2011; Wilk et al. 2021).

Table 2 Inquiry and two-step screening procedure result for city models

City model	Initial search	1st step screening	2nd step screening
Smart city	6995	768	436
Circular city	141	111	66
Green city	205	167	69

DMAIC model

Identified key concepts and emerging trends were used for designing a DMAIC conceptualisation model, further implemented in Maribor, Slovenia. DMAIC enabled a holistic and systematic approach to process improvement and was mainly used in enterprise or manufacturing sectors. However, its employment was lately also observed in other sectors, such as environmental management (Reid et al. 1999), IT technology (Biesialska et al. 2018), and management of cities (Qayyum et al. 2021). Its adaptability and flexibility due to the generic method conception are advantageous when applied to different sectors (Sokovic et al. 2010). Including statistical and measurement approaches is a valuable asset for DMAIC (de Mast and Lokkerbol 2012). However, the DMAIC tool is yet to entail environmental aspects, measurement systems that support sustainable development and integration of digital data ("big data"), increasing its competitiveness (Sony et al. 2020). The DMAIC is commonly represented as a circular cycle consisting of five stages with successive steps linked to at least two other steps (Sokovic et al. 2010). The five steps consist of (1) Defining the goal and its requirements, (2) Measuring the current process, (3) Analysing the results of measurements, (4) Improvement of processes, implementation, and removal of imperfections and (5) Control over-improved processes, and constant monitoring (Pyzdek et al. 2010; Sony et al. 2020). Such distribution enables a continuous and holistic approach to either resolve or improve the current status.

Aside from the DMAIC tool, we incorporated the problem-structuring approach as a problem-solving option. Unstructured challenges are characterised by multiple actors, perspectives, conflicting interests, critical uncertainties, and essential intangibles (Rosenhead & Mingers 2001). Considering cities' complexity, we can discern that any predicaments occurring within them has attributes related to one of the characterisations above. Problem-solving allows us to construct a holistic map and identify causes associated with the challenge (Mingers & Brocklesby 1997; Chakravorty et al. 2008). The problem-solving models must be constructed so that they can operate iteratively, can be easily accessible to users with different knowledge backgrounds and can be identified and implemented on a local scale (Mingers and Rosenhead 2004). We combined the 5S method challenge identification, information gathering, generation and evaluating solutions and implementation of the best result (Chakravorty et al. 2008) with a systematic problem-solving structure to create conceptual model.

When considering a city, it is vital to view it as a complex living ecosystem. It is a natural counterpart and employs many aspects of nature's circularity, such as metabolism, with its distinct inputs (e.g. products) and outputs (e.g. waste) (Golubiewski 2012). Such an approach enables us to view the city from another standpoint, not as a human-created system, but as a "living creature" that adheres to the same laws as all living creatures, e.g. Lotkas maximum power principle (Ulgiati and Zucaro 2019). Nature, without the interference of society, can be considered the best-optimised closed loop with zero losses during multiple

Fig. 2 A model, based on guidelines questions and actions needed for implementing circular city's activities

iterations of its cycle (Long 2020) and creating closed-loop systems (Kara et al. 2022). Closed loops prevent the loss of vital resources (Wahlström et al. 2019), prolong their use (Blomsma and Brennan 2017) and positively contribute towards the environment (Yang et al. 2022) and climate change issues (Stefanakis et al. 2021). Considering the DMAIC tool, promoting a circular approach to resolving existing problems and a problem-solving structure approach, we can theoretically achieve an artificial loop similar to nature. A visualisation is represented in Fig. 2.

It is crucial to consider areas in the city to readdress. Cities are built systems with many subsystems referred to as resource flows, energy production, infrastructure, and society. Any potential solution for a subsystem needs to reconsider possible changes to other subsystems related to it (Johnson 2012). The conceptual model was divided into the five steps of the DMAIC model, with an explanation for the needed actions to complete it. The execution of the model presented will enable a systematic approach and ease future improvements to the city itself.

The Define phase is the initial phase of the DMAIC method and is crucial when approaching the challenges the city wants to address. Considering the problem-solving structure, a systematic approach to identifying interesting city areas is needed, with a basis on available data. Before solution implementation, several mid-goals and actions are needed such as (1) strategic approach creation, (2) constraints, (3) city holders, stakeholders, and other public groups inclusion, and (4) value stream creation, which are derived from the following question.

- *Q1: What does a city want to accomplish or address?*

Establishing challenging city areas and approaches to improve them is crucial for a state-of-the-art map. With a global acceleration towards sustainable development, cities have many model guidelines to follow. The model choice requires presenting beneficial improvement to the current status quo.

- *Q2: For whom will the changes be beneficial?*

Sustainable development is structured on three dimensions: economic, environmental and social. The city structure is similar to sustainable development, with an artificially created ecosystem comprising living organisms (parks, waterways), inhabitants (businesses, residential areas, services) and infrastructure (buildings, public transport). Any development, similar to sustainable development, should promote beneficial improvements to all actors within the city.

- *Q3: What will the changes affect when implemented?*

The complexity of the city system and its subsystems presents a challenge to any solution implementation and the changes it will bring. Improvement in one subsystem (*e.g.* energy production) could enhance the livelihood of inhabitants while decreasing the negative impacts on the environment. Therefore a holistic approach is suggested when evaluating solutions' effects on city.

The measure phase continues the process of the define phase and implements several initial setups, most notably the established value streams from the previous stages. Multiple iterations are possible until satisfactory results are gained. The phase needs to resolve two key factors by conducting activities such as (1) create a measurement scope, (2) prepare a wholesome measurement system, (3) validate measurement systems and (4) collect statistical data.

- *Q4: What data is vital to attain for accomplishing the city's goals?*

The established value streams and plans refer to needed data for attaining goals. The data is then transformed into a "state-of-the-art", referring to areas of interest, and statistical database creation as the basis for comparison after the implementation of solutions.

- *Q5: How to attain the needed data?*

Several approaches can be undertaken when referring to data type—establishing procedures to garner data and associating tools, frameworks and technologies enabling it. Data should be reliable, available for further analyses and computable between different technical systems.

Statistical data gathered in the measure phase is analysed in the analysis phase. Multiple iterations of actions such as (1) appropriate tools and framework choice for conducting analyses, (2) gained data statistic analysis, (3) statistical results validation, (4) "state-of-the-art" and "hot-spot" creation and (5) issue identification and systematic distribution by available resources might be needed, until mid-goals are fulfilled and a follow-up with the next phase is possible.

- *Q6: What is the city's current standing?*

As already considered in the measurement phase, the most comprehensive way to establish cities current state is through statistically available data. The analysed data provides guidelines for establishing a holistic overview of areas and subsystems. These areas are crucial for decision-makers, experts and researchers for area evaluation and distribution importance of addressing.

- *Q7: How far away from the set goals are we?*

A comparison between the goals and the current state can be established. Understanding our standing is essential, as it provides insight into identified challenges and systematic distribution by considering the funds, technology, policies, and workforce needed to address them.

In the improve phase, we can follow-up on the established initial approaches and their availability, focusing on their implementation in practice. Solutions performance is constantly measured until satisfactory progress in-line with the proposed results. This is achieved through actions: (1) potential solution development, (2) solution evaluation, (3) solution optimisation, (4) solution compliance validation to a circular and sustainable approach and (5) solution implementation.

- *Q8: Which solutions are most appropriate, and how to implement them?*

Solution selection to address identified issues must follow sustainable development and chosen city model core attributes. Following the selection, a holistic plan for solution implementation is conducted, considering legal limitations, funding, and technology availability.

- *Q9: How will the implemented solutions improve current standing?*

Both questions should be considered simultaneously. The selected solutions considered for realisation need to provide visible improvements across all affected areas.

The control phase represents the conclusion of the entire process. If an appropriate approach is considered, it can also act as an initiator of semi-loops or continuous circular loops, theoretically promoting and enabling a constant process of improvement and progress. In hindsight, creating such a loop can help further development towards sustainable development and circularity or, to a degree, maintain the status quo achieved through the whole DMAIC process. Loop creation is achieved through actions (1) indicator set creation, (2) indicator set validation, (3) indicator implementation for regular monitoring, (4) ensuring a maintainable improvement process and (5) semi- and final-loop creation.

- *Q10: What indicators to create and use for measuring checks in the city?*

After the solutions realisations, there is a clear need to establish a monitoring system for either an unspecified or specified time. The reverse information flow feeds the established statistical database. For further improvement, a measurement system with a compatible indicator framework is needed to measure the new values. The acquired data, compiled with existing data, can be processed for reports and presented to raise public awareness and potential investors and guide policy creation or improvement.

- *Q11: Which loops to establish and nurture?*

The DMAIC tool's primary purpose is continuous loop creation, providing a long-term improvement process. Considering the addressed issues, not all are valid for such a loop, established by referring to the benefits added by each iteration. A “dummy” model should be created and tested for improvement rates and, based on the results, considered if applicable for inclusion into a semi-loop.

Case study Maribor and data collection

Maribor is the regional capital of the statistical region “Podravska”, the second largest city in Slovenia. Maribor covers 40.96 km2 (MOM 2022). According to the Statistical Office of the Republic of Slovenia (SURS, 2022), Maribor has 96.302 inhabitants in 2022. Maribor actively follows sustainable development guidelines, as detailed in European Circular Economy Action Plan (European Commission 2015), Green Deal (European Commission, 2021) and Slovenian Development Strategy 2030 (Government of the Republic Slovenia 2017). For this reason, it joined the consortium Circular Cities and published its declaration (ICLEI 2023a) and cooperated in the "Deep demonstration" circular Slovenia project, a joint operation by the EIT Raw Materials, EIT Climate-KIC, the Joint Research Center of the European Commission, and the Government of the Republic of Slovenia (Kovačič Lukman et al. 2022). Maribor adopted its Circular Economy strategy in 2018 (CORDIS, 2018) and actively monitors and reports its progress to Circular Cities consortium (ICLEI 2023a). The reports were further used for the basis for evaluation of current circular development of Maribor and projects.

Results

This section represents content analysis results, establishment of circular research fields and comparative analysis with current standing of Maribor. The content analysis is followed up by a case study analysis of Maribor based on the DMAIC model phases.

Content analysis

We carried out a content analysis to identify current trends in city models, with focus on circular city. The publications related to the city models have indicated an irregular distribution, yet a visible increase between 2019 and 2021.

From Fig. 3, we can perceive that the number of publications increased significantly from the initial year, attaining peaks in multiple years depending on the city model. The highest number of publications in the case of the circular city was detected in 2021, smart city in 2022 and green city in 2019. The overall increase in publications related to city models can be attributed to the inclusion of cities within the UN Sustainable development goals (SDGs 17) for green cities, the adoption of the circular economy action plan in 2015 for circular cities, while smart cities the increased interest and growth of blockchain technology and recognition by organisations such as EU, UN. The interest in each specific city model lies in what wants to be achieved by its implementation. For green cities, this is incorporating green spaces, an increased sustainable approach to food production, and green practices in industry and society. For smart cities, this is the implementation of digital technology and solutions, IoT, and big data, spearheading the fourth industrial revolution. Meanwhile, for circular cities, this can be attributed to improving energy production and consumption, improving waste management, increasing circulation in loops for extended periods, and preserving resources for future generations.

WoS enables multiple analyses capabilities surveys, including publication distribution analyses according to subject categories. The database comprehends approximately 250 subject categories and research areas, which provide insight into the city model evolution. The subject categories distribution per city model can be seen in Table 3.

We can perceive similarities between the distribution per subject category, indicating a common research field for all the city models. These fields are perceived from subject categories. For example, such as Environmental Sciences, Green Sustainable Science, and Environmental Studies. Thus, environmental-related research fields are at the forefront of all three city models, while additional fields were detected for separate city models. In the case of smart cities, there is a clear focus on digital technologies, supported by the fact of categories such as Computer Science Information Systems ($n=61$), Computer Science Theory Methods ($n=58$) and Engineering Electrical Electronic ($n=57$). The circular city focuses on energy production and consumption, visible by categories of Engineering ($n=26$) and Energy Fuels ($n=23$). A similar notion can be perceived for the green city with its focus towards urban planning of green spaces due to categories Regional Urban Planning ($n=12$), Urban Studies ($n=12$) and Transportation ($n=6$). Additional analysis within the WoS platform included the journals that identified a total of $n=455$ publication titles for all the city models. With multiple publications identified across the model, only the top 10 journals were considered and presented in Table 4.

We can perceive a similar distribution to subject categories attributed to all the observed city models, for example, Sustainability, Sustainable Cities and Society. As for categories, there is also some specific orientation for publications. For smart cities, it is again focused on computer sciences, *e.g.* Lecture Notes in Computer Science ($n=8$) and Progress in IS ($n=8$). The circular city is more oriented towards increased circularity of resources, as visible by the Journal of Cleaner Production ($n=11$) and Resources Conservation and Recycling ($n=3$). For the green city, we can once again discern increased interest towards environmental technology, urban planning and human health, with publications such as Environmental Technology Innovation ($n=2$), International Journal of Environmental Research and Public Health ($n=2$) and Town Planning Review ($n=2$).

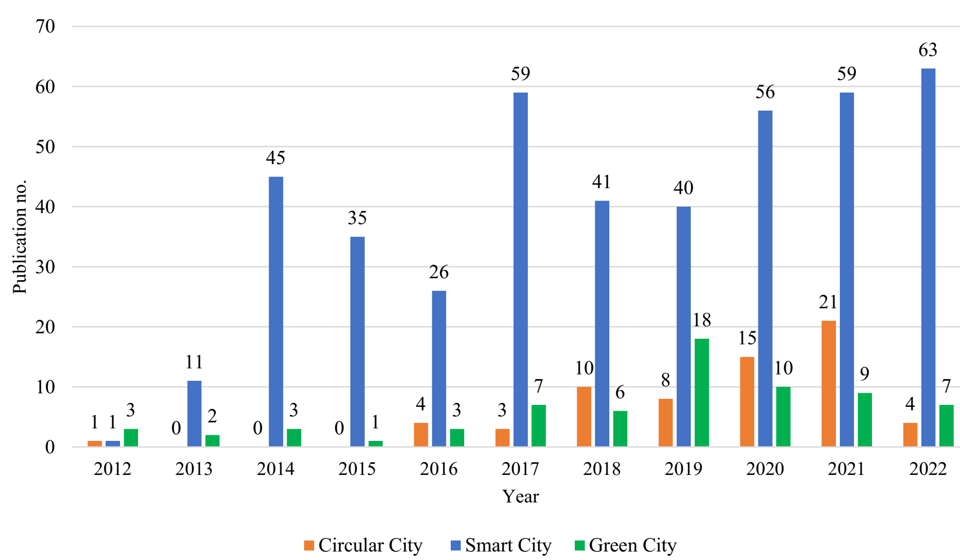

Fig. 3 Number of published papers per city model ranging from 2012 to the 2022 year

Table 3 Ten most frequent WoS subject categories for smart, circular and green cities

City model	WoS subject category	No. of hits
Smart city	Green sustainable science technology	64
	Urban Studies	63
	Computer Science Information Systems	61
	Computer Science Theory Methods	58
	Engineering Electrical Electronic	57
	Environmental Sciences	46
	Environmental Studies	43
	Regional Urban Planning	38
	Computer Science Interdisciplinary Applications	36
	Telecommunications	33
Circular city	Environmental Sciences	49
	Geography	27
	Engineering	26
	Energy Fuels	23
	Business Economics	3
	Architecture	2
	Art	2
	Meteorology Atmosphere Science	1
	Materials Science	1
	Biodiversity Conservation	1
Green city	Green Sustainable Science Technology	24
	Environmental Sciences	17
	Environmental Studies	14
	Regional Urban Planning	12
	Urban Studies	12
	Transportation	6
	Engineering Environment	5
	Computer Science Theory Methods	3
	Economics	3
	Management	3

We have employed Leximancer to model concepts to discern interactions between the employed city models. The initial settings within the Leximancer were the collection of 517 documents. The second phase entailed concept generation, where we merged concepts with the same semantic meaning, *e.g.*, economy and economies, as Engstrom et al. (2022) suggested. The city models were constructed and implemented as tags for distinct overviews in the final concept map (Wilk et al 2021). The concept map comprised 62 unique concepts with three tags. Multiple reclustering processes were implemented in the final phase to establish logical themes (Engstrom et al. 2022). The final concept map comprehends four significant themes: *city, urban, systems* and *circular,* see Fig. 4.

As perceived from the obtained concept map, the dominant theme is *city*, comprising concepts 'smart', 'technology', 'services', and 'concept', implying research towards the smart city conceptual model. Other identified concepts included 'digital data', 'network', 'control' and 'information', indicating development towards smart control system solutions. Another cluster consisted of concepts 'public', 'knowledge', 'support', and 'solutions' that can be related to increase public awareness of digital technologies.

The second theme was *urban*, comprising concepts of 'planning', 'environmental', 'population', 'development', and 'planning', indicating a systematic and sustainable approach towards urban development. Another concept cluster included 'global', 'local', 'natural', 'resources', 'community', and 'activities', emphasising establishing and improving resource flows within urban communities.

The third identified theme was *systems*, consisting of two clusters. The first cluster included concepts of 'performance', 'framework', 'process', 'management' and 'model', indicating a managerial and systematic approach towards city development. 'Projects', 'energy', 'implementation', 'design' and 'building' concepts comprised the second cluster, implying designing energy-efficient infrastructure on the scale of city projects.

Table 4 Ten most frequent journals for smart, circular and green cities

City model	Journal	No. of publication
Smart city	Sustainability	26
	Cities	16
	Sustainable Cities and Society	12
	IOP Conference Series Earth and Environmental Science	8
	Lecture Notes in Computer Science	8
	Progress in IS	8
	Applied Sciences Basel	5
	smart Cities	5
	Technological Forecasting and Social Change	5
	Communications in Computer and Information Science	4
Circular city	Sustainability	14
	Journal of Cleaner Production	11
	Resources Conservation and Recycling	3
	Sustainable Cities and Society	3
	Urban Geography	3
	Blue-green Systems	2
	Open House International	2
	Water	2
	Applied Science Basel	1
	Business Strategy and the Environment	1
Green city	Transportation Research Procedia	5
	Strategies for Sustainability	4
	Sustainability	3
	Environmental Technology Innovation	2
	International Journal of Environmental Research and Public Health	2
	IOP Conference Series Materials Science and Engineering	2
	Journal of Environmental Planning and Management	2
	Town Planning Review	2
	Urban Forestry & Urban greening	2
	Baltic Journal of Economic Studies	1

The last theme was *circular*, which included two clusters. Concepts 'indicators', 'value', and 'materials' formed a cluster related to establishing measurement systems for flows within city. 'Economy', 'waste', 'production', 'activities' and 'water' comprised the second cluster, which indicated implementing a circular economy within city activities.

The position of city model tags provides additional perspective for research fields. A likelihood concept consisting of city models was established, comparing only concepts with the highest likelihood towards a city model. For a smart city some concepts with the highest interaction rate were 'smart', 'technology', 'control', and 'citizens'. The most critical aspects of smart cities are implementing innovative or digital technologies, accelerating greater control over the flow of digital or "big" data in cities and increasing citizens' digital knowledge, governance, services and systems. In circular city concepts, the highest interaction rate was detected for circular materials, waste, production and economy. The acceleration of circular economy principles and material flows through resource circulation can be considered at the forefront of circular cities. In the green cities case, the highest interaction rates were discovered for green area, land, health, population and nature. Application of green technology, green areas within urban areas, environment and human population health improvement can be considered as focal for green cities.

Content analysis also identified resemblance and diversity in research areas. Considering the identified concepts from the thematic map (see Fig. 4), we have combined them by semblance into research fields. Including the likelihood between the city model and concepts considered in a research field, we were able to rate their importance as visible in Fig. 5.

Our analysis has identified twenty-seven research fields derived from content analysis. These fields align with sustainable development, built environment, and urban planning

Fig. 4 City model relation to publication on city core concepts

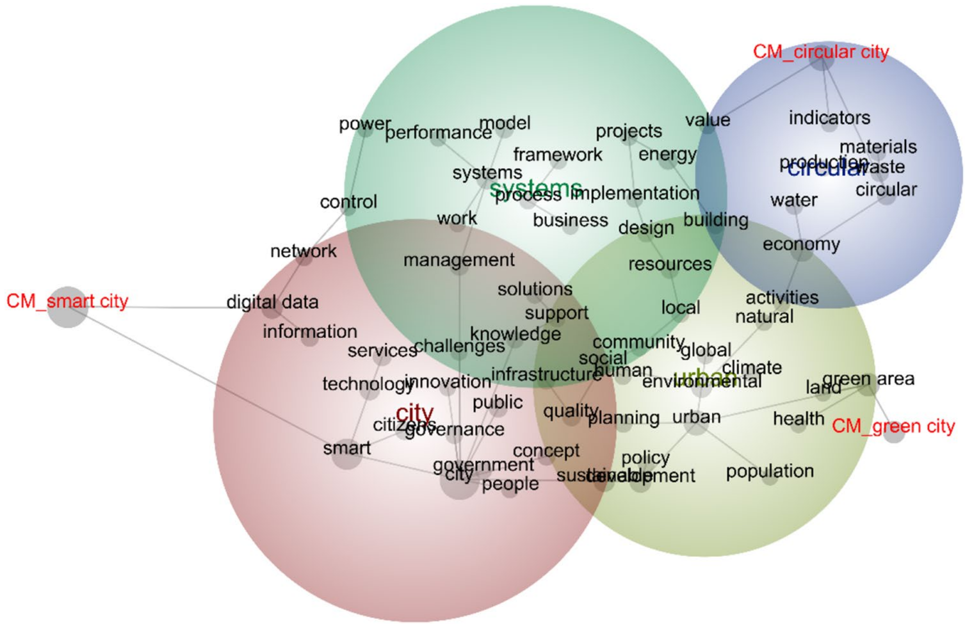

Fig. 5 The interaction among city models and research fields

Research Field in Cities Research Papers — City Models	Smart City	Circular City	Green City
Sustainable development	High likelihood	High likelihood	High likelihood
Social dimension	High likelihood	High likelihood	High likelihood
Economic dimension	Medium likelihood	High likelihood	Small likelihood
Environmental dimension	High likelihood	High likelihood	High likelihood
Management Systems	High likelihood	Medium likelihood	Small likelihood
Production Systems	Medium likelihood	High likelihood	Small likelihood
Waste management	High likelihood	High likelihood	Medium likelihood
Energy Production	Medium likelihood	High likelihood	High likelihood
Green Space/Area Incorporation	Small likelihood	Small likelihood	High likelihood
Smart and Digital Technology	High likelihood	Medium likelihood	Medium likelihood
Circularity concept	Small likelihood	High likelihood	Medium likelihood
Material Flow Analysis	High likelihood	High likelihood	Medium likelihood
Project Implementation	High likelihood	Medium likelihood	Small likelihood
Inclusion of Governance	High likelihood	High likelihood	High likelihood
Water Consumption	Medium likelihood	High likelihood	High likelihood
Creation of Network Systems	High likelihood	Medium likelihood	Medium likelihood
Climate Changes	Medium likelihood	Medium likelihood	High likelihood
Development of Policies	Medium likelihood	Medium likelihood	Medium likelihood
Care for Healthy Environment	Medium likelihood	Medium likelihood	High likelihood
Care for Healthy Population	Small likelihood	Medium likelihood	High likelihood
Built Environment	High likelihood	High likelihood	High likelihood
Urban Planning and Communities	High likelihood	High likelihood	High likelihood
Land usage and Natural Systems	Medium likelihood	Medium likelihood	High likelihood
Performance Quality	High likelihood	High likelihood	Medium likelihood

Legend	
Color	Meaning
(dark grey)	High likelihood
(medium grey)	Medium likelihood
(light grey)	Small likelihood

as the foundational concepts shared by the three city models. The research fields reflect cities' pursuit of sustainability, although variations exist. Smart cities prioritise digitalisation, urban interconnectedness, and digital literacy. Circular cities emphasise economic aspects, material flows, value creation, and energy production. Green cities focus on environmental improvement, urban area redesign for green practices, and public health enhancement. Industry inclusion pertains to advancing green technology.

The research fields identified underscore the specialised focus of each city model within the core conceptual framework. By incorporating these core concepts, individual city models can be enhanced and refined for effective real-world implementation. To ensure accuracy and specificity in relation to circular cities, we conducted a comprehensive content analysis encompassing relevant publications, thereby enabling us to discern research fields directly aligned with circular cities and identify areas that are relatively less represented. This approach facilitates model optimisation. Our

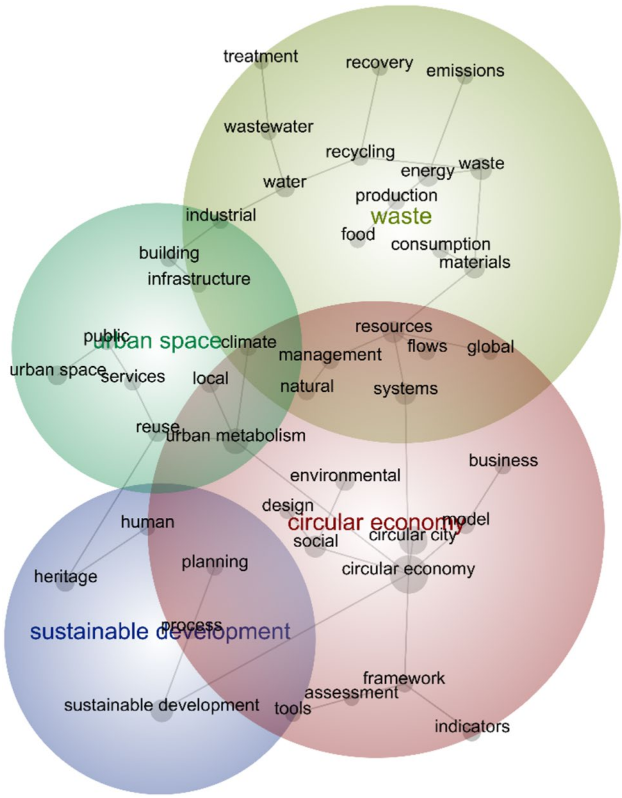

Fig. 6 Circular city concept map

findings yield a concept map comprising 44 unique concepts distributed across four distinct themes: *circular economy*, *waste*, *urban space*, and *sustainable development* (refer to Fig. 6 for visualisation).

The most dominant theme identified was *circular economy*, which included concepts 'circular city', 'social', 'systems' and 'environmental', indicating relatedness towards sustainable development dimensions. The other relevant cluster included concepts 'resources', 'flows' and 'management', indicating system development to manage resource flows.

The second theme was *waste*, where two three clusters were detected. Concepts such as 'waste', 'energy', 'water' and 'food' were identified to be related to the Water-Energy-Food-Waste nexus. Concepts 'materials', 'consumption', 'waste', 'recycling' and 'recovery' are related to promoting resource circulation. The third cluster was shared with the circular economy.

In the theme *of urban space,* the concepts 'building' and 'infrastructure' refer to the built environment or inanimate city park, while 'public' and 'services' present the live city part and their influence on city development. The importance of interaction between society and the built environment is visible in the concepts 'human' and 'heritage', referring to the cultural, and historical meaning cities have to society and the issues of preserving them by a sustainable approach.

The theme of *sustainable development* exhibited the least dominance, characterised by concepts such as 'planning' and 'process', indicating a systematic and well-planned approach to city transformation. Additionally, the concepts of 'human' and 'heritage' suggest a focus on the preservation of cultural heritage within cities. Building upon the initial identification of twenty-seven research fields, we further conducted content analysis of circular city research papers, leading to the identification of twenty-four additional research areas deemed essential for an optimal circular city model. These established research areas were subsequently employed to evaluate the city of Maribor, with variations in colour reflecting the inclusion of individual areas within Maribor (see Fig. 7).

Maribor demonstrates active engagement in becoming a circular city, aligning with its commitment to implementing a circular economy strategy. Our analysis indicates substantial progress in various areas, particularly concerning sustainable development dimensions such as water, waste, and resource management, as evident from current development reports. However, certain areas warrant further attention, including establishing smart and digital network systems, effective construction management, education on circular economy and circular city concepts, and efficient supply and value chain management. Additionally, addressing health, environmental costing, circular built environment, and performance management within Maribor's forthcoming circular strategies is essential. These areas represent valuable opportunities for Maribor to advance its circular initiatives and reinforce its commitment to sustainable urban development.

Conceptual model on the case of Maribor

After assessing Maribor using the established research fields, we proceeded with a case study employing our conceptual model, based on the guideline questions and actions needed (see Fig. 2), and implemented. Publicly accessible project documentation and declarations formed the foundation for addressing the corresponding questions in each phase. During the Define phase, we derived the following conclusions based on our analysis.

Strategic approach creation and constrains identification

Maribor demonstrates compliance with both national and international policies, including Directive 98/2008/EC and the Slovenian Development Strategy 2030. As part of its circular management strategy, Maribor aims to integrate various sectors, including municipal waste, construction,

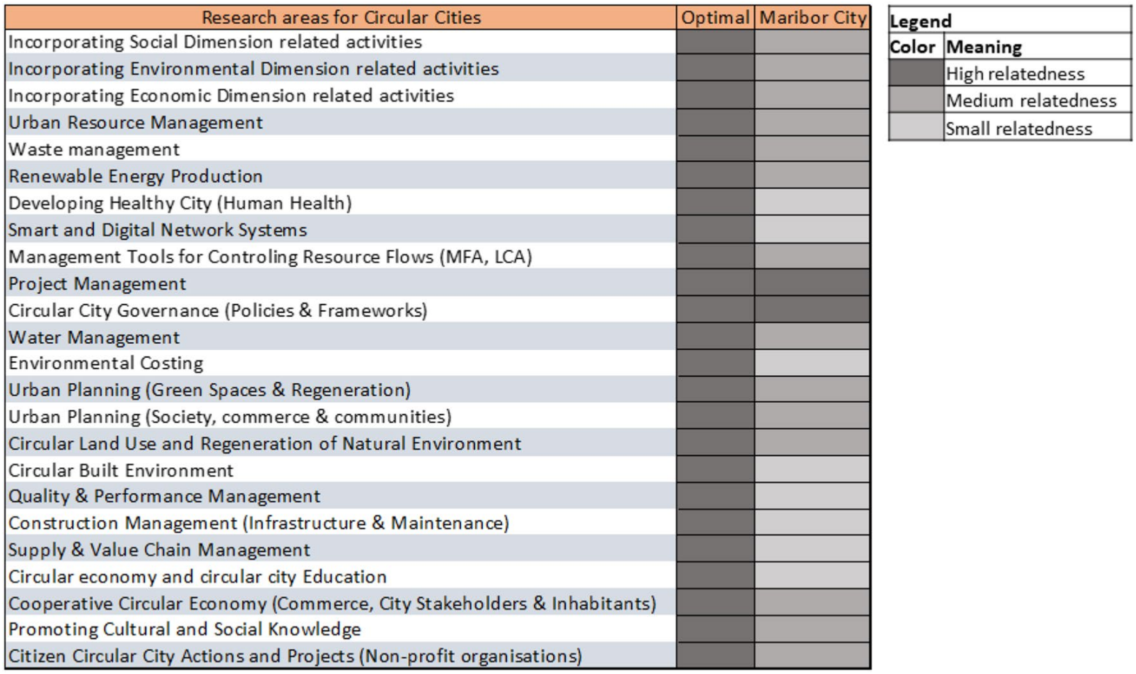

Fig. 7 Research areas required for optimal circular city model and evaluation of Maribor

industry, energy, water management, land usage, and social mobility. This holistic approach seeks to establish a comprehensive managerial system that effectively governs all available resources within the city and its broader urban area.

City holders, stakeholders and other public groups inclusion

The changes aim to improve the cities and wider urban area cooperative economy. The target group of the circular strategy are public companies, inhabitants, industry and local government. Implementing the goals will increase cooperation between all stakeholders and benefit the surrounding areas with which the city cooperates already.

Value stream creation

The successful implementation of the circular economy is anticipated to optimise resource flows within cities, enhancing their self-reliance and reducing the consumption of natural resources. Moreover, it is expected to bolster using renewable energy sources, promote efficient water consumption, and facilitate sustainable land management. The anticipated benefits encompass improved economic conditions for all stakeholders by creating new green employment opportunities, reducing environmental impact, and generating value-added economic growth. Additionally, this endeavour aims to foster the development of proprietary technologies and innovative research and development models. Maribor has laid a solid foundation for the subsequent stages in the light of the preliminary phase.

During the measurement phase, we specifically focused on two pivotal inquiries, the details of which are presented below. By analysing the gathered data, we have formulated the corresponding responses tailored to Maribor's context.

Tools, framework and measurement choice and validation

The project team swiftly recognised the necessity of establishing and maintaining a statistical database for Maribor. The primary objective was to acquire data on specific areas identified during the Define phase. The objective encompassed municipal waste, construction and demolition waste, soil composition and health, heat and renewable energy generation and utilisation, sustainable mobility, water reuse and recycling, land management, and regenerating degraded land areas. The data collection process adhered to circular indicators developed by CityLoops, serving as a framework for gathering data essential for reports and analysis while also facilitating the measurement and validation of the collected raw data.

Collecting statistical data

Data acquisition will be accomplished by implementing material flow analyses (MFA) examining the urban area's current resource flows. To obtain the necessary raw data for MFA, individual statistical databases from companies (e.g. Snaga d.o.o., Marprom d.o.o., Nigrad d.o.o.), as well as regional and national statistical databases from SURS, and locally generated statistical data by Maribor, will be collected. The gathered data will be stored and analysed at Maribor's dedicated resource management centre. This centre will serve as an observatory and knowledge hub, facilitating the city's enhancement and dissemination of circular knowledge management practices. Based on the findings of this foundational effort, Maribor identified the areas requiring measurement and devised a systematic approach to gather the requisite data, thereby accomplishing all objectives of this phase.

The analysis phase is tightly interconnected with the measurement phase, as it is a continuation of managing the gathered raw statistical data. The main goal here was thus identifying what approach did Maribor city followed in analysing the gathered data, conducting following actions.

Solution development, evaluation and optimisation

Based on research and analysis published in the relevant literature, the project team has identified several primary areas based on the gathered data for immediate attention. In the context of Maribor, these areas primarily encompass waste management improvements aimed at gradually phasing out landfill waste, enhancing recovery rates, increasing recycling rates, and promoting material reuse. A second critical area involves optimising heat usage within the heating district centre by expanding the utilisation of renewable resources. Regarding sustainable mobility, the focus lies on gradually restricting road vehicle access to the city centre while enhancing public transport options and promoting alternative modes of transportation such as bicycles. The water sector emphasises reducing current losses, minimising unnecessary consumption, and increasing recovery rates by implementing advanced filtration techniques and wastewater recycling. The cooperative economy sector targets implementing sharing economy concepts, promoting material and product reuse, and initiating building reconstruction projects within the city. Lastly, attention is devoted to regenerating degraded areas impacted by industrial activities, transforming them into vibrant green spaces. Based on analysis and research, these findings contribute to the scientific community and provide a comprehensive foundation for future endeavours in sustainable urban development.

"State of the art", "hot-spot" creation and systematic identification and distribution of resources

A SWOT analysis was conducted to evaluate the current state of Maribor. The analysis revealed that Maribor had already implemented a Sustainable Urban Strategy and had emerged as a prominent centre for advancing the circular economy in Slovenia. Furthermore, a comprehensive Roadmap towards a circular economy had been established, serving as a foundation for future progress. As a result, many goals outlined in the circular strategy for 2018 had been either fully or partially accomplished by 2023. However, the most pressing challenges in Maribor presently revolve around land regeneration, reducing and recycling water usage, establishing cooperative economy networks, and utilising renewable energy sources and surplus heat. Despite these challenges, Maribor demonstrated a well-structured approach to data analysis, facilitating identifying potential solutions for the existing circumstances.

The improve phase relied heavily on the results of analysis phase, as it enabled an insight into current state and identification of potential areas for improvement. This are achieved through analysis of activities by Maribor related to needed actions to achieve them.

Solution development, evaluation, optimisation and implementation in compliance with circular and sustainable approach

For the phase, we have analysed projects, either active or finalised, where Maribor city addressed the areas deemed challenging to accelerate the city's transformation towards a circular one. Improvement for waste management, considered solution related to transforming waste management activities to comply with the circular economy approach, developing own comprehensive business system for managing material flows within the Municipality of Maribor (MOM) and increasing recycling rates by closing loops for resource leakage. The social aspects considered establishing a monitoring network for prolonging product usage in the loop (reuse, refurbishment, repair ships) and educating, raising awareness and increasing integration of all stakeholders (citizens, organisations, administration). Nigrad Maribor partially achieved set goals for the area by joining the project "CINDERELA" within the Horizon 2020 CIRC: 2016–2017 grant framework (CORDIS 2018). The project's main goal entailed improving construction and demolition waste, as it represents the largest collected share within urban areas. The project encourages using secondary raw materials from recycled construction and industrial waste. The aimed results is creating a circular resource utilisation model that could reduce negative environmental impacts by up to 20% and increase the recycling rate of waste from the construction sector by up to 30% (CINDERELA 2023).

The optimisation of energy utilisation for heat and electricity production and the incorporation of renewable resources are key strategies being implemented in Maribor to address current heat usage and increase the utilisation of renewable energy sources. These efforts involve the construction of heat storage facilities, utilising landfill gas, biogas, and synthesis gas derived from biological waste, and efficiently utilising available surplus heat. In collaboration with the circular economy-HEAT consortium, the Maribor Waste Management Centre has successfully implemented a project that utilises waste heat from electricity production to heat a museum (circular economy HEAT 2019). Additionally, Energetika Maribor, in partnership with MOM, is currently engaged in a project focused on incorporating thermal energy solutions. The project aims to achieve 60% energy self-sufficiency by expanding the hot water network and connecting facilities in densely populated areas by 2020 (ManagEnergy 2022). The goals include integrating renewable energy sources such as solar and biowaste to reduce CO2 emissions, ensure the affordability of energy and heat, and distribute them efficiently to the local population. Furthermore, MOM has completed a collaboration with ENERGAP in a project titled "Energy refurbishment of twenty-four public buildings in the City of Maribor using the Energy Contracting model", which aims to improve energy efficiency and increase self-sufficiency through the use of renewable energy sources (FEDARENE 2021). This project is estimated to reduce energy consumption by 5,952 MWh, costs, and CO2 emissions.

Maribor has undertaken various projects to promote sustainable transportation, with some still in progress and others completed. A current initiative led by Maribor is the "MBAJK" project, which focuses on the sharing economy and the promotion of sustainable and healthy transport. This project, scheduled to run until 2037 (MOM 2023a), aims to establish a public bicycle rental/sharing system within the Maribor Waste Management Centre (MOM). The system is already operational and improved with IT assistance and adding more bicycle charging stations. Additionally, Maribor has made improvements to logistical infrastructure to facilitate business development (MOM 2023b, 2023c) and enhance public spaces for recreation (MOM 2023d; 2023e), with these enhancements completed in 2022. The decision to restrict traffic in the city centre has increased the importance of effective logistical planning. In response, Maribor is developing a project to establish an enclosed market where residents can sell meat and dairy products, reducing the reliance on regional supply chains (MOM 2023f). These projects in Maribor collectively contribute to the advancement of sustainable transportation, the promotion of sharing economy principles, the improvement of logistical infrastructure, and the enhancement of public spaces.

Maribor, as a partner city, collaborated on "The City Water Circles" (CWC) project under the umbrella of the "Interreg" organisation. Within this collaboration, a pilot project called "Secondary Raw Material from Rain and Wastewater in Maribor" was undertaken and concluded in 2022 (Interreg Europe 2022). The pilot project focused on water recycling and alternative water resource usage. One of the main objectives was to reintroduce purified wastewater and rainwater into the construction sector as secondary raw materials. A storage and collection unit for rainwater was established, and purified wastewater from local treatment plants was transported for reuse. The obtained materials were utilised for road maintenance and revitalising degraded areas, specifically targeting the degraded urban area in Dogoše. The project's outcomes demonstrated that, despite higher initial costs compared to conventional water usage, the incorporation of purified wastewater and rainwater reduced average costs by 25% when considering environmental impacts and associated costs (Interreg 2023). The project highlights the potential economic and environmental benefits of utilising alternative water resources in construction activities.

In collaboration with the University of Maribor, Maribor is actively engaged in the European Union Regenerative Urban Lighthouse (UPSURGE) project. This initiative aims to develop city models centred on Nature-Based Solutions (NBS) and address urban area degradation and revitalisation. As part of UPSURGE, Maribor is undertaking a pilot study focused on the waterway of the Pekrski River. The pilot study aims to establish a green corridor, implement pocket gardens, and introduce blue infrastructure along the Pekrski River. These measures are intended to enhance the ecological quality and livability of the area. The project is yet to be implemented (UPSURGE 2023). By incorporating Nature-Based Solutions and promoting sustainable urban development, the city aims to achieve its circular economy goals.

The control phase represents a conclusion to the established model and the phase that starts a continuous improvement process, initiating another round of the whole DMAIN circle. Five actions need addressing in this phase.

Indicator set creation, validation

The analysed projects in this study have established specific indicators for measurement and analysis purposes.

These indicators enable continuous monitoring and provide opportunities for improvement. Maribor's circular economy strategy aligns with the circular city indicators developed by ICLEI (2023b). By incorporating these indicators and implementing measurement systems during the analysis phases, Maribor has adopted a systematic approach to monitoring its progress in transitioning towards a circular city. This approach ensures a comprehensive evaluation of the city's efforts and promotes the achievement of circularity objectives.

Indicator set implementation for monitoring, maintaining improvement process and creation of loops

Given the ongoing development of new projects in Maribor, it is challenging to determine the specific loops to establish at this stage. Moreover, certain projects require further measurement and evaluation to identify potential benefits and areas for improvement, which can inform the establishment of appropriate loops. Therefore, it is recommended to implement semi-loops involving analysis, improvement, and control phases until all project goals are attained. Following the initial project phase, a comprehensive assessment of Maribor's current state is advised to facilitate the creation of an updated circular economy strategy. This approach ensures a more informed and targeted implementation of effective loops, enabling the city to progress towards its circular economy objectives.

Discussion

The research provided information and cooperation on developing and designing smart, circular, and green city models from research paper content analysis. Results revealed an increased publication number for city models. An increase coincided for models with the introduction of SDG17 goals by the United Nations (General Assembly UN 2015), the Circular Economy Action Plan for circular cities (European Commission 2015; European Commission 2019), and the smart City Expo World Congress in Barcelona for smart cities (European Commission 2019). According to the city model orientation, differences between models were identified in publications and WoS categories.

The findings derived from the content analysis have revealed distinct research trends concerning the conceptual core of each city model. Smart cities, for instance, prioritise the development of innovative technologies and services that facilitate enhanced control over city activities and their ease of use by residents (Moradi 2020). Additionally, there is a growing interest in establishing smart networks and digital databases to enable seamless communication between technology and users, with the ultimate aim of reducing environmental impacts and integrating different sectors of the city into a unified system (Tiwari et al. 2021; Hajek et al. 2022). Consequently, implementing sustainable development in smart cities entails the establishment of smart environments, IoT solutions, and networks (Moradi 2020).

The analysis of green cities has revealed a distinct focus on integrating a green mindset and technologies. The research indicates that green cities need help attempting to incorporate green urban planning, particularly concerning the inclusion of green spaces and the promotion of natural environment regeneration, which can be hindered by existing city layouts (Jia et al. 2021). However, researchers are addressing these issues by investigating the potential benefits and advantages of promoting a healthy, sustainable lifestyle for residents, such as increased biodiversity and economic opportunities (Jai et al. 2021; Zhang et al. 2022; Javidroozi et al. 2023).

Through a cross-analysis of the three city models, a total of twenty-seven research fields were identified. While some overlap between the models, the results surprisingly demonstrated a high degree of interaction. The overlap indicates that city models are actively evolving and seeking potential opportunities that can accelerate their transition towards sustainable development. Comparisons with the findings of Javidroozi et al. (2023) and Ahvenniemi et al. (2017) suggest that cities progressively integrate proven and beneficial solutions from competing city models. By adopting this approach, cities can expedite the development of solutions, offer established ideas to policymakers, and ultimately gain an advantage in achieving their sustainable goals (Javidroozi et al. 2023). The high level of interaction between the city models indicates a positive trend towards adopting successful strategies and solutions from different models, accelerating the progress towards sustainable development.

The content analysis results pertaining to circular cities are centred around the core concept of the circular economy. The circular cities' focus is to achieve sustainable development in line with the goals set by the United Nations for establishing sustainable cities (United Nations 2022). The findings reveal key areas requiring attention to implement circular economy principles. One important aspect is the establishment of urban flow maps and the principles of urban metabolism for future urban planning (Lucertini and Musco 2022). These approaches can progressively increase resource circularity and self-sufficiency within cities (Kalmykova and Rosado 2015; Mazzarella and Amenta 2022). Another significant area identified is the integration of the

Water-Energy-Food nexus with the 9R strategies. Cities are major consumers of resources (Mulier et al. 2022), which are often quickly disposed of. The challenge lies in retaining these resources, and while recycling and reuse activities are being implemented, the need for upper 9R strategies suggests slow development in this regard. Research by Potting et al. (2017) indicates that the full realisation of a circular economy requires implementing upper strategies, which are currently underrepresented in the literature.

Furthermore, circular cities face the challenge of improving their inhabitants' economic and social aspects while mitigating potential environmental impacts associated with urban development (General Assembly UN 2015; Circular City Funding Guide 2023; United Nations 2022). Since cities are built environments, most changes occur in infrastructure and its utilisation for commerce, residential sectors, transportation, and services. Limiting resource losses through construction and demolition activities is crucial by employing upper 9R strategies such as repurposing and reusing existing buildings (Cimen 2021). These solutions aim to adapt buildings to meet the proposals of the inhabitants, thereby increasing the cultural and economic value for a more socially sustainable urban lifestyle (Cimen 2021; EMF 2023).

The case study conducted on Maribor revealed that the city has a well-established circular strategy. Furthermore, by integrating this model with the research focus areas of circular cities, a systematic analysis of the city's progress towards achieving circular goals was facilitated. The results indicate that Maribor is aligning its activities with its projected plans while considering all three dimensions of sustainability as defined by the United Nations (United Nations 2022) and the Circular City Funding Guide (2023). However, it is important to note that the final phase of the circular strategy, namely the control phase, has yet to be fully established. This phase could be crucial in advancing future planning efforts to improve circularity. The challenge of monitoring progress is not unique to circular cities but is also a concern for smart cities (Lai and Cole 2023) and individual sectors (Zope et al. 2019; Batalhao and Texeira 2020). As the authors point out, the main issue lies in establishing effective monitoring management systems that assess the current situation and provide data for future development.

The results gained from our case study and content analysis, suggest that cities are implementing project oriented approach in establishing circular activities in cities. The main issue is not implementing circular approach, but establishing monitoring management, that would enable assessing current standings, benefits and provide groundwork for future strategies and policies to be employed (Marin et al. 2020; Henrysson et al. 2022). Future projects should provide monitoring frameworks with circular city indicators (Vangelsten et al. 2020; Lindgreen et al. 2020; Paoli et al. 2022), establishing a consequential "state-of-the-art" map of the progress towards circularity. Continuous improvement and promotion of more permanent loops are dependable on the progress we achieved and needed to attain sustainable development, as our established city model constituted in the control phase.

Conclusion

Gaining insights into current research trends and the core conceptual evolution of city models is crucial for achieving sustainable development. While each city model pursues its approach to sustainability, their specialisation presents an opportunity for improvement through cross-pollination. The content analysis identified similarities and differences among the smart, circular, and green city models and twenty-seven research trends that correspond to all three city models. Such identification is necessary to properly manage cites according to the identified models.

An additional content analysis focused on circular cities only enabled the identification of specific trends within the circular city model. Combining the findings with the previously established twenty-seven research trends led to identifying twenty-four fields contributing to the development of an optimal circular city model. To structure these fields, we incorporated them into a conceptual model based on the DMAIC framework and problem-solving tools. The results showed that DMAIC-based tool allows cities to establish a continuous improvement cycle in their transition towards circularity. The model emphasises the establishment of semi-loops and loops and, when combined with a problem-solving systematic approach, provides a systematic and constructive means for potential policymakers to develop circular strategy maps.

The case study on the city of Maribor validated the proposed model, and also revealed the current weakness of inadequate monitoring of the progress towards a circular economy. Additional case studies focusing on the conceptual model are necessary to validate further and improve its application. Future research will enhance the conceptualised model, particularly by establishing measurement frameworks and indicators for validation during the control phase. Understanding the effectiveness of implemented circular activities is vital for future development and avoiding the unnecessary expenditure of time, funds, and resources in achieving a sustainable society.

Appendix

See Figs. 8, 9, and 10.

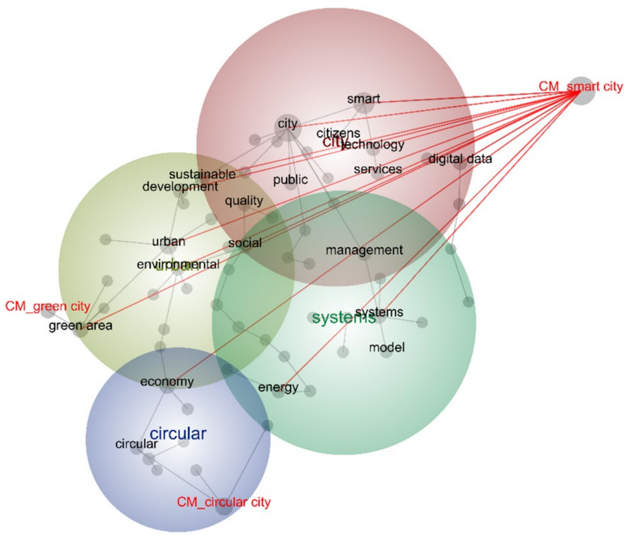

Fig. 8 Major themes relatedness to smart city model

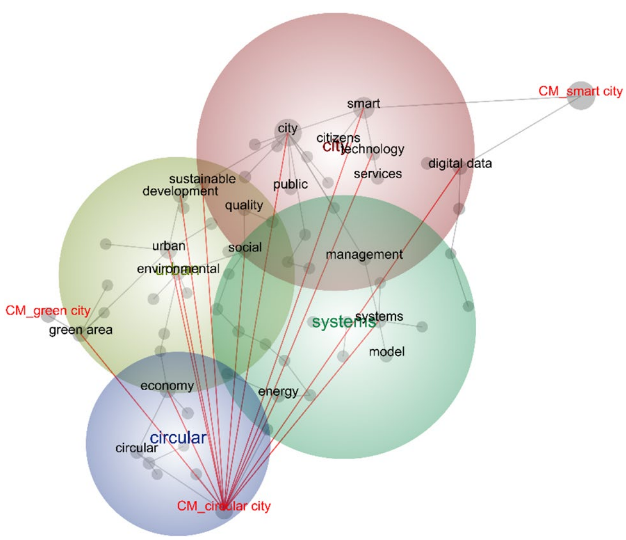

Fig. 9 Major themes relatedness to circular city model

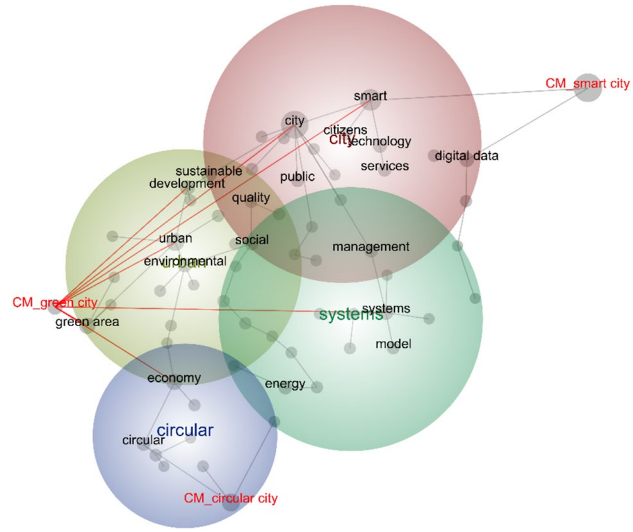

Fig. 10 Major themes relatedness to green city model

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Author contribution Kristijan Brglez contributed to conceptualisation, methodology, leximancer, analysis, writing—original draft, visualisation, resources. Matjaž Perc contributed to leximancer network perspective, writing—review and editing. Rebeka Kovačič Lukman contributed to analyses, resources (literature review), writing—original draft, visualisation, supervision, writing—review and editing.

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Declarations

Competing interests 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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