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Spatial approaches to a circular economy

Determining locations and scales of closing material loops using geographic data

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6 Criteria for locations and scales of tomorrow

Based on the publication:
Spatial parameters for circular hubs: criteria for future facility locations for a circular built environment in the Netherlands
Tanya Tsui, Cecilia Furlan, Alexander Wandl, Arjan van Timmeren
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ABSTRACT

Implementing a circular economy in cities has been proposed by policy makers as a potential solution for achieving sustainability in the construction sector. One strategy that has gained interest by both policy makers and companies is to develop 'circular construction hubs': locations that collect, store, and redistribute waste as secondary resources. However, there is limited literature taking a spatially explicit view, identifying the spatial parameters that could affect the locations of hubs both for now and in the future. This study therefore aims to categorize different types of circular hubs for the construction industry, collect spatial parameters required for finding suitable locations for each type of circular hub, and translate the spatial parameters into a list of data and spatial analysis methods that could be used to identify potential future locations. The study used the Netherlands as a case study, extracting spatial parameters from two sources: Dutch governmental policy documents on circular economy and spatial development, and interviews with companies operating circular hubs. Four types of circular construction hubs were identified: urban mining hubs, industry hubs, local material banks, and craft centers. The spatial parameters were extracted for each type of hub from four perspectives: resources (such as material type, business model), accessibility (such as mode and scale of transportation), land use (such as plot size, land use), and socio-economic (such as labor availability). The parameters were then translated into a list of spatial data and analysis methods required to identify future locations of circular construction hubs.

KEYWORDS

Circular cities, circular construction hub, GIS, spatially explicit circular economy, urban mining, site selection analysis

6.1 Introduction

The construction sector has a significant environmental impact in terms of waste production and resource use. Over the last century, while global population increased by a factor of ~4, usage of construction materials increased by a factor of ~42 (Krausmann et al., 2017). The construction sector consumes the largest share of materials globally (Levermore, 2008; Schandl et al., 2016; Urge-Vorsatz et al., 2014), and this consumption is expected to further increase in the future (Fishman et al., 2016).

Since 2015, transitioning to a circular economy (CE) has been proposed by policy makers in the European Commission as a potential solution to sustainability (European Commission, 2020). Although there is no consensus on its definition (Kirchherr et al., 2017), a commonly adopted notion of CE is keeping materials and products performing at their highest application level for as long as possible, while reducing environmental impacts and being aware of environmental trade-offs. CE has also been put forward as an alternative economic paradigm that stays within planetary boundaries and is socially just (Marin et al., 2020).

CE concepts were first applied to industrial sectors, but more recently, the importance of applying circularity to the built environment has been recognized by researchers and policy makers alike (D. A. Ness & Xing, 2017). In the Netherlands, CE concepts have been integrated into governmental policy in the form of a national strategy, where construction and demolition materials have been highlighted in a specific transition agenda for a circular construction economy ("Transitieagenda Circulaire Bouweconomie") (Het ministerie van Infrastructuur en Waterstaat, 2021).

Within circular built environment research, the application of CE concepts has expanded from building materials and products to larger spatial scales, to include cities and regions. Much of these efforts fall under the topic of 'circular cities' (Tsui et al., 2022), and take the perspectives of urban governance, which studies the circularity of a city's policies and stakeholders (Amenta et al., 2019; Prendeville et al., 2018; Williams, 2019); and urban metabolism, which studies the material, water, or energy flows of cities or regions (Broto et al., 2012; Dijst et al., 2018; Kennedy et al., 2007). While existing research explores circular cities from a governance and resources perspective, the spatial or territorial implications of a circular economy still remain broadly unexplored (Bahers et al., 2022; Furlan et al., 2022; Tapia et al., 2021).

Circular cities research has started to inform Dutch policy, initiating circular strategy documents at the national (Het ministerie van Infrastructuur en Waterstaat, 2021), provincial (Metabolic et al., 2019; Provincie Noord Holland, 2021; Provincie Zuid Holland, 2019), and municipal level (Gemeente Amsterdam, 2020; Gemeente Den Haag, 2018; Metabolic et al., 2018). Moreover, circular cities thinking have been implemented in spatial strategies at the national (Ministry of the Interior and Kingdom Relations, 2020), provincial (Provincie Noord Holland, 2018; Provincie Zuid Holland, 2021), and municipal level (Gemeente Amsterdam, 2021) as well.

One frequently mentioned idea in Dutch circular economy and spatial strategy documents are “circular hubs”, often for the construction sector - locations where clusters of circular companies can gather to exchange resources and knowledge, or where waste can be stored, processed, and re-distributed as secondary resources. This triggered a number of companies to start circular hubs of their own, operating mainly within the demolition sector. While there seems to be a lot of interest in circular (construction) hubs, this new phenomenon is not well studied or defined in academic literature. There is very limited understanding of where the future locations of these hubs could be, or what spatial factors would determine these locations.

This study therefore aims to collect the spatial parameters that could determine the future locations of circular construction hubs in the Netherlands. Additionally, we aim to derive, from the spatial parameters, the data and spatial analysis methods that would be required to identify suitable circular hub locations. This study will therefore answer the research question, “what are the spatial parameters for locating circular construction hubs in the Netherlands?”

Using the construction sector in the Netherlands as a case study, this study will conduct a document review of Dutch policy documents on spatial and circular economy strategies; as well as semi-structured interviews with circular construction companies, including building material banks, construction logistics centers, and industrial estates.

From the document review and interviews, we identified four types of circular construction hubs, which varied in spatial scale and focus on logistics versus industrial activity. These types are: urban mining hubs, industry hubs, craft centers, and local material banks. Spatial parameters were identified for each hub type, and categorized into four perspectives: resource, accessibility, land use, and socio-economic.

6.2 Theoretical background

In recent years, researchers from the fields of industrial ecology, economic geography, and urban planning have started to advocate for the importance of space as a major factor in the study of the CE (Bahers et al., 2022; Bourdin et al., 2021; Schiller et al., 2014; Tapia et al., 2021). Although the implementation of CE solutions have an obvious spatial expression, the spatial parameters of CE remain broadly unexplored. A spatial understanding of CE is important, because many CE activities require spatial factors such as agglomeration and accessibility to succeed. For example, circular companies may need to be close to larger industrial clusters, or be highly accessible to sources of secondary products or materials (Tapia et al., 2021).

Researchers have identified a number of disciplines that use a spatial perspective to study CE and related topics such as urban metabolism and industrial symbiosis. (Tapia et al., 2021) identifies six territorial factors for CE: land-based, agglomeration, hard territorial factors, access to technology, knowledge-related factors, and governance; and (Bahers et al., 2022) identified five spatial approaches to urban metabolism: political, territorial-economic, socio-ecological, governance and planning, and spatially explicit modeling.

Within spatially explicit circular economy research, two major perspectives study material stocks and flows: industrial clustering and urban mining. The study of industrial clustering examines the potential economic and environmental benefits of clustering companies together in order to share and exchange resources, infrastructure, or knowledge. This is studied mostly by industrial symbiosis literature, which studies the methods and factors that allow clusters of industrial facilities to successfully gain financial and environmental benefits from exchanging and sharing resources. The benefits of industrial proximity and co-location within industrial symbiosis literature is borrowed from the study of agglomeration economies within the discipline of economic geography (Chertow et al., 2008; Desrochers, 2000).

Agglomeration theory proposes that clusters of businesses in close proximity to one another create additional benefits that would not have occurred if those businesses were far apart (Harrison et al., 1996; Hoover, 1937; Jacobs, 1969; Porter, 1998). These benefits were understood as economies of scale achieved from external factors, and could be categorized as localization and urbanization economies. In localization economies, most companies belong to the same industry, and generally use similar resources and generate similar products, co-products, by-products, and waste. This gives opportunity for more efficient management of common resources.

In urbanization economies, companies belong to different industries, which gives opportunities for firms to exchange their large variety of inputs and outputs. Similar ideas on the benefits of agglomeration have also been introduced in gray literature, under the concepts of “zero waste industrial hubs”, “hubs for circularity” (Mendez Alva et al., 2021), and “circular city ports” (Architecture Workroom Brussels, 2021).

Industrial symbiosis researchers have also started to study the spatial constraints of material exchanges, understanding that transportation distance of materials could depend on the material type, value, as well as company diversity in the local area (Domenech et al., 2019; Jensen, 2016; Jensen et al., 2011). Some studies have also tried to define the ‘optimal’ scale for industrial symbiosis from these spatial constraints (Lyons, 2008; Lyons et al., 2009; Sterr & Ott, 2004).

The urban mining perspective, on the other hand, estimates the availability of secondary resources in cities and countries by mapping the location of material stocks and flows within a given geographical area. Often, these studies use cadastre data (governmental recording of real estate properties) to estimate the amount of material potentially available. This is done by categorizing buildings into different archetypes, estimating the amount of materials for each archetype together with experts, and applying this information to an entire geographical area, such as a city or a country (Sprecher et al., 2021; Tanikawa et al., 2015; Verhagen et al., 2021). Because buildings contain a large amount of materials, and because of the availability of cadastre data, urban mining studies often focus on construction materials.

The increased understanding in urban mining has inspired various concepts that resemble circular hubs, in the form of pilot projects and proposals in gray literature. Examples are urban resource centers, which are smaller scale and closer to citizens (Urban Agenda for the EU, 2019); building material banks, which collect, store, and re-sell building materials (Marin et al., 2020); or building logistics hubs, in which building materials are collected in one facility and redistributed to multiple construction sites in order to improve transportation efficiency (TNO, 2018).

From literature on industrial clusters and urban mining, the concept of “circular construction hubs” can be understood in two ways: as industrial clusters, where circular companies are close to one another in order to share and exchange resources and knowledge; or as urban mining hubs, were materials are collected, stored, processed, and re-distributed.

Building on these two perspectives, a limited number of spatial data analysis studies have emerged, identifying the potential locations of circular hubs. Studies have identified clusters of circular industrial activity at both the national and European scale, and efforts have also been made to identify potential locations of urban mining facilities (Hodde, 2021; Mendez Alva et al., 2021; Misra et al., 2019; Tsui et al., 2022; Xue et al., 2017).

In addition to academic literature, there has also been interest in circular hubs in Dutch governmental policy. This can be seen in both governmental strategy documents on CE and spatial development, which often envision circular hubs for the construction sector. Circular hubs have been mentioned in governmental strategic documents at both the provincial (Metabolic et al., 2019; Province of Gelderland, 2022; Provincie Noord Holland, 2021) and municipal level (Gemeente Amsterdam, 2020; Gemeente Den Haag, 2018; Metabolic et al., 2018).

The recent interest in circular hubs stem from the risks and limitations associated with centralized global supply chains, which were further heightened by the COVID-19 pandemic and mutating geopolitical relationships (Dumée, 2022; Wuyts et al., 2020). Manufacturing companies are rethinking their import and export strategies (Vet et al., 2021), making it more likely that European and Dutch policies will value local sourcing and production using secondary materials.

Currently, literature taking a spatially explicit view on circular hubs, or identifying spatial parameters for locating circular hubs, is limited. From the industry or industrial symbiosis perspective, much more attention is placed on technical solutions, such as possible material or energy exchanges between industrial facilities; or business management perspectives, such as how issues of ownership, company retention, and network typologies affect the environmental performance of industrial clusters. Although there have been studies explaining how transportation distance is limited to material value, weight, or company diversity, these studies ignore other location factors such as accessibility, labor availability, plot size, and land use constraints.

Additionally, existing spatially explicit CE studies are not identifying future potential locations of circular hubs. Instead, they are mapping existing phenomena - circular clusters (Mendez Alva et al., 2021; Tsui et al., 2022) and material stock (Deetman et al., 2020; Sprecher et al., 2021; Stephan & Athanassiadis, 2017, 2018; Tanikawa et al., 2015; Tanikawa & Hashimoto, 2009; van Oorschot et al., 2023). Spatially explicit studies from the industrial perspective identify existing industrial clusters for CE, but don’t speculate where these clusters will be in the future. Most spatial studies from the urban mining perspective focus on the location and availability of existing material stock, without identifying potential future locations of circular hubs.

There are three research aims for this study. The first aim is to categorize the different types of circular hubs for the construction industry, both from industrial and urban mining perspectives. The second is to collect spatial parameters required for finding suitable locations for each type of circular hub. The parameters should combine both the industrial symbiosis and urban mining perspectives, incorporating other spatial factors such as proximity to other companies, labor availability, or land use. The third is to translate the spatial parameters into a list of data and spatial analysis methods that could be used to identify potential future locations of circular hubs.

For this study, circular construction hubs are defined as locations that are attractive for circular companies in the construction sector. These companies are part of the waste to resource supply chain. They can be building material banks, building logistics hubs, or manufacturers of building products that use waste as raw material. Circular construction hubs can vary in a variety of ways. They can vary in spatial scale, operating within neighborhoods, cities, provinces or even countries. They can vary in terms of target groups, working with citizens, start-ups, established companies, or governmental organizations. They can vary in terms of ownership, and can be owned by port authorities, industrial estates, governments, or not-for-profit foundations.

The main research question of this study is therefore, “what are the spatial parameters for locating circular construction hubs in the Netherlands?”, which will be answered by the sub-research questions: “How can circular construction hubs in the Netherlands be spatially categorized, and what are the different types?” and “What are the spatial data and analysis methods required to identify the potential locations of circular construction hubs in the Netherlands?”

To summarize, there are three main motivations behind this study, which are addressed by the research questions above. Firstly, within the field of circular cities, there is an increasing interest in developing the concept of circular hubs, both by policy makers and academics. However, the current concept is not well defined yet, and has a variety of different perspectives. This issue is addressed by the first sub-research question, “How can circular construction hubs in the Netherlands be spatially categorized, and what are the different types?”.

Secondly, there is a limited understanding of space in circular cities literature, even though academics have already been advocating for the importance of space (or geography) for a circular economy. This study provides a spatial perspective to circular cities literature, specifically to circular hubs, by answering the main research question, “What are the spatial parameters for locating circular construction hubs in the Netherlands?”.

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Finally, within the limited existing studies on circular economy, there are almost no studies exploring future spatial perspectives, speculating on future locations of circular infrastructure (such as circular hubs). This study therefore provides a future spatial perspective using the Netherlands as a case study, answering the sub-research question, “What are the spatial data and analysis methods required to identify the potential locations of circular construction hubs in the Netherlands?”

6.3 Methodology

The research question “What are the spatial parameters for circular construction hubs in the Netherlands?” was answered using the case study approach, gathering information from two sources: Dutch governmental policy documents on CE and spatial development, and interviews with companies operating circular hubs. Spatial parameters for circular hubs were collected from four spatial perspectives: resources, accessibility, land use, and socio-economic.

6.3.1 The Netherlands as a case study

The Netherlands was used as a case study to understand the spatial parameters of circular construction hubs. The case study method was chosen because the topic of circular hubs is still a relatively new concept, making it more suited for exploratory research (Yin, 2015). With a limited documentation of circular hubs in both academic and gray literature, more systematic research methods such as statistical analysis or literature review are not feasible. The case study approach is a well established method that has been used in other academic studies related to circular cities - understanding patterns of circular transition in Belgian ports (Haezendonck & Van den Berghe, 2020), city-level circular transitions in the Netherlands (Campbell-Johnston et al., 2019), as well as circular city types in Europe (Prendeville et al., 2018).

The Netherlands was chosen as the case study, because ideas related to circular economy are relatively well developed in the country, and are embedded in governmental policy at the national, provincial, and municipal level (Gemeente Amsterdam, 2020; Het ministerie van Infrastructuur en Waterstaat, 2021; Provincie Zuid Holland, 2019). The Netherlands has had a circular economy strategy since 2016 (Dutch Ministry of Infrastructure and Water Management & Dutch Ministry of Economic Affairs, 2016), and circular economy concepts are integrated into the spatial development plans at the municipal and provincial scale (Gemeente Amsterdam, 2021; Provincie Noord Holland, 2018). Moreover, the Netherlands also has an active circular building industry, partially encouraged by the government's emphasis on developing a circular economy. Organizations have started operating circular hubs - collecting, storing, processing, and redistributing various types of building materials, elements, and products. Using the Netherlands as a case study therefore allows for a multi-scalar understanding of the spatial parameters of circular hubs, from the perspectives of both policy and industry.

6.3.2 Document review

The document review was conducted on Dutch governmental strategy documents on circular economy and spatial development. The aim of the review was to understand the aims of the Dutch government when it comes to circular construction hubs, as well as understanding hubs within the larger context of circular economy and spatial development policy in the Netherlands.

The circular economy documents were examined to extract spatial parameters when circular hubs were mentioned, while the spatial development documents were examined on how they incorporated circular hubs or clusters in their strategy. The parameters collected could be concrete requirements such as "requires industrial land with environmental category 3 or above", but can also be more vague, such as "hubs should allow citizens to get involved in neighborhood renovation activities". These more vague requirements can then be translated into concrete spatial parameters such as "within 1 km of high density residential areas".

The criteria for document selection was that they needed to be published or commissioned by the Dutch government, be about circular economy or spatial development strategy, and can be at multiple governance scales. The CE related documents were either circular economy strategy documents (Gemeente Amsterdam, 2020), or more in-depth research documents such as (De Bouw Campus & Provincie Zuid Holland, 2020). The spatial development strategy documents were documents produced at the municipal, provincial, and national scale, and were named "omgevingsvisie" in Dutch.

The documents were found using desk research, combining the search terms “circular economy” or “circulaire economie” and “omgevingsvisie” (spatial vision), together with the names of all provinces and major municipalities in the Netherlands. All provinces and major municipalities in the Netherlands had circular economy strategy documents, but some spatial development documents were omitted because they did not integrate a circular economy strategy.

In total, 24 documents were reviewed. 17 were on circular economy strategy, and 7 were spatial development documents. Table 6.1 below shows an overview of the documents.

TABLE 6.1 Overview of documents reviewed

Name	Scale	Strategy type
Chemport Europe - circular plastics northern netherlands	1 - area	circular economy
Circular city port workbook - exploring the port region	1 - area	circular economy
M4H spatial framework	1 - area	spatial development
Amsterdam circular 2020 - 2025 strategy	2 - city	circular economy
Circular Amsterdam report	2 - city	circular economy
Circular Den Haag	2 - city	circular economy
Circular Rotterdam report	2 - city	circular economy
Omgevingsvisie Amsterdam (spatial vision Amsterdam)	2 - city	spatial development
The circular economy in Groningen, the Netherlands	2 - city	circular economy
Bouw Campus - circular resources center final report	3 - region	circular economy
Bouw Campus - Towards a spatial and economic model for a circular resources cluster in Zuid Holland	3 - region	circular economy
Circular biz (circular business parks research in Zuid Holland)	3 - region	circular economy
Circular Gelderland	3 - region	circular economy
Circular Noord Nederland (northern NL provinces)	3 - region	circular economy
Circular North Holland	3 - region	circular economy
Circular Utrecht policy vision	3 - region	circular economy
Circular Zuid-Holland	3 - region	circular economy
Omgevingsvisie Provincie Noord Holland	3 - region	spatial development
Omgevingsvisie Provincie Utrecht	3 - region	spatial development
Omgevingsvisie Provincie Zuid Holland	3 - region	spatial development
Regions of the future	3 - region	spatial development
TNO - opportunities for circular bouwhubs in South Holland	3 - region	circular economy
National implementation agenda - Circular economy 2021-2023	4 - country	circular economy
National strategy on spatial planning and the environment	4 - country	spatial development

6.3.3 Semi-structured interviews

The semi-structured interviews were conducted with circular construction companies that participate in the storage, redistribution, or processing of construction and demolition waste. The aim of the interviews was to understand how the construction industry viewed and implemented circular hubs, as well as gathering concrete spatial parameters such as facility sizes in square meters, or travel distance limits in kilometers. The interviewees also provided more explanation about the spatial parameters, such as why a certain amount of storage space is needed, or why it is important to be located near a certain type of industry.

Most companies interviewed were based in the Netherlands, although there was one company from Belgium and another from Austria. The criteria for choosing the interviewees was that they worked in a company that participates in the collection, storage, redistribution, reselling, or processing of construction and demolition waste; and had a good understanding of the company's operations. The companies chosen were required to be located in the Netherlands, or at least in a country nearby. The interviewees were found through email, a public post on LinkedIn, as well as personal contacts of colleagues in the Faculty of Architecture and the Built Environment at the Delft University of Technology.

The interview questions covered the companies' operations from the four spatial perspectives: resources, accessibility, land, and socio-economic. Because these were semi-structured interviews, the amount of time spent on each question varied per interviewee, according to their expertise and interest. Table 6.2 below shows the list of interviewees. Please refer to the supplementary materials section for the interview questions and transcripts.

TABLE 6.2 List of interviewees.

Date	Name	Role	Company	Duration
30 May	Interviewee A	Commercial Manager for Circular & Renewable Industry	Port of Amsterdam	1 hour
3 June	Interviewee B	Chief Marketing Officer	DHK Kozijnen	1 hour
10 June	Interviewee C	Architect and civil engineer	BauKarussell	1 hour
10 June	Interviewee D	Founder	Material Bank Leuven	45 mins
17 June	Interviewee E	Program manager	TKI Dinalog	1 hour
21 June	Interviewee F	Circularity and sustainability officer	Vlasman	1 hour
21 June	Interviewee G	Circular Economy Advisor	KplusV	1 hour
21 June	Interviewee H	Project manager	Fiction factory	1 hour
24 June	Interviewee I	Founder	Stichting Insert	1 hour
7 July	Interviewee J	Director	Buurman	1 hour
15 July	Interviewee K	Circular Supply Specialist	New Horizon	1 hour

6.3.4 Four spatial perspectives for circular hubs

The spatial parameters of circular construction hubs were collected from four spatial perspectives: resources, accessibility, land, and socio-economic. The collected parameters could then serve as an input for future studies using quantitative spatial analysis methods to identify locations of circular construction hubs.

"Resources" refers to the topic of location science in operations research, which uses optimization algorithms to determine where facilities should be located in order to minimize the cost of satisfying demands (Hale & Moberg, 2003). Relevant spatial parameters from this perspective are the types of suppliers and clients (such as material and building types) for circular construction hubs, as well as travel distance limits.

"Accessibility" refers to transportation network analysis, which uses network analysis methods to understand the accessibility of locations on a transportation network, such as streets or waterways (A. van Ness, 2019). Relevant spatial parameters from this perspective are the scale of accessibility for different types of circular hubs, and their mode of transportation.

"Land" refers to urban morphology research, which provides a quantitative understanding of the morphology of buildings, plots, and urban blocks (Berghauser Pont et al., 2019; D'Acci, 2019). Relevant spatial parameters from this perspective are building size and height, plot size, street frontage, plot diversity, and land use restrictions.

"Socio-economic" refers to economic geography research, which studies the spatial factors affecting location of companies, such as labor availability, agglomeration of companies, and local taxation policy. For this study, relevant parameters are labor availability, proximity to other companies (Anselin, 2010; Rosenthal & Strange, 2003).

As mentioned in the beginning of this section, the spatial parameters were collected with two methods: document review and semi-structured interviews.

6.4 Results

From the interviews and document reviews, four types of circular construction hubs were identified: craft centers, industry hubs, local material banks, and urban mining hubs. These hub types were categorized by their spatial scale of operations (regional versus local), and whether they had a focus on processing or redistributing secondary materials (industry versus logistics perspective). The four categories can be seen in Figure 6.1 below.

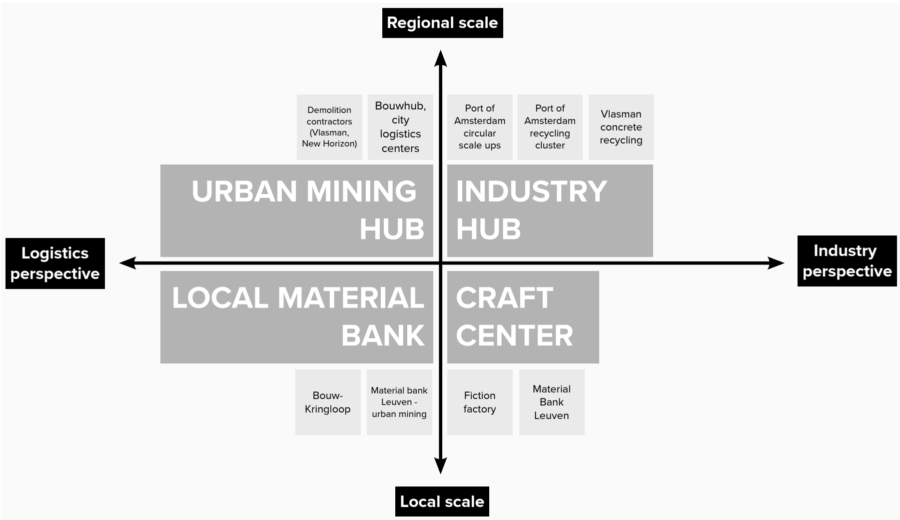

FIG. 6.1 Four types of circular construction hubs. Four types of circular construction hubs were identified during the interviews: urban mining hub, local material hub, industry hub, and craft center. The four types vary in terms of their scale (y-axis), and focus on industry or logistics (x-axis).

Circular industry hubs house large scale and industrial circular activity, and process bulk construction materials such as asphalt and concrete. They operate at a large scale, at a provincial or even national level; and can benefit from water transport. They require industrial sites with a high environmental zoning category (Vereniging van Nederlandse Gemeenten, 2009) and large plot sizes. They could benefit from co-locating with existing industrial or recycling clusters.

Urban mining hubs are for sorting, storing, and distributing building components and products (whereas bulk building materials are processed in industrial hubs). They can work as a ‘hub-and-spoke’ system, with a larger scale central hub connected to a network of smaller scale ‘satellite hubs’. The smaller satellite hubs are 5-10 ha, with an environmental category of 2-3.

Circular craft centers use residue construction flows to make smaller scale products, such as furniture or retail spaces. Suppliers and customers are usually located within the same city, connected using the road network. It is often connected to a local material bank, which is a large space that stores materials. Often, local labor is used, and there is also usually a ‘citizen-facing’ component to the operations of a craft center - locals either attend workshops, or supply or buy materials from the center.

Local material banks collect, store, and re-sell residue flows ignored by larger companies, and are usually co-located with craft centers (or owned by the same organization). Materials are usually collected and sold within the same city, using road transportation. A large space with high ceilings (1200-1500 sqm) is required for storage of materials. People with a distance from the labor market are often employed for operations.

Table 6.3 summarizes the spatial parameters for the four hub types from four perspectives - resources, accessibility, land, and socio-economic. Spatial parameters, data, and analysis methods are further explained and elaborated in the discussion section, and full details can be found in the supplementary materials section.

TABLE 6.3 Summary of spatial parameters for four types of circular construction hubs. For the full list, please refer to the supplementary excel sheet (see supplementary materials for full table).

	Resource perspective	Accessibility perspective	Land use perspective	Socio-economic perspective
craft center	Works with materials with smaller scales, sometimes with a shorter life cycle, such as wood for furniture workshops. Both the suppliers and customers are citizens, and citizen workshops are hosted, so are close to urban areas.	Suppliers and customers are located within the same city (10-20km). Road is the main type of transportation, Water transportation doesn't make sense because flows are not large / consistent enough	Buildings of 1200-1500 sqm with loading and unloading areas needed. Exemptions are often made for craft centers. They don't fit into industrial land because they have social activities like workshops, and they don't fit into cultural land because they have industrial machinery.	craft centers should be close to human capital (mix of skills - designers, craftsmen, people with distance from labor market), as well as citizens for educational purposes.
industry hub	Processing bulk construction materials such as asphalt, concrete, soil, sand, and gravel. They can be part of a recycling cluster, mainly focused on recycling as it is currently most profitable.	The suggested scale varies from 1 hub per province to 1 hub for the whole of western Europe. The transportation limit for asphalt and concrete is 50-100km. Currently, road transport is used, but there is interest in using waterways of class III or higher, as bulk transportation is cheaper and more sustainable on water.	10-30ha, usually located in existing ports or (industrial) business parks, environmental category 4.1 or higher.	can build on existing recycling capacity, embedded in ecosystem of circular industry and construction companies
local material bank	materials for small scale private housing renovations, governmental or university buildings, or furniture. Targets smaller residue flows that larger companies ignore.	materials are collected and sold within the same city, 10-20km. Typically road transportation is used. Water transportation is interesting for scaling up.	1200-1500 sqm. Large amount of storage space is needed because building materials are bulky. Existing buildings with loading areas and high ceilings are preferred.	work with people with a distance from the labor market, and be near other hardware stores or thrift stores,
urban mining hub	Urban mining hubs redistribute building elements (e.g. bricks) or products (e.g. doors) from housing, governmental buildings, and offices. There is potential to combining logistics hubs with circular hubs to reduce transportation emissions and encourage a more 'demand-driven' hub	Currently, service areas vary from 30-50km. One way to determine the scale would be to optimize environmental impact and supply-demand matching. Road transport is used, although there is interest in connecting to water and rail networks at larger scales.	Plot sizes are 5-10ha, with environmental category of 2 or above. Temporary storage could be vacant plots and demolition sites, and more fixed hubs could use existing ports, industrial estates or business parks.	Hubs could be made by expanding existing clusters of concrete plants, waste processors, or construction hubs. While some say that combining logistics with industry could be useful, others claim that there is no benefit (or problem) with combining bulk material processing and building product (reverse) logistics. Some hubs work with people with a distance from the labor market.

6.4.1 Spatial parameters, data, and analysis methods for each circular hub type

The spatial parameters, data, and analysis methods for each circular hub type are summarized in the paragraphs below. The spatial parameters are categorized into four perspectives: resources, accessibility, land, and socio-economic. For more details, please refer to the methodology section. For more details on spatial parameters, such as environmental categories or waterway sailing classes, please refer to the supplementary materials section.

The spatial analysis methods recommended in this section are site selection, spatial clustering, and facility location. Site selection analysis selects the best location or site for a facility based on spatial criteria such as proximity to amenities, availability of materials, or accessibility (Randazzo et al., 2018; Rikalovic et al., 2014). Spatial clustering analyzes the degree of clustering of points distributed in space, and allows for the identification of hotspots (Aldstadt, 2010; Tsui et al., 2022). Facility location analysis identifies the optimal placement of facilities to minimize transportation costs (Melo et al., 2009).

6.4.1.1 Industry hubs

For "resources" parameters, industry hubs process bulk construction materials such as asphalt, concrete, sand, gravel (De Bouw Campus & Provincie Zuid Holland, 2020; Interviewee F, personal communication, June 21, 2022), and top-soil (Interviewee C, personal communication, June 10, 2022). These processing methods are different from processing building products such as windows, so there is no clear benefit to placing them together on the same site (TNO & Provincie Zuid Holland, 2022).

For accessibility parameters, the suggested scale for industry hubs vary - some sources suggest there is potential to expand to the whole of western Europe (Interviewee A, personal communication, May 30, 2022), while others suggest there should be 1 hub per province, connected with a number of construction hubs at a local level, suggesting a 'hub-and-spoke' system operating at multiple scales (De Bouw Campus & Provincie Zuid Holland, 2020). However, the transportation distance limit for asphalt and concrete is around 50-100 km (De Bouw Campus & Provincie Zuid Holland, 2020; Interviewee K, personal communication, July 22, 2022).
While the road network is currently used (Interviewee F, personal communication, June 21, 2022), there is interest in using waterways (Architecture Workroom Brussels, 2021; Interviewee A, personal communication, May 30, 2022; Ministry of

the Interior and Kingdom Relations, 2020) of class III or higher (De Bouw Campus & Provincie Zuid Holland, 2020) for transportation, as it is cheaper and more sustainable to transport bulk materials on water.

For land use parameters, industry hubs are usually located in existing ports or industrial parks, preferably with a hard boundary from residential areas to give greater long-term location and investment security (Provincie Noord Holland, 2018). Larger plots of 10-30 ha are needed (De Bouw Campus & Provincie Zuid Holland, 2020), and should have an environmental category of 4.1 or higher to avoid nuisance (De Bouw Campus & Provincie Zuid Holland, 2020; Provincie Zuid Holland, 2021; TNO & Provincie Zuid Holland, 2022). Additionally, major landfalls for offshore renewable energy could be attractive for circular companies that want to combine circular economy and energy ambitions. These landfalls are ports and industrial areas near the coast of the Netherlands (Ministry of the Interior and Kingdom Relations, 2020).

For socio-economic parameters, a strong local ecosystem is needed, consisting of innovative circular industry and supply chains (Interviewee A, personal communication, May 30, 2022), construction related companies (Gemeente Amsterdam, 2020; Provincie Zuid Holland, 2019), and existing recycling capacity (De Bouw Campus & Provincie Zuid Holland, 2020; Interviewee A, personal communication, May 30, 2022), in order to form circular clusters (Provincie Noord Holland, 2021; Provincie Zuid Holland, 2019), and share energy, space, materials, and knowledge (Gemeente Amsterdam, 2020; Interviewee A, personal communication, May 30, 2022; Provincie Noord Holland, 2021; Provincie Zuid Holland, 2019).

To identify suitable plots for industry hubs, the following spatial analysis steps can be taken. For data required for each step, please refer to the supplementary materials. Find industrial estates with an environmental category of 4.1 - 4.2, with plots of at least 10-30 hectares. Then, find hotspots of bulk construction waste recyclers with spatial clustering methods such as local Moran's I (Tsui et al., 2022) or DBSCAN (Mendez Alva et al., 2021). Rank industrial estates by their distance away from nearest residential areas (the further the better), whether there is hard boundary between the plot and nearby residential areas, as well as proximity to major landfalls of offshore renewable energy and recycling clusters.

To take into account the material yield for industry hubs, the following steps can be taken: From the chosen industrial estates, find locations that can reach a high supply and demand of bulk materials within a 50km travel distance limit on the road network, and prioritize locations that are next to waterways. The location and availability of bulk materials (concrete, asphalt, sand, top-soil) can be identified using in two ways: firstly, future supply of concrete, sand, and asphalt can be found in data on future demolition sites, in which the availability of the bulk materials are estimated. Secondly, the future supply of top-soil can be found in data on future construction sites that overlap with greenfields.

6.4.1.2 Urban mining hubs

For resources parameters, urban mining hubs deal with building materials and products that don't need processing before redistribution (TNO & Provincie Zuid Holland, 2022). This can include building elements (e.g. bricks) or products (e.g. doors) (Interviewee F, personal communication, June 21, 2022; Interviewee K, personal communication, July 22, 2022), greenery (Interviewee C, personal communication, June 10, 2022; Interviewee I, personal communication, June 24, 2022), and infrastructure elements. Housing, governmental buildings, and offices can be prioritized. Housing and offices are attractive because they often have standardized materials, and require regular renovations (Interviewee I, personal communication, June 24, 2022; Interviewee K, personal communication, July 22, 2022). Government buildings are backed by the governmental circular public procurement strategies, which allow for more centralized coordination of construction and demolition (Province of Gelderland, 2022; Provincie Utrecht, 2021).

For accessibility parameters, interviewed hubs state that they are currently serving clients within their own city, meaning the operations scale is around 30-50km (Interviewee A, personal communication, May 30, 2022; Interviewee C, personal communication, June 10, 2022; Interviewee F, personal communication, June 21, 2022; Interviewee I, personal communication, June 24, 2022). The road network is usually used because it's more efficient and reliable than waterways (Interviewee B, personal communication, June 3, 2022; Interviewee F, personal communication, June 21, 2022; Interviewee I, personal communication, June 24, 2022; TNO & Provincie Zuid Holland, 2022). There is interest in using waterways or railways to reduce environmental impact, but flows are not large enough to make this financially feasible (Architecture Workroom Brussels, 2021; Interviewee A, personal communication, May 30, 2022; Interviewee C, personal communication, June 10, 2022; Interviewee K, personal communication, July 22, 2022).

For land use parameters, existing ports, industrial estates, or business parks can be used (Metabolic et al., 2018; Provincie Noord Holland, 2021; Provincie Utrecht, 2021), with plots that range from 1-10ha, with an environmental category of at least 2 (Architecture Workroom Brussels, 2021; Interviewee I, personal communication, June 24, 2022; TNO & Provincie Zuid Holland, 2022). Large plots are required because building materials are bulky, fragile, and difficult to stack (Interviewee B, personal communication, June 3, 2022; Interviewee C, personal communication, June 10, 2022).

For socio-economic parameters, urban mining hubs could be made by expanding existing construction logistics hubs (TNO & Provincie Zuid Holland, 2022), and should be close to possible customers, such as building product resellers and construction companies. Manual labor is required, some hubs work with people with a distance from the labor market (Interviewee C, personal communication, June 10, 2022; Interviewee F, personal communication, June 21, 2022; Interviewee I, personal communication, June 24, 2022).

To identify suitable plots for urban mining hubs, the following spatial analysis steps can be taken. For data required for each step, please refer to the supplementary excel sheet (online resource 1). Select existing industrial estates with plots of at least 5 ha, with environmental category 2-3, near populations of low income and low education (as some hubs work with people with a distance from the labor market). Then, identify hotspots for waste processors and building product resellers using local Moran's I (Tsui et al., 2022) or DBSCAN (Mendez Alva et al., 2021), and rank the selected locations by their distance from hotspots.

To take into account the material yield for urban mining hubs, the following steps can be taken: From the chosen industrial estates identified in the previous steps, find locations that can reach a high supply and demand of materials suitable for urban mining hubs within a 50km radius - these are building elements from housing, governmental buildings, and offices; with a priority for large buildings, as they are more attractive to demolition companies. Additionally, locations of high yield can also be ranked by their multi-modal accessibility. This can be understood by seeing if the location can access multiple modes of transport - road, water, and rail.

6.4.1.3 Craft hubs

Through the interviews, we found that local material banks and craft centers are often two departments run by the same organization, in the same locations, with very similar spatial requirements (Interviewee D, personal communication, June 10, 2022; Interviewee J, personal communication, July 7, 2022). These two types were therefore combined into one - craft hubs.

For resources parameters, craft hubs collect residue waste from the building industry that larger companies ignore, often wood from public buildings. Its customers are private individuals, who use these materials for small scale projects like renovations and furniture (Interviewee D, personal communication, June 10, 2022; Interviewee J, personal communication, July 7, 2022).

For accessibility parameters, materials are collected and sold within the same city, although some customers are willing to travel further for a cheaper product. Roads are the main mode of transportation, although there is interest in waterways when operations scale up (Interviewee D, personal communication, June 10, 2022; Interviewee G, personal communication, June 21, 2022; Interviewee J, personal communication, July 7, 2022).

For land use parameters, around 1-2 ha is needed, as a large amount of storage space is needed for bulky building materials. Existing and often abandoned buildings with good loading areas are used to save costs (Interviewee D, personal communication, June 10, 2022; Interviewee J, personal communication, July 7, 2022).

For socio-economic parameters, craft hubs are closer to residential areas because they hold workshops, sell to citizens, and work with people with a distance from the labor market. They can also be close to hardware stores or thrift stores, as they share similar customers (Interviewee D, personal communication, June 10, 2022; Interviewee G, personal communication, June 21, 2022; Interviewee J, personal communication, July 7, 2022).

To identify suitable plots for craft hubs, the following spatial analysis steps can be taken. For data required for each step, please refer to the supplementary excel sheet (online resource 1). Filter locations within 1 km (15 minute walk) from housing or commercial areas, prioritizing locations near high population density and high diversity of population income and education level, as well as accessible by public transport and bicycle network. Then, find buildings of at least 1200 square meters in size. Prioritize older buildings, as they will more likely be abandoned. Then, find hotspots of hardware stores and thrift shops with local Moran's I (Tsui et al., 2022) or DBSCAN (Mendez Alva et al., 2021), and rank locations according to distance from hotspots.

To take into account the material yield for craft hubs, the following steps can be taken: Taking the chosen locations from the previous steps, find locations that can reach a high supply and demand for wood from housing and governmental buildings within a 30 km travel distance limit. Locations of material supply is defined by future demolition site locations, and demand is estimated by population location. Population numbers (instead of future construction sites) should be used to estimate demand, because most craft hub consumers are using the materials for consumer products, such as wooden furniture.

6.4.1.4 From site suitability to facility location

The spatial analysis methods listed above create suitability maps – maps that show the locations that could be potentially attractive to circular hubs, without specifying how many of these locations would actually be used in a fully functioning circular building economy. The suitability maps can therefore be further elaborated into facility location maps, which use facility location algorithms to identify the number and locations of hubs that would hypothetically be required if all available building materials were to be processed by circular construction hubs (Hale & Moberg, 2003). The potential and number of facilities are identified by minimizing the travel distance from the facility (the circular hub) to its suppliers (demolitions sites) and customers (construction sites).

6.5 Discussion

From the interviews, we found that the concept of circular construction hubs is a contested issue. While many policy documents assume that there is a need for a centralized 'hub' for storing, processing, and redistributing secondary construction resources, not all interviewees saw the necessity in this. Some demolition contractors do not need a 'hub' to operate (Interviewee C; Interviewee F; Interviewee K). Instead, materials are immediately collected from the demolition site and sold to nearby construction material recyclers and dealers. However, hubs are still necessary because a longer term storage location makes it more likely that materials will be reused instead of recycled. More importantly, even if demolition contractors don't need a hub, a storage location is still needed by construction material dealers and recyclers, who could also be located on circular hubs.

6.5.1 Three perspectives for circular construction hubs

The concept of circular construction hubs seems to have emerged from three perspectives - urban mining, logistics, and craft. The urban mining perspective argues that hubs are necessary because it is impossible to match supply and demand of secondary construction resources within a narrow timeframe. Resources supplied from demolition sites today might not be needed until next year. A 'hub' is needed to store resources for a longer time to increase the chances of reuse. This perspective is mainly taken by demolition companies and their partners in their network.

The logistics perspective argues that existing construction logistics hubs, where primary materials are efficiently organized and then distributed to construction sites, can re-distribute secondary materials as well. This perspective is mainly taken up by construction companies and researchers in construction logistics.

The craft perspective argues that citizens and small companies should get involved in the circular economy, and that circular making activities should be reintroduced into cities via neighborhood hubs or maker spaces. This perspective is taken by community-based organizations.

6.5.2 Alternative models for circular hubs

The spatial parameters listed in the results section (Table 3) focus on the operations of a single hub on a permanent location. However, three other network models have been proposed by interviewees to identify the locations of circular hubs - decentralized (and temporary) hub network, multi-scale hub-and-spoke network, and spatially optimized hubs.

The concept of a decentralized hub network comes from interviewed demolition contractors. Instead of working with a centralized 'hub', materials are stored directly on the demolition site or nearby vacant land, then by nearby building material resellers (Interviewee C, personal communication, June 10, 2022; Interviewee F, personal communication, June 21, 2022; Interviewee K, personal communication, July 22, 2022). This avoids unnecessary transportation and storage costs, and takes advantage of existing storage capacity of partners. The resulting hubs could be smaller, temporary, and decentralized, leading to hub locations that change over time, according to the changing locations of temporary vacant land and demolition sites.

The hub-and-spoke network would consist of a 'central' hub surrounded by a network of 'satellite' hubs (TNO & Provincie Zuid Holland, 2022). A potential spatial analysis method would be to first identify the 'satellite' hubs with facility location analysis, in order to minimize the travel distance between each satellite hub and individual demolition and construction sites. Then, the same method can be used to determine central hub locations, minimizing the travel distance between each central hub and nearby satellite hubs (instead of individual demolition or construction sites). Additionally, hub location methods, an important sub-field of location science, could be used to identify the location of interacting hub facilities (Campbell & O'Kelly, 2012).

While most interviewees have provided an approximate service area of their hub (e.g. "our partners are generally within a 30km radius from us"), some interviewees have suggested spatial optimization as a way of determining the scale and locations of hubs. The larger the service area of a hub, the more likely supply of building materials can be matched with demand. However, larger service areas also increase transportation emissions. There is therefore an opportunity to use spatial optimization methods (Tong & Murray, 2012) to balance between these two opposing factors to find a suitable service area of a circular hub (Hodde, 2021; Interviewee E, personal communication, 2022; Interviewee K, personal communication, July 22, 2022).

6.6 Conclusion

In conclusion, this chapter provided a spatially explicit perspective to the study of the circular built environment by answering the research question, "What are the spatial parameters for circular construction hubs in the Netherlands?" The research question was answered through document review of Dutch governmental policy documents, and interviews with circular construction companies involved in the collection, storage, processing, and redistribution of construction and demolition waste.

This study categorized circular construction hubs into four types: urban mining hubs, industry hubs, craft centers, and local material banks. For each type of hub, spatial parameters were collected from four perspectives: resources (material and building types, business model), accessibility (mode and scale of transportation), land use (land use, plot size), and socio-economic (proximity to other companies, labor). The spatial parameters were then translated into spatial data and analysis methods that could be used to find potential locations for each type of circular construction hub. The most promising spatial analysis methods were site selection analysis, facility location analysis, and spatial optimization between travel distance emissions costs and embodied emissions savings from secondary resource use.

This study provides both theoretical and practical contributions to existing knowledge and practice on the circular built environment. In terms of theoretical contributions, this study provides an overview of different types of circular construction hubs in the context of the Netherlands. By focusing on spatial parameters, this study contributes to developing a spatially explicit understanding of the circular built environment. This was done by combining spatial perspectives from different disciplines: location theory, economic geography, and urban morphology.

The spatial parameters, data, and analysis methods identified can be directly implemented into a quantitative analysis study to identify future locations of circular construction hubs. We believe this type of study would be most useful if conducted at the provincial or national scale in the Netherlands. It could help policy makers prioritize existing industrial estates for implementing the circular economy.

6.6.1 Limitations

While this study provides spatial parameters for circular hubs, the locations of hubs don't only depend on geographical factors like proximity or accessibility, but also on social factors like existing company networks. Hubs could choose their location based on personal connections with local stakeholders, such as existing companies or industrial estate managers. These factors are not captured by the spatial perspectives chosen for this study.

While the suggested spatial analysis methods provide a first step to identifying the location of circular construction hubs in a quantitative manner, more understanding on the exchange and storage of secondary building resources is required in order to increase the accuracy of these methods. Currently, there are no detailed studies on how different material types have different transportation limits, how to calculate the yield of different building types in terms of building elements or products instead of materials, the amount of time different building elements and products are stored in a circular economy, and the relationship between material storage time and the amount of space required.

Finally, this study was a single case study on the Netherlands, which is not as rigorous of a multiple case study comparing the parameters for different countries. Because of this, results generated for this study are only applicable to the Netherlands (and perhaps nearby countries), but not to other contexts. For example, the almost unanimous interest in water transport is only relevant to countries with a functioning water transport infrastructure.

6.6.2 Recommendations for further research

The spatial parameters identified in this study can be used to identify locations of circular hubs in the Netherlands using spatial analysis methods such as multi-criteria site selection, spatial agent based modeling, spatial optimization, and hub location. The result can be maps of the Netherlands that show potential locations for different types of circular hubs, which could be useful to spatial policy makers in the Netherlands.

The locations of circular hubs can be further studied from a social, economical, or political perspective, in order to understand the factors that attract companies to a certain location, in addition to geographical factors.

A dataset could be developed to identify the amount of building products and elements in different building types. While urban mining datasets already estimate the amount of materials per building type, the next step is to create an ontology that connects building types to building products and elements. Having an inventory on the location and availability of building products and elements will allow for a more detailed distinction between industry hubs, which process bulk materials, and urban mining hubs, which process building elements and products.

More could also be understood on the relationship between distance, time, and the movement of building materials. Studies could explore how different attributes of building (secondary) resources, such as value, weight, or volume, could affect the amount of time it gets stored in a hub, or the distance stakeholders are willing to travel to exchange it.

Finally, this study's methods can be applied to other countries in order to identify the spatial parameters of circular hubs in different cultural and geographical contexts.

Supplementary materials

Supplementary materials for this article can be found in the following link: https://link.springer.com/article/10.1007/s43615-023-00285-y#Sec20