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Circular Maker Cities: Maker Space Typologies and Circular Urban Design

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Abstract: Maker spaces can contribute significantly to the circular economy of cities; they demonstrate not only the economic potential of inner loop circularity, but also provide tangible evidence of spatial and social integration of production into the urban context. This paper presents findings from a typological analysis of 326 maker spaces in seven European cities, with a focus on selected exemplar case studies to reveal design characteristics, principles, and opportunities for circular city development. The research shows that circular economy principles of 'reduce-reuse-recyle' are aligned with maker spaces such as repair cafés, secondhand shops, and fab labs, but requires additional definition with respect to material flow and spaces for recycling to underpin circular making. In the context of cities, circularity is revealed by a spatial tightening of resource cycles that close the loops of product life cycles. Furthermore, urban maker spaces demonstrate social engagement and a relationship to local production that inherently includes maintenance, repair, reuse, and redistribution. This paper defines five maker typologies, presents exemplars of each from different urban contexts and posits hybrid design strategies for the transition to circular maker cities. Through the adoption of these findings into urban planning policy, it is possible accelerate circular urban production and close the sustainability gap between small-scale local and large-scale regional manufacturing.

Keywords: maker spaces; circular cities; urban manufacturing; circular economy; reuse; repair; craft; fabricate; distribute

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1. Introduction

The circular economy (CE) provides the framework to move from the 'take-make-dispose' approach of the linear economy based on principles of 'reduce-reuse-recycle'. The CE approach is particularly important in the face of the urgent climate crisis, the supply of crucial raw materials, and the impacts of waste on health [1]. An increasing number of theoretical definitions, frameworks, and indicators of CE in cities—or 'circular cities'—has emerged in the literature, e.g., [2–4]. This reveals that the circular city is a complex and evolving concept, often starting with theoretical and technocratic descriptions of resource flows.

The following definition is of interest here because, apart from a focus on resources, it also hints at the spatial context: 'A circular city is based on closing, slowing and narrowing the resource loops as far as possible ... with remaining needs for fresh material and energy being covered as far as possible based on local production' [2] (p. 6). Others have subsequently carried out an extensive literature review, which in particular identified the additional need for the inclusion of a broader social agenda: '[The circular city] also integrates a way ... to improve human well-being, reduce emissions, protect and enhance biodiversity, and promote social justice' [3] (p. 7).

The impacts presented by circularity are wide ranging, particularly in cities, where both population density and resource consumption are at their greatest. Williams [4] comprehensively spells out the potential virtues of adopting circular urban development, combining resource efficiencies with social and economic opportunities:

> 'A circular approach to the way in which we manage the resources consumed and produced in cities... will significantly reduce the consumption of finite resources globally. It will also help to address urban problems including resource security, waste disposal, greenhouse gas emissions, pollution, heating, drought and flooding. Taking a circular approach can also tackle many other socio-economic problems afflicting cities, for example, providing access to affordable accommodation, expanding and diversifying the economic base, building more engaged and collaborative communities in cities. Thus, it has great potential to improve our urban living environments'. [4] (p. 2746).

Circular cities have been defined in techno-centric terms but are increasingly understood in terms of social and spatial integration [5]. CE policies now feature in wider sustainability agendas [6] and require manufacturers to build consumer-repairable products [7]. CE is prioritized in planning for global cities [8], by waste management authorities [9], through zero-waste campaigns [10], and zero-waste targets [11].

At a practical level, CE focuses on attention on repairing, reusing, remanufacturing, and recycling [12]. These cycles aim to maintain the embedded value of products and materials and attempt to eliminate waste. The inner loops represent local cycles (maintain, reuse, repair) whereas outer loops involve regional systems more susceptible to energy and material leakages resulting from transportation, disassembly, and reprocessing (see Figure 1).

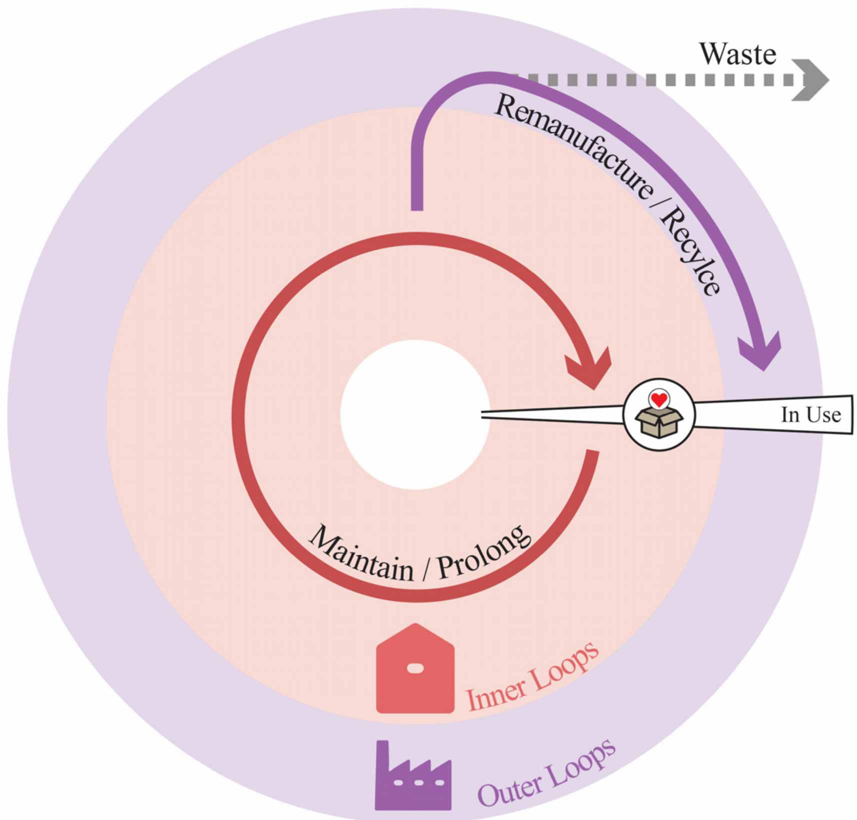

Figure 1. Principles of CE inner and outer material recovery routes. The diagram represents the circulation of value back into use via inner loops in proximity to the user, reducing reliance on outer loops and leakages to waste disposal.

Models of CE focus on the top-down activation of the outer loop activities, targeting manufacturers and often overlooking the role of bottom-up, user-orientated, inner loops [13]. Some authors conclude that:

> 'Evidence from practical examples have indeed shown that the greatest challenges ahead lie not in further technological innovation but rather in the role of people, both as individuals and as a society... Research into the role of policy measures to promote circularity should also be furthered...' [13] (p. 714).

Subsequent literature on circular cities has confirmed the gaps between the idealistic strategies that define the circular economy and the ability for these strategies to affect change in urban development [14].

This paper examines the tangible urban conditions that exemplify circular activity. Having established that inner loops have the most potential, the focus of this paper is on illustrating the richness and complexity of local circular production—i.e., maker spaces. The literature has recognized that the making capacity of citizens and consumers in the production cycles will have a significant role to play in reuse and repair routes [15–17]. Others suggest that a radical societal and behavioral shift is required to reach those essential circular functions [5,13].

Recent research has shown that urban manufacturing has the potential to contribute environmentally to the circular economy [18] and that it is the growing maker movement that 'has been touted as a harbinger of the next industrial revolution' [19] (p. 459). A maker ecology brings with it not only environmental advantages but also social collaboration, knowledge sharing, low-cost innovation, and entrepreneurship [19]. In this paper, we define maker spaces as socially and spatially contextual, drawing on local needs and skills, limiting transportation of products and consumers, and thus providing models of urban manufacturing that can be replicated and expanded. In this research, we are particularly interested in the intersection between makers and the circular economy—i.e., 'circular makers'. Thus, maker spaces include not only places of local production (such as high-profile fab labs or hacker spaces) but also spaces focused on reuse, repair, and remanufacturing. Additionally, places associated with the flow of materials (collecting, cleaning, grading, storing, etc.) provide an important resource to circular makers.

In summary, the evidence from the literature is clear: maker spaces can play a vital role in the development of circular cities [20]. The aim of this research is to reveal the architectural and urban characteristics of the inherent circular capacity, shaped by and rooted in social and historical maker spaces, that represent models of inner loop circular activities.

2. Methods

To understand the nature of urban maker ecology, a case-study-based approach was used to assess existing maker spaces, supported primarily by desk studies. The employment of such a method has been used in studies of circular cities before and is considered particularly suitable to reveal social, technical, and spatial aspects [5,14]. An analysis of socio-spatial characteristics was based on the cataloguing of 326 maker spaces across seven European cities. The buildings and urban contexts were analyzed to define, compare, and contrast maker spaces. From this overview, several circular maker typologies were identified, and for each typology exemplars are presented in more detail in this paper.

This research was undertaken to underpin the building and urban design aspects of the EC 'Pop-Machina' H2020 project [21]. 'Pop-Machina' examined the links between the maker movement and circular economy to promote environmental sustainability and generate socio-economic benefits in seven European cities: Leuven (B), Istanbul (TR), Piraeus (GR), Santander (ES), Thessaloniki (GR), Kaunas (LT), and Venlo (NL).

2.1. A Survey of Maker Spaces

Commencing with a literature review (summarized in the introduction above) to define the terminology and characteristics of 'circularity' and 'makers', followed by desk research and interviews, a total of 326 maker spaces were identified as follows. The nature of the desk research started with internet-based searches of international, national, and regional maker databases and websites. Makers only located in the seven pilot cities were collated. A wide range of types of maker spaces were identified and a taxonomy was developed, which will be discussed in more detail below. This taxonomy helped to focus searches on those makers that were potentially involved in circular production, such as secondhand stores, repair shops, fab labs with recycled plastics facilities, recycling centers, materials and tools libraries, etc. This was based on publicly available information collated from websites of maker spaces and related activities. Where the information available included physical locations in the cities, which could be checked using Google Street View, these were included in the database so that it was possible to map these on plans of the cities. A total of 326 maker spaces in the seven cities formed the database for this research.

By collating and cataloguing the characteristics of these maker spaces in relation to circular activities, five generic programmatic typologies emerged that have the potential to stimulate CE inner loop activities. The definition of these maker space typologies evolved initially from the generally accepted circular principles of reuse, refurbish, remanufacture, and recycle [22], but here the aim was to relate the typologies to the activities, actors, architecture, and spatial context of maker spaces (discussed and illustrated in detail and through case study examples in the results section below). These CE principles were not sufficiently nuanced to define different activities and their urban and spatial requirements related to circularity loops. For example, 'remanufacture' can imply anything from a small-scale craft-based neighborhood workshop to a high-tech shared fab lab linked to a major university, or a regional (re)manufacturing plant. And 'recycle' does not make clear whether this relates to an out-of-town municipal waste center or a bespoke local supplier of reconditioned materials. As a result of the cataloguing process and in the context of circular inner loop activities, a taxonomy of maker space typologies was proposed. This provided the structure for further detailed analysis of the case study exemplars reported in the results section below.

2.2. Semi-Structured Interviews

The identification of the 326 maker spaces was followed by an assessment of their urban contexts in each of the seven cities. This involved semi-structured interviews with international experts in urban analysis and with representatives of the seven municipalities for local circular planning information. This was a significant undertaking and will be reported in a separate publication because the research addressed a wider range of urban planning, policy, and analysis topics beyond maker spaces.

However, the nature of the urban analysis that is of relevance here derives from interviews with 30 international experts identified through literature pertaining to urban analysis, circularity, and makers. Their primary expertise covered urbanism, architecture, policy, and engineering, with specialist focus on themes including spatial analysis, circularity, industry, social, economic, and cultural aspects of the city. The list of opening questions that guided the semi-structured interviews of experts focused on data-capturing techniques as well as the operational and strategic implications of these urban analysis methodologies related to circular economy and maker spaces. Spatial mapping of the maker spaces in the city was seen as the key step to collate the information necessary to assess the urban context of circular maker ecology.

This general expertise was complemented by local knowledge gained from interviews with city planners from each city. Here, the questions focused on policy, particularly related to the CE and maker communities, as well as the availability of maps and visual material related to urban planning. The combination of local information, maps, and data, with more generic approaches to urban analysis, established the framework for assessing the urban context of maker spaces.

2.3. Urban Mapping

The research involved mapping each city's case study samples in relation to different urban characteristics such as: urban spatial structure (morphology); road transport, public transport, etc. (networks); population characteristics (demographics); historic fabric; knowledge and skills zones. To gather urban data, we employed a combination of methods, based in part on the feedback from the experts, designed to ensure comprehensive and accurate information. These methods included open-source data mapping using GIS and OpenStreetMap for geographical insights, case studies for in-depth examination of specific urban scenarios, urban imagery analysis to extract visual information, and on-site city visits. We also used tools like Google My Maps, Google Maps Street View, and captured shared photographs and videos to document and analyze various characteristics of the urban environment (e.g., spatial, historical, and visual conditions). This multi-pronged approach allowed us to collect a diverse and well-rounded dataset for our research. The sources for this information included combining a range of open-source data sources and evidence provided by the municipalities. This urban analysis facilitated comparisons of the urban contexts of maker spaces across each of the seven cities.

For closer analysis, 35 case studies were selected representing each of the five typologies for each of the seven cities. For these case study maker spaces, more detailed information was gathered—from city visits, interviews, maker websites, and Google Street View—for the following factors:

- General program,
- People (who works there and who uses the space?),
- Materials (what is used and what is produced?)
- Machines and tools used,
- Interior space description,
- Location in the city, and general features of surrounding area,
- Urban form of the space.

The purpose of these case studies was to reveal their characteristics at a building and urban level and to examine the conditions for makers to be integrated within the wider circular metabolism of cities.

2.4. Limitations

There are several important limitations to note in this research. Case study research is empirical and qualitative and can involve a risk of bias and limitations in generalizability. Although the overall number of circular maker spaces reviewed (n = 326) and case studies examined (n = 35) exceeds those from previous literature (typically n = 6), the level of detail and direct engagement with makers was limited. Furthermore, the desk research of maker spaces relied on publicly available sources and promotional material, some of which can be out of date or misleading. Although there is confidence in the identification of the taxonomy and the value of limiting this to five typologies, one can imagine that other researchers may have identified alternative, more nuanced, or more complex combinations of makers. For example, it would be possible to categorize circular makers further in terms of the predominant materials used, products made, commercial/economic success, the socio-economic status, etc.

Regarding the interviews, the 30 experts were selected based on their academic knowledge of circular urban planning. Although they represented a diverse range of backgrounds and specialisms, few had practical expertise regarding maker spaces. The semi-structured interview questions were consistent, and interviews were recorded and transcribed. Despite this, bias of the interviewees and interviewers cannot be wholly discounted. The interviews with planners representing the seven case study cities were similarly structured, but in this instance the interviewees were collaborators on the Pop-Machina research project. Although the key questions were factual in nature, the risk of bias in portraying a city as particularly successful or proactive was nevertheless noted.

The urban analysis relied on information that was publicly available using open-source data wherever possible, supported by visits and interviews. In some cases, the data set was incomplete or not big enough to allow for comprehensive analysis. Such urban data is also constantly changing and so by definition represents a snapshot or a marker in time. As a result, the data gathering, verification, and preparation at a future point in time may solicit new and potentially different insights, which could then be compared with the current research.

3. Results

3.1. Maker Space Taxonomy

The research identified the following five types of maker spaces, with activities for each typology is described below.

3.1.1. Reuse

Spaces that facilitate second-hand trading activities, where people have access to second-hand goods or can drop off their used items for someone else to use. Used furniture, thrift, and charity stores are well established examples, often located in publicly accessible, central urban areas. There are no specific tools or skills required by the traders, as the spaces are focused on trade and exchange. Typically, items that have been donated to the store will be sorted, cleaned, and repaired, if necessary, but reuse spaces do not support significant repair, storage, and redistribution activities.

3.1.2. Repair

Spaces that are equipped with facilities, tools, and expertise to repair damaged products. Items can be repaired by the customer or by an expert. Repair programs are approachable, easily accessible, and human-friendly places. They are typically distributed throughout the city, within walking distance of users. Sometimes they are social spaces that accommodate non-specialized participation. They can occasionally provide tools, libraries, and online platforms for skills and knowledge exchange, or have the capacity to pass down repair skills and knowledge.

3.1.3. Craft

Spaces that host traditional forms of production such as woodwork, metalwork, fabrics, jewelry, etc. Craft making is often described as artisanal, handmade, or DIY. These crafts workshops provide a tools library and enable specialized skills exchange within the local district. Items produced here can range in size and function and rely on traditional craftsmanship techniques that are passed down generationally.

3.1.4. Fabricate

Spaces that host making activities that rely on non-traditional digital fabrication techniques, including prototyping and experimental technologies—often referred to as fab labs. These spaces include specialized tool libraries, machines, and machine-aided design tools. They are sometimes open-source spaces with specialized skills-exchange platforms. These sites are often linked to or part of educational institutions and cater to experts or students. Design or engineering courses will have a dedicated space with fab lab machinery such as CNC machines and laser-cutters.

3.1.5. Distribute

Spaces where materials can be collected, stored, and distributed are an essential part of the circular materials resource for makers, and to an extent are a feature of circular maker spaces. However, usually these are larger waste collection-and-sorting facilities. They often operate at the municipal level or operate alongside local governmental institutions to provide a public service. Specialist local 'material banks' are a notable feature of inner loop circular production. This typology enables materials of various scales to be collected, sorted, cleaned, graded, and stored prior to redistribution to makers.

3.1.6. Overview of Typologies

The diagram below (see Figure 2) depicts these five typologies of maker spaces in relation to the circular economy by relating their program and implied urban scale to the main theoretical CE material recovery routes. This diagram is an elaboration of the innermost loop of the CE diagram presented earlier (see Figure 1). The diagram is an idealized version of the relationships between cascading inner loops and outer loop circularity. It proposes that:

(1) if materials or products cannot be reused, they could be repaired,
(2) if not repaired, then crafted into another product,
(3) if not crafted, then disassembled into component materials and recombined to fabricate new products,
(4) if not fabricated, then collected and distributed to the makers in (1), (2), or (3) above,
(5) and finally, products and materials that cannot be reused, repaired, recrafted, refabricated, or redistributed within the city are destined for the outer loop to be recycled by industry or disposed of.

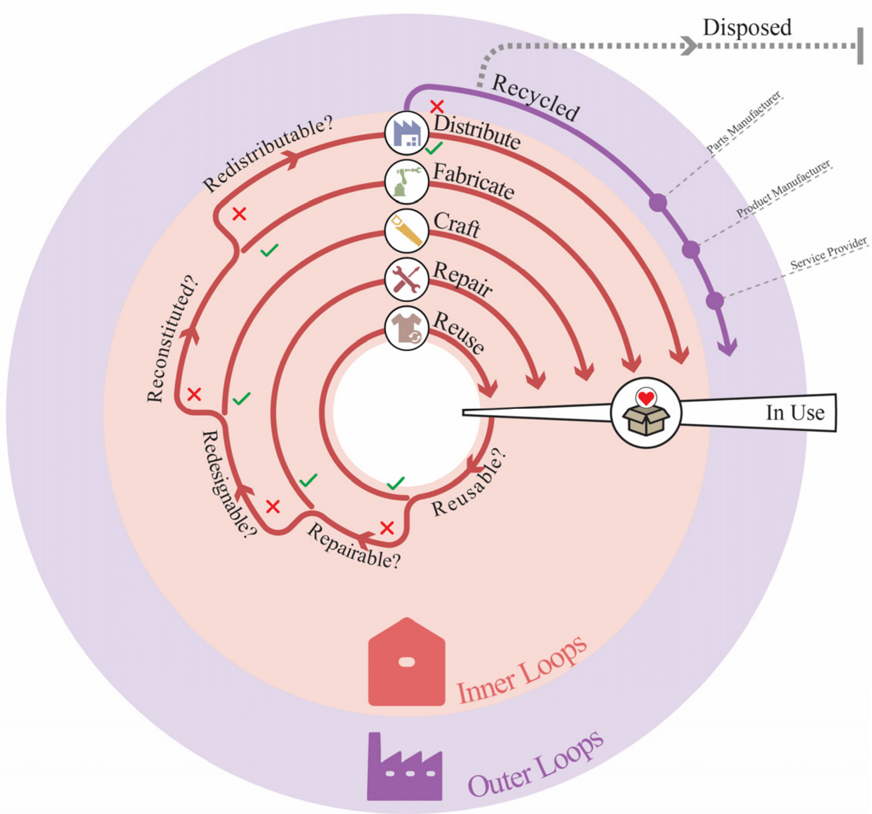

Figure 2. Circular Economy cascading inner loops of material recovery routes. This diagram outlines the possible material recovery routes available within the inner loops (the walkable city center or neighborhood). The material recovery routes cascade from most to least effective, correlating with the approximate physical distance to the user. A green tick represents the option to stay within the inner loop whereas a red cross signifies that it is necessary to move out one loop.

This theoretical proposition is likely to be more complex in response to context, and this paper goes on to discuss these complexities and interactions between circular maker activities. In other words, although we can identify five individual maker typologies, there is potential for mixed or hybrid typologies. This is addressed in the discussion section of this paper.

Apart from depicting product and material cycles, the diagram (Figure 2) also implies spatial dimensions. Inner loop activities are typically within the historic core of smaller cities (such as Leuven, population circa 100,000) or neighborhoods (circa 1 km in diameter) in larger cities (such as Istanbul). This reflects the notion of the walkable neighborhood or the 15 min city. The outer loop activities are typically in extra-urban locations, including industrial estates or out-of-town infrastructure. The diagram suggests the proximity of maker space typologies and circular processes to the user, cascading outwards to limit reliance on large-scale manufacturers and service providers in the outer loop. These spatial characteristics are noted in the case study exemplars discussed below.

The cataloguing of the survey data suggested that these five typologies represent the full range of circular maker spaces that exist across the different cities, exhibiting different features depending on their context. Prior to the definition of the five typologies, and from insights gathered from interviews, many of these spaces were largely unrecognizable as circular or maker-oriented by municipalities. The typologies thus provided a useful framework that more comprehensively revealed circular makers and their various manifestations within their urban contexts.

3.2. Maker Space Exemplars

The sections below summarize the key characteristics and findings, drawing from the 35 detailed case studies to illustrate each of the maker space typologies.

3.2.1. Reuse Maker Space Typology

The examination of the Reuse typology has identified the key traits that typically characterize this typology as follows:

1. Reuse activities mostly occupy spaces associated with second-hand goods such as flea markets or second-hand stores.
2. They are easily accessible and accrue frequent, high footfall.
3. They appear mostly around zones of the city where residential and commercial activity meet.
4. They flourish in more densely populated areas.
5. Reuse activity coincides with important public transport hubs which helps attract footfall.

For some cities in this study, such as Leuven, Santander, Venlo, and Thessaloniki, the Reuse typology case studies are in the form of second-hand chain stores and follow a clear agenda of circular activity and product life extension. These function as reputable, accessible, and easily recognizable bases for people to either buy or drop off second-hand items. They tend to occupy active, noticeable, high-street locations whilst remaining close to local residents. The products are packaged and displayed in a similar manner as fashion goods. The shops use commercial rails, shelves, and display cabinets in the main shopping area of the space, with additional back-of-house storage and support spaces, such as an office or small kitchen.

The multiple locations of these chains increase and diversify their reach. This benefits their sustainable and social mission by engaging diverse communities across the city, region, or country. Leuven's Think Twice (see Figure 3) demonstrates this benefit. It is owned by the larger Baltic Textile Trading company, which owns and manages several second-hand clothing stores and sorting centers and raises funds for international sustainable development and environmental protection projects. The company has more than 200 chain stores that promote fashionable reuse trends and aims to reduce the demand for 'fast fashion'. Due to its presence in 12 locations in Belgium alone, Think Twice has become a trusted brand, known for supporting circular fashion.

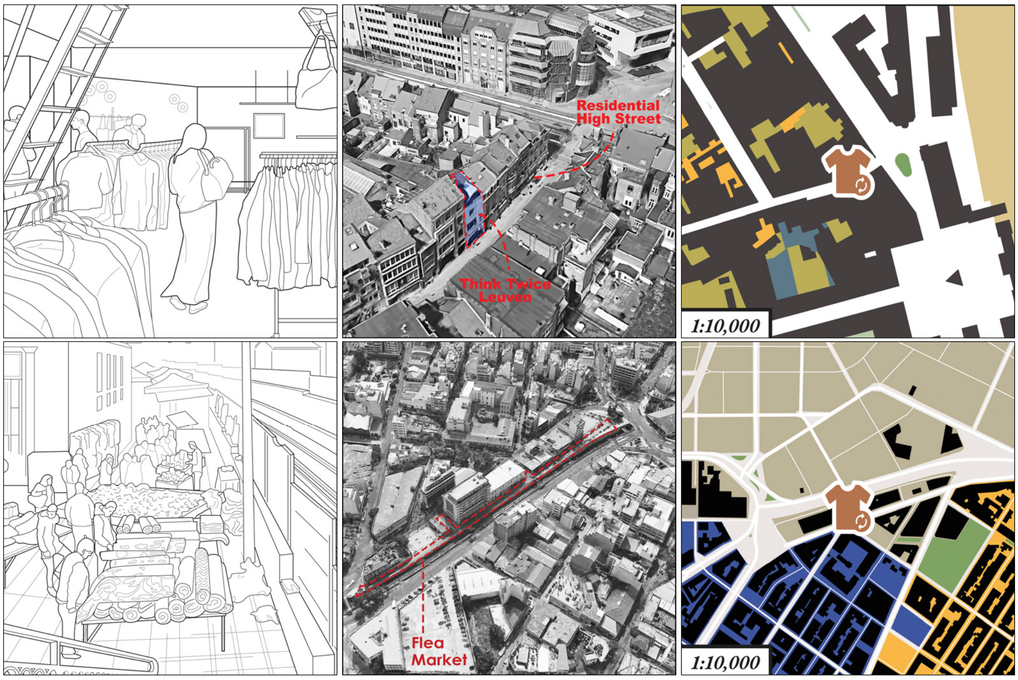

Figure 3. Illustration and mapping showing the Reuse typology case studies 'Think Twice' in Leuven (**top row**) and the Reuse typology case study Flea Market in Piraeus (**bottom row**). Each row illustrates the following: (1) spatial character, (2) urban form, and (3) surrounding land use map in relation to case study location (blue: commercial; yellow: residential; green: green space, grey: industrial; red: educational).

This pattern highlights the Reuse typology's capacity to engage in public awareness of social and sustainability goals. In the Netherlands, Venlo's Terres des Hommes Kringwinkel operates in a similar manner and is part of a much larger humanitarian organization focused on preventing the exploitation of children in East Africa, Asia, and Europe. Similarly, in Spain, Santander's Koopera Store is part of a project that focuses on environmental and social awareness and aims to bring attention to principles of the circular economy. Koopera collaborates with local public entities such as social services to offer training to people in marginal social conditions and currently employs 433 people (of which 243 are from marginalized groups).

The flea markets in Istanbul, Piraeus, and Kaunas represent another Reuse sub-typology. These accommodate reuse in a similar manner but utilize different spatial and urban conditions. They occupy much larger areas with smaller stalls per trader and are often located close to busy public transport stations for easy access and high footfall. The Sunday Piraeus Flea Market (see Figure 3) is a good example that demonstrates the popularity and accessibility of this model. Located on the urban boundary with Athens, in the north of Piraeus, the market sprawls adjacent to the crowded M1 overground metro tracks. It has no permanent shelter, no clearly defined boundaries, and relies on both formally structured and informal booths.

The Piraeus Flea Market is run and frequented mainly by locals, and it trades in a wide variety of used and new items. The flea market's Reuse model provides opportunities for a variety of traders, some more frequent than others, which could be suitable for cities that flourish under this particular trade culture. It offers an informal, temporary setting that is conducive to alternative trading mechanisms such as bartering, bargaining, and sharing of stalls. These markets play a particularly valuable role within the context of economic constraint, in which people have restricted access to mainstream markets.

These two examples of Reuse typologies (second-hand chain stores and flea markets) demonstrate different spatial characteristics. However, both attract similar users, and they function at 'reuse' level and thus the innermost loop of the urban circular economy. The range of programs and spatial characteristics reveal the conditions under which reuse activities can flourish in the city. Although presented as two distinct options within the Reuse typology, it is by no means restricted to one or the other. For example, we can see an overlap between two such spaces in the case of Thessaloniki's HOB thrift store. Besides operating from their large premises in the center of Thessaloniki, HOB stores also occasionally travel to flea markets and 'swap festivals', occupying designated stalls to sell their goods to a wider audience. This form of hybrid scenario presents a useful precedent, related to urban configuration and circular opportunities, that will be discussed later.

3.2.2. Repair Maker Space Typology

The Repair typologies we have identified vary slightly depending on their context but share similar traits and urban characteristics. The main similarities across the seven cities include:

1. Repair activities mostly occupy small commercial spaces such as shops or cafes, marketed with an identity that reflects the city culture.
2. They are easily accessible for local people.
3. They appear mostly in zones of the city where residential and commercial land uses meet.
4. They flourish in more densely populated areas.

The differences between the examples studied here reveal this typology's adaptable and evolving nature. For some cities, such as Leuven and Venlo, the Repair typology appears in the form of a designated 'repair café' following a clear agenda of circular activity and product life extension. These repair cafés are open for the public to use, functioning as a local café where customers repair their belongings (with access to tools and expertise) while socializing. Repair cafés are widely acknowledged as a type of maker space, encouraging the democratization of making and normalizing self-driven repair in society [23].

The Maakbar repair café in Leuven (see Figure 4) represents a clear case study of the ways in which a repair café functions. Here, citizens are invited to repair and circulate their products for life extension themselves by utilizing and sharing knowledge, materials, and space with other customers. People are encouraged to repair together as a social activity and help others repair their items. Maakbar also provides a 'tools-library' that members can use to repair their items with and then return them for others to use. This space is primarily run by volunteers and targets local hobbyists as well as the general public. Membership costs EUR 30 for an annual subscription. Maakbar's recorded activity shows that most items that get repaired are electrical appliances, clothing, small furniture, bicycles, and toys. It occupies a generic commercial space in a very central area, close to main roads and key train stations, making it easily accessible to the majority of Leuven's population.

Repair cafés build on smaller, bottom-up, local level groups [23] but benefit from top-down awareness-raising activities of the city. In Venlo and Leuven, the municipality continues to advocate for more sustainable circular policies and incentives, linking these directly to the creative economy and enabling local maker networks to grow. Such top-down policies can positively influence citizens' relationship to circularity and sustainable lifestyles and, in turn, their consumption habits and responsiveness to circular marketing strategies. Repair cafés have therefore emerged as a visible new alternative space where citizens can engage in small scale repair activities of everyday items, whilst also building on the popularity of these spaces due to their association with an everyday social space: the café.

In other cities such as Istanbul, Santander, and Thessaloniki, repair cafés are not so prominent. Instead, the Repair typology appears most commonly in the form of small private businesses such as the traditional local shoemakers, tailors, electronics repair services, or even car repair garages. While this sub-typology is also present in other cities (including Venlo and Leuven), there are observable cultural differences in citizens' attitudes towards the role of 'repair'. Repair activities in these contexts are often based in the home, less public, and associated with social activities. When they do leave the home, they are conducted by repair specialists who are affordable and have a long-trusted reputation amongst the locals. In these socio-cultural contexts there is less of an explicit emphasis on top-down circular incentives, or an association of 'repair' with sustainability. However, a repair culture has long existed in these cities, and it is manifest in a diversity of forms that have evolved over many years.

Figure 4. Illustration and mapping showing the Repair typology case studies 'Maakbar' in Leuven (**top row**) and 'Terzi Mustafa' in Istanbul (**bottom row**). Each row illustrates the following conditions for every case study: Spatial character, urban form, and surrounding land use map in relation to case study location (blue: commercial; yellow: residential; green: green space, grey: industrial; red: educational).

In Istanbul, we have looked at one of the many Terzis (tailors) as a Repair typology case study. Terzi Mustafa (see Figure 4) is a clothes repair shop in Istanbul, providing services for sewing, alteration, and repair. Like most tailors in Istanbul, Terzi Mustafa specializes in servicing expensive garments—such as jackets, dresses, and gowns—extending their life and use which attracts people due to its affordability and resourcefulness.

The shop has a very poor online presence but relies on word-of-mouth via the locals in the neighborhood to reach target customers. The shop is a fourteen-minute walk from Bakirköy metro station, close to Osmaniye District in the west of the city. While not closely linked to public transport networks, it is within walking distance of its regular customers. The shop is situated on the ground floor of a residential block with visible signage and a wide glass shopfront that provides a noticeable street presence. This specialism of Terzis is historically and traditionally rooted in the local culture and directly correlates with the inner loop of circular economy activities—product life extension through repair—yet is rarely seriously considered as an official makerspace of circular economic activity.

In Piraeus and Kaunas, a similar model of local private repairers is also prevalent, however, as with some Reuse case studies, these exist as chain stores that are emerging as a sub-type. Takoyni Star shoe repair and locksmith store in Piraeus, for example, is linked to other branches around Greece and Cyprus. The small branch in Piraeus is a family-run business where the master shoemaker is greatly valued by customers. The space it occupies is a small shop with the open plan loosely divided into the 'maker' zone and the customer zone. Similarly, we see this sub-typology in the form of electronics repair shops in the commercial center and residential high-street. For example, Linos Artele in Kaunas is part of a chain of 22 shops In Lithuania often located within large supermarkets.

3.2.3. Craft Maker Space Typology

The Craft typology is distinguished from Repair and Reuse by its activity associated with making new products. From the samples we have studied, we found the following common characteristics of all Craft spaces:

1. Craft spaces vary in size but typically require more space than Repair and Reuse, depending on the type of materials and items being produced.
2. The Craft typology tends to flourish in commercial or industrial zones, depending on their type of production.
3. These spaces typically attract craft specialists or require advanced training.
4. There is a link between historic fabric and the presence of craft spaces, associated with historically rooted local traditional craftsmanship.

From the seven case studies we have analyzed further, the Craft typology inhabits two main distinguishable spaces, a large workshop/studio or a shop/café space, depending on the objects and items being produced. The shop/café sub-typology responds to the type of craft spaces that are less specialized, handle smaller objects, involve less material processing, and target the general public to engage in their activity. Plastikourgeio in Athens (see Figure 5) presents a Craft maker space example that aims to engage and train the general public in the use of waste plastics to make new products. This example occupies a prominent shop in a commercial/residential area. The shop's promotion of sustainability and circular awareness is aided by its easily accessible location and significant presence on the street, increasing its exposure and capacity for accommodating larger groups or attracting passers-by.

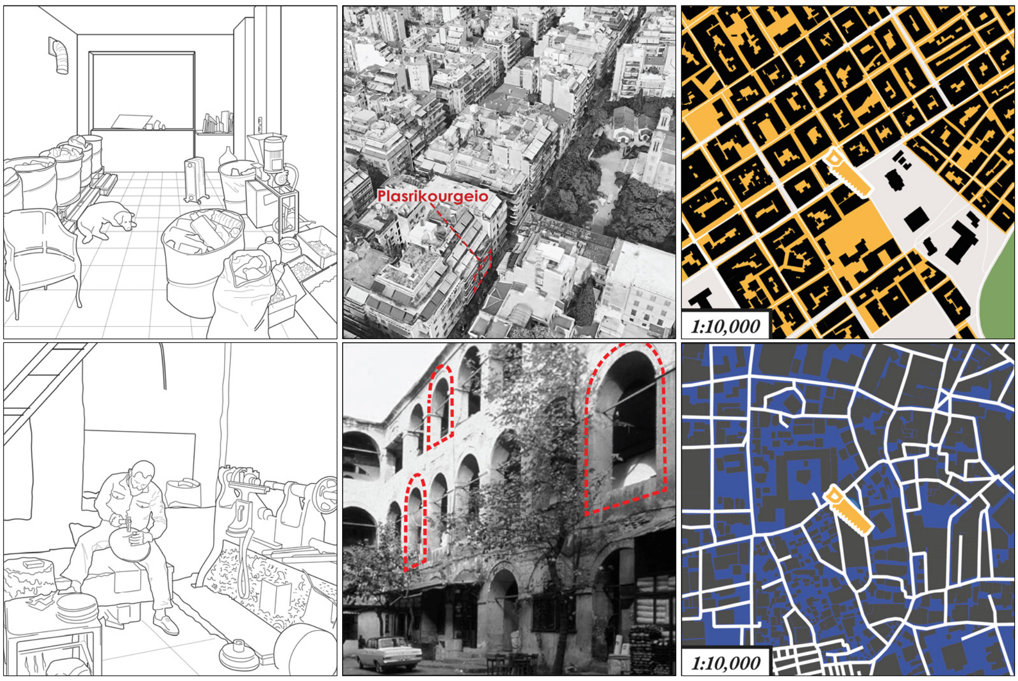

Figure 5. Illustration and mapping showing the Craft typology case studies 'Plastikourgeio' in Athens (**top row**) and 'Buyuk Yeni Han' in Istanbul (**bottom row**). Each row illustrates the following conditions for every case study starting from left to right: Spatial character, urban form, and surrounding land use map in relation to case study location (blue: commercial; yellow: residential; green: green space, grey: industrial; red: educational).

Koumpi Coffee & Crafts in Thessaloniki is another example of the Craft shop sub-typology. This is a hybrid social space of a coffee shop and a crafts space for making textiles, jewelry, and toys. It offers workshops and skills knowledge sessions. The interior space is divided into two connected rooms, one with a bar and coffee-making equipment where customers can enjoy the café as well as buy items made in the workshop, and the other with a large table and craft supplies. Both rooms are permeated by café customers and have large shop front windows that give good exposure to the main street. Like Plastikourgeio, Koumpi Coffee & Crafts is located in a residential area that is very close to the commercial center of Thessaloniki old town. This ensures proximity to passers-by and regular customers in the local area.

The other craft sub-typology observed relies on larger, more heavily equipped workshops/studios for more specialized production such as carpentry, metalwork, pottery, and watchmaking. These typically require more space and are dedicated to production activities that attract specialists or students with specific skills and are usually based in more industrial zones of the city. We have identified prominent examples of these in several cities including Leuven, Istanbul, Kaunas, and Venlo. Venlo's Houtvast furniture maker demonstrates the specialist requirements of such spaces. This woodworking company custom-makes furniture and is locally renowned for their skill in using reclaimed wood. Woodworking equipment such as handsaws, bandsaws, planers, drills, and dust extractors are essential for the running of such a workshop. Due to these specific requirements, Houtvast occupies a large warehouse production space in the Veegtes industrial area. Products are either designed in-house, made to order, or customized to client specifications. This maker space is less visible to the general public and more accessible to large vehicles for loading and delivery.

Some cities present a more thriving specialist craft culture than others, often due to historical trading patterns or crafts heritage. Istanbul is a prominent example of this. Our studies of the workshop craft spaces in Istanbul revealed that workshops and traditional making skills are often hosted in the important historical Hans buildings, which have become home to many artists and skilled craftsmen. Most Hans in Istanbul have been appropriated as a form of collaborative 'workshop factory', each with a specific craft specialization, such as jewelry, metalwork, textiles, and silversmithing. The Buyuk Yeni Han case study (see Figure 5) demonstrates the collaborative environment of local craftsmen who make unique silver statues, trays, candle sticks, and vases, which are sold on the ground-floor shop.

The Hans are typified by a series of cellular, small, and adaptable spaces, usually connected by outdoor corridors. These spaces do not open directly onto main streets but can still be visible to passers-by if they are walking through the courtyard of the Han. Every craftsperson has their own personal workspace, organized according to their preferences and workflow. The collaboration of craftsmen in Buyuk Yeni Han utilizes the spatial organization of this building to perform a complete process of silver working from grain to object.

Silver grain is melted, thinned into sheets, cut, and baked in the workshop of Dursun Sahin. Rectangular or circular silver sheets are passed to Eftal Akardere's workshop for metal spinning, then to Mustafa Karabey for beating, and then Halis Vavci for embossing. Finally, the completed products go into the Sinan Gur polishing workshop before they are displayed for purchase. The cluster of silver working craftsmen in Buyuk Yeni Han is one of the few remaining traditional examples of this Craft typology in the historic center of the city.

3.2.4. Fabricate Maker Space Typology

The Fabricate typology, or fab lab (fabrication laboratory), is primarily considered as part of the production rather than maintenance cycle of reuse and repair. Here, new products can be made in close proximity to the user/maker, using high-tech digital tools and machinery, and drawing on locally sourced, inexpensive waste feedstocks of inert and biomaterials [24]. From our analyses of Fabricate examples across the seven cities, we have found that the main characteristics include the following:

1. They are closely linked to educational/university facilities in most cities.
2. They are identified as and referred to as fab labs, where prototyping and experimental making activities take place.
3. They require specialist skills, machines, and tools for small-scale digital manufacturing such as 3D printers, laser cutters, and precision mills in combination with 3D modelling software and computer aided design (CAD).

Most of the Fabricate case studies across the seven cities were connected to the FabLab Network online. This is a network of 1500 fab labs, located in more than 90 countries, supporting creative communities of fabricators, artists, scientists, engineers, educators, and students 'inventing the next generation of manufacturing and personal fabrication' [25]. Digital fabrication is considered by some to be the cornerstone of the emerging fourth industrial revolution [26]. It represents local circular economies and provides an opportunity to bridge the sustainability gap to larger and more centralized manufacturing industries [24].

A typical example is FabLab Istanbul (see Figure 6), which operates from the Cibali Campus of the Kadir Has University and is open to the public. This fab lab focuses on educational facilitation, organizing workshops, digital skills sharing, and events networked with other local stakeholders such as Living Lab Basaksehir, Salt Galata Museum, Istanbul Maker Lab (Maker Atolye), and ImeceLAB. Although the educational setting promotes use by students, the FabLab is open to anyone who would like to use it, subject to a reservation or booking. In other cities, a fab lab's strong dependence and link to university education creates an even more specialized setting for students to use. In Kaunas, the fab lab operates in the Kaunas University of Technology campus and is heavily supported by electronics manufacturing company Kitron. This has influenced the fab lab's focus on electronics manufacturing themes including Avionics and Nanosatellites.

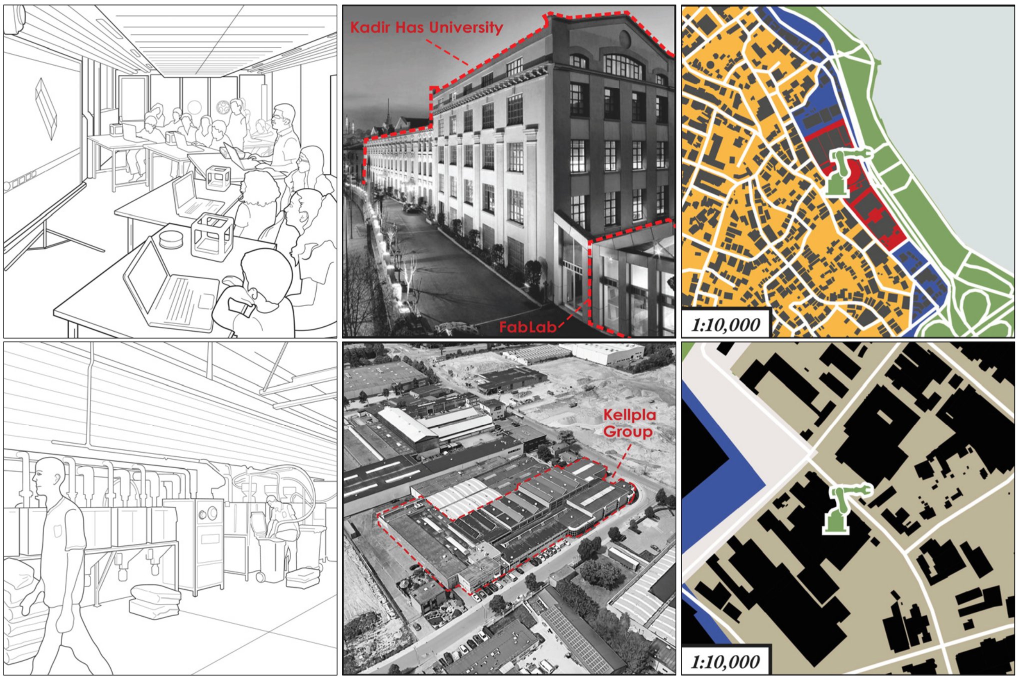

Figure 6. Illustration and mapping showing the Fabricate typology case studies 'Istanbul Fab Lab' (**top row**) and 'Kellpla Group' in Venlo (**bottom row**). Each row illustrates the following conditions for every case study starting from left to right: Spatial character, urban form, and surrounding land use map in relation to case study location (blue: commercial; yellow: residential; green: green space, grey: industrial; red: educational).

Almost all the Fabricate case studies we have analyzed were fab labs with an experimental, educational, and small-scale manufacturing agenda. The only exception was Venlo's Kellpla Group (see Figure 6), which is an active manufacturer of plastic injection molding, offering highly flexible and customizable production due to their use of digitized manufacturing robotics that can easily be programmed to adjust to the client's diverse needs. Kellpla collaborates with schools to organize tours, presentations, and workshops with school children to expose young generations to digital manufacturing. It occupies a large warehouse space and operates in the form of a digital factory in the industrial zone in Venlo.

3.2.5. Distribute Maker Space Typology

The Distribute typology is different to the other four typologies in that it focuses on the spaces and programs that facilitate material recycling (collection, sorting, storage, and distribution). It strengthens the circular capacity of the other four typologies where materials are processed. The Distribute case studies we have analyzed typically include waste-sorting sites and recycling centers. There is usually a main large site with networks of smaller waste collection sites around the city. Our results have identified the key traits that characterize the Distribute typology as follows:

1. Distribute activities are multi-nodal and operate within a larger network of spaces, vehicles, and roads.
2. The main material sorting and redistribution sites are found in industrial zones, relying on large vehicle access rather than public access.
3. Distribute activities are managed at an urban and regional scale, usually under a waste management entity.

Even though this typology does not present a significant manufacturing or making capacity, it is essential in connecting the other typologies to material resources that would otherwise go to waste. The other typologies become circular if their materials (input and output) are sourced and distributed as part of a larger circular material flow system. Therefore, we have identified the programs and spaces with a distribution capacity as a specific typology, acting as material collector and supplier.

The Distribute typology is exemplified by recycling centers or parks, where waste is collected, sorted, graded, prepared, and sometimes processed or compressed before being redistributed. These sites can host larger scale items such as vehicles, scrap metal, furniture, tires, household appliances, and construction waste. The various Distribute programs are often split into different facilities run by the same company or municipal waste management network. For example, the Kaunas RATC (see Figure 7) is a waste management initiative funded by the EU and the UAB Kauno Svara private waste company. It aims to reduce the amount of landfill by redistributing salvageable waste.

There are various sites associated with RATC that handle different stages of the redistribution process. Our study focused on the Julijanavos Street collection site as it exhibited strong capacity for waste collection and acted as a channel to relevant material sorting sites. Julijanavos Street has no capacity for sorting or processing of materials but is devoted to collection and redistribution. It only accepts waste brought in by the general population and by its own municipal waste collection network and generally does not accept industrial or business waste on its site. Customers are obligated to correctly sort the waste into designated containers under the supervision of Kaunas RATC employees. The collected waste is then taken to other sorting plants from which it is recycled or placed in the 'Exchange and Resurrection Scheme' where salvageable items are made available to people for free.

Other case studies exhibit specific material specialization such as Çavuşlar Hurdacılık scrap metal distributor in Istanbul (see Figure 7). This is a semi-formal Distribute model that operates from a junkyard on the lower ground floor of a vacant building. Unlike other Distribute case studies, Çavuşlar Hurdacılık is based in a commercial rather than industrial area and is able to make good use of local waste streams. This site collects scrap metal from the local area, sorting it and redistributing it for new uses.

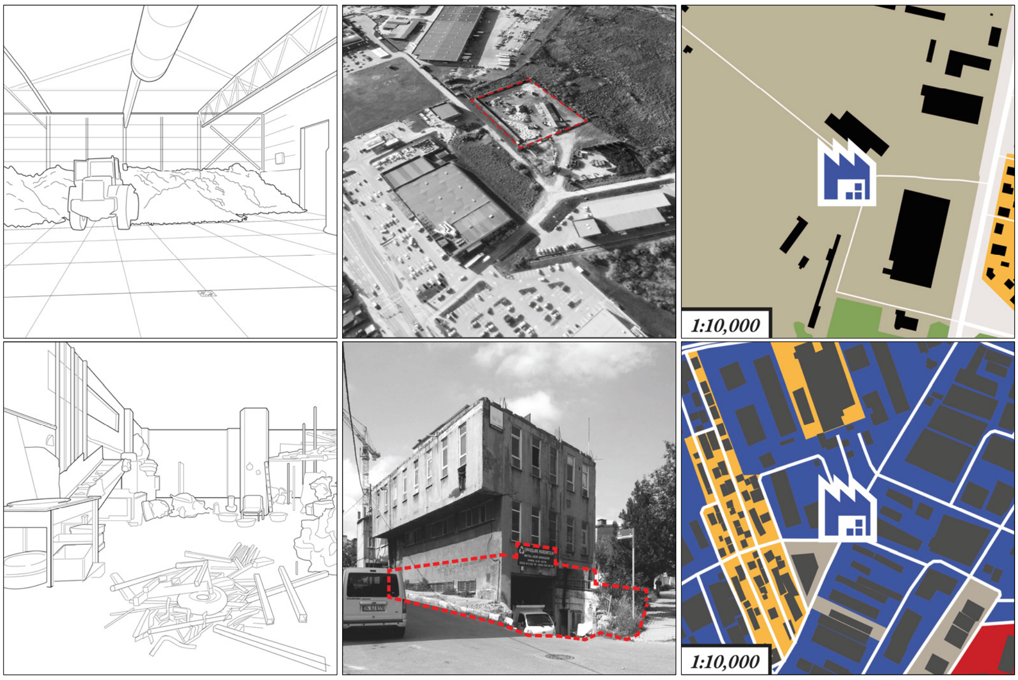

Figure 7. Illustration and mapping showing the Distribute typology case studies 'Kaunas RATC' (**top row**) and 'Çavuşlar Hurdacılık' in Istanbul (**bottom row**). Each row illustrates the following conditions for every case study starting from left to right: Spatial character, urban form, and surrounding land use map in relation to case study location (blue: commercial; yellow: residential; green: green space, grey: industrial; red: educational).

4. Discussion

4.1. Diversity and Commonality

The definition of the five maker space typologies enables the identification of the spatial and urban contexts of circular programs and the relationship to the inner loops of CE. This insight can inform an understanding of how such diverse everyday spaces are part of a circular urban metabolism. This study examined the urban conditions that facilitate circular activity and identified spaces as circular exemplars, often hidden in plain sight. Revealing and describing such everyday maker spaces, their context, and their activities is a key step in informing circular strategies in the city, providing context-specific exemplars for more diverse and effective circular city development.

The findings have revealed some common urban characteristics between Craft, Reuse, and Repair spaces in particular—those associated most closely with the inner loop of circular making. These spaces cluster in the city and rely on similar land use characteristics—mostly a mix of commercial and residential areas with high footfall and pedestrian access (see Figure 8). This recurrent pattern across different cities suggests that the social and spatial conditions required for these activities to thrive depend on similar location, facilities, and types of spaces.

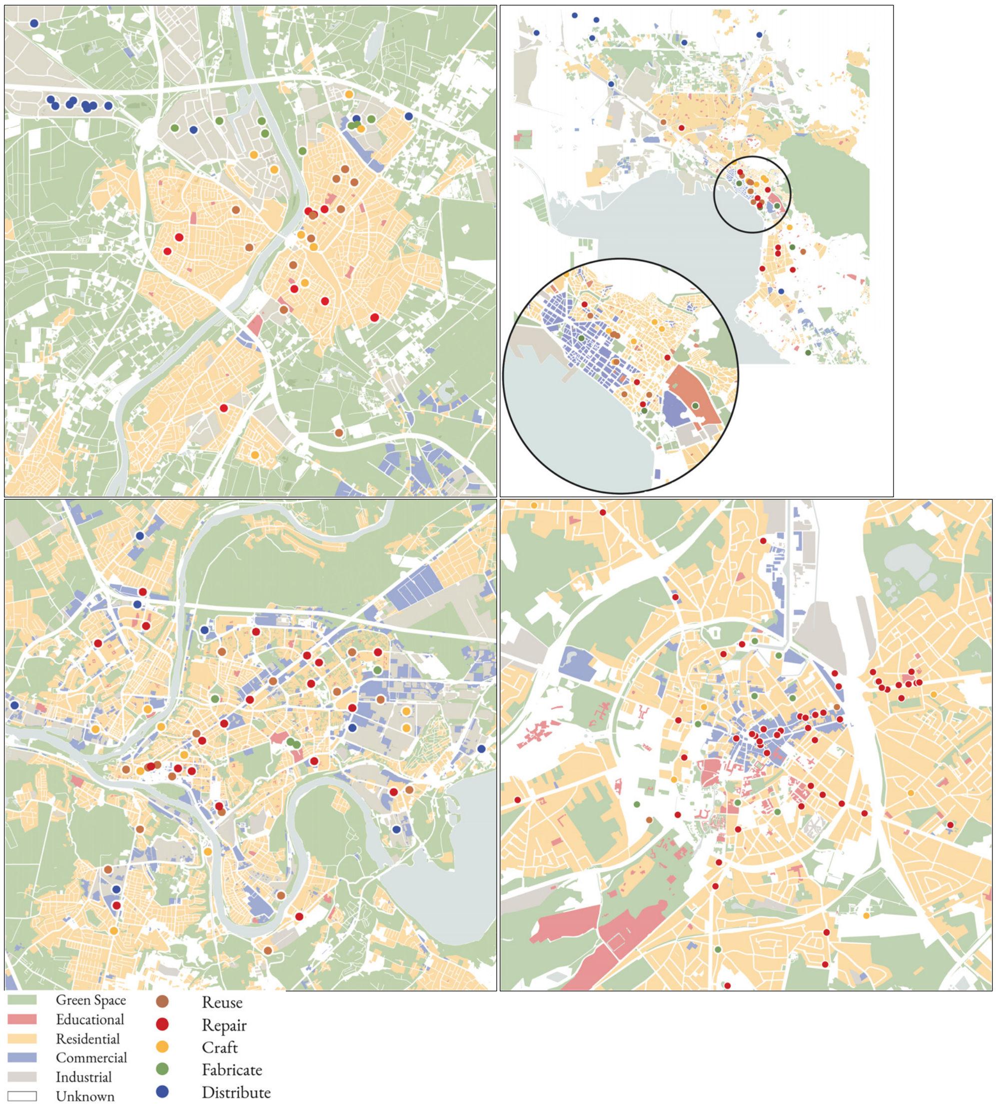

Figure 8. Maps showing clusters of Reuse, Repair and Craft typologies across four cities: Venlo, Thessaloniki, Kaunas, Leuven (from **top left** to **bottom right**). Maps include surrounding land use information (blue: commercial; yellow: residential; green: green space, grey: industrial; red: educational).

4.2. Hybridity

In Thessaloniki, the Repair and Craft case studies have similarities, and in some cases, they combine the two activities to for a hybrid typology. For example, the neighborhood seamstress identified as a Repair typology is a small business run by Georgia in the east of Thessaloniki. Her business focuses on garment repair and alterations, but also custom-made original clothing made from scratch. Koumpi Coffee & Crafts on the other hand has been identified as a Craft typology, which operates as a regular coffee shop while using a part of the space where customers and makers frequently mix. These two examples are very similar in terms of their circular functions. The seamstress may indeed craft new products within the scope of her facilities, whilst the Koumpi Coffee & Crafts facilities can be used to repair items. Both operate within a typical retail or shop space.

In other cities the division between Repair and Craft is clearer, often dictated by the scale of the materials being processed, repaired, or crafted. For example, Istanbul's craft case study, Buyuk Yeni Han workshop, is a highly specialized type of making. The Craft typology here becomes more distinguishable, though it still holds potential for repair activities.

It is thus helpful to consider potential overlaps between typologies and circular functions according to the type of space that they occupy. Reuse and Repair share the 'maintain and prolong' phase of CE. Out of the cases studied, we found that 79% occupy conventional retail space (shops, cafés, stores) while 21% occupy open markets. Craft and Fabricate examples share the 'make and remanufacture' function of CE and 43% occupy digital lab spaces, 29% manual workshop space, 21% conventional retail space, and 7% industrial sites. Distribute types can potentially circulate materials across all the typologies, and in our sample we found that 86% of them occupy large scale industrial or waste management sites, while 14% occupy urban garages.

From these insights, it becomes clear that for the 'maintain and prolong' phase, conventional retail spaces play an important role in hosting Reuse and Repair activities. Meanwhile, for the community-based making and remanufacture phase of CE, a combination of digital labs, manual workshops, and conventional retail space is crucial. For the materials distribution, collection, and storage, larger-scale industrial and waste management sites play a significant role in connecting channels of material flows to other typologies.

This study also detected relational and networking capacities that enable circular makers to thrive. Such symbiotic relationships reveal that these typologies do not exist in isolation; they flourish within a network of various partners and diverse programs. An example of such partnerships forming amongst the typologies can be seen in Leuven: the Ecowerf case study, which was identified as a Distribute typology, works closely with the Maakbar Repair typology. In this productive partnership, Ecowerf acts as a form of materials bank for Maakbar where products are repaired, requiring constant streams of e-waste, fabrics, etc. Maakbar acts both as an outlet for repaired goods but also as a resource base for waste materials which then flow back to Ecowerf where it is sorted and recirculated or recycled.

4.3. Design Implications

The above insights related to typologies, context, and symbiosis have circular planning implications. There is a potential opportunity to leverage the knowledge gained of maker spaces to bridge the 'sustainability gap' between local- and regional-scale manufacturing [24] (p. 27). A 'design-research' mode of enquiry was employed to identify unique and practical lessons building on the results and findings [27]. A series of design studies were carried out that combine circular maker space programs for locations in each of the seven cities. It provided an opportunity to examine and visualize hybrid formations of the five typologies within the context of each city.

Different hybrid maker spaces were proposed responding to specific city needs and assets. For example, in Kaunas, the proposal examined a design strategy that bridged the gap between the high-tech industry developing through KTU and the prevalent low-tech Repair and Reuse industries in the city (see Figure 9). A hybrid model of the Craft and Fabricate typologies places technology in proximity to traditional craft making, encouraging cross-pollination, and initiating the development of a making network across the city. This hybrid incorporated satellite sites in vacant buildings that could act as Distribute typologies by creating new channels of material flows around the city.

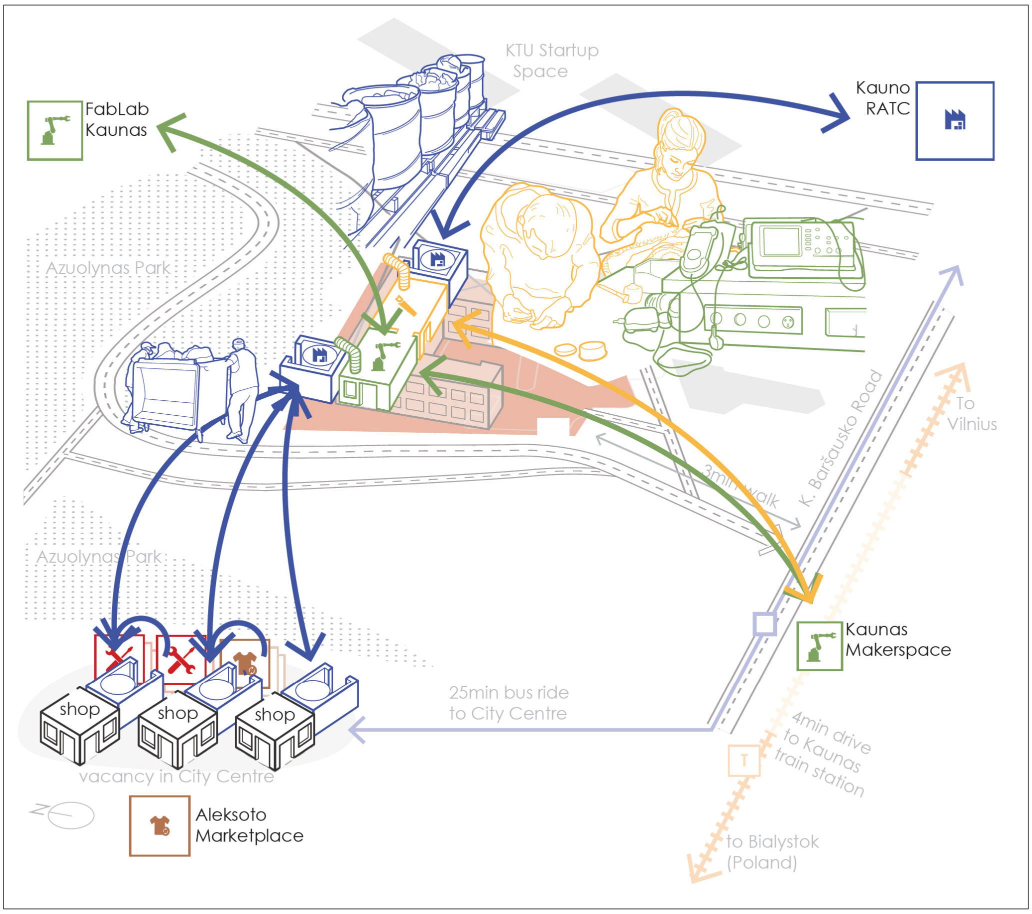

Figure 9. Axonometric sketch proposal (in black/coloured) overlaid on diagram of context (in grey) of Kaunas city incorporating typology hybridity principle.

In Istanbul, the hybrid proposal was designed to demonstrate a strategy for sharing spaces as well as resources to enhance each typology's operations (see Figure 10). The thriving Reuse typology was adopted as a link to the local Beyogli Reuse area. A Fabricate center was envisaged as a means to manage the waste-to-material technology in collaboration with other Fabricate typologies in the city. Meanwhile the site was structured as a base for craftsmen to share tools, space, skills, and resources with aspiring repair specialists in domains such as carpentry, electronics, shoes, and bicycle repairs.

Such proposals have prompted wider application and exploitation of relational possibilities of the five typologies and how they can interact in various combinations, depending on their spatial and urban context. The identification of such relationships reveals ways to increase the critical mass and diversity of makers spaces in the city and strengthening circular city planning strategies. The hybridity and relationality of maker spaces provide a model vision for redistributed manufacturing (RDM) and 'Industry 4.0′ [28].

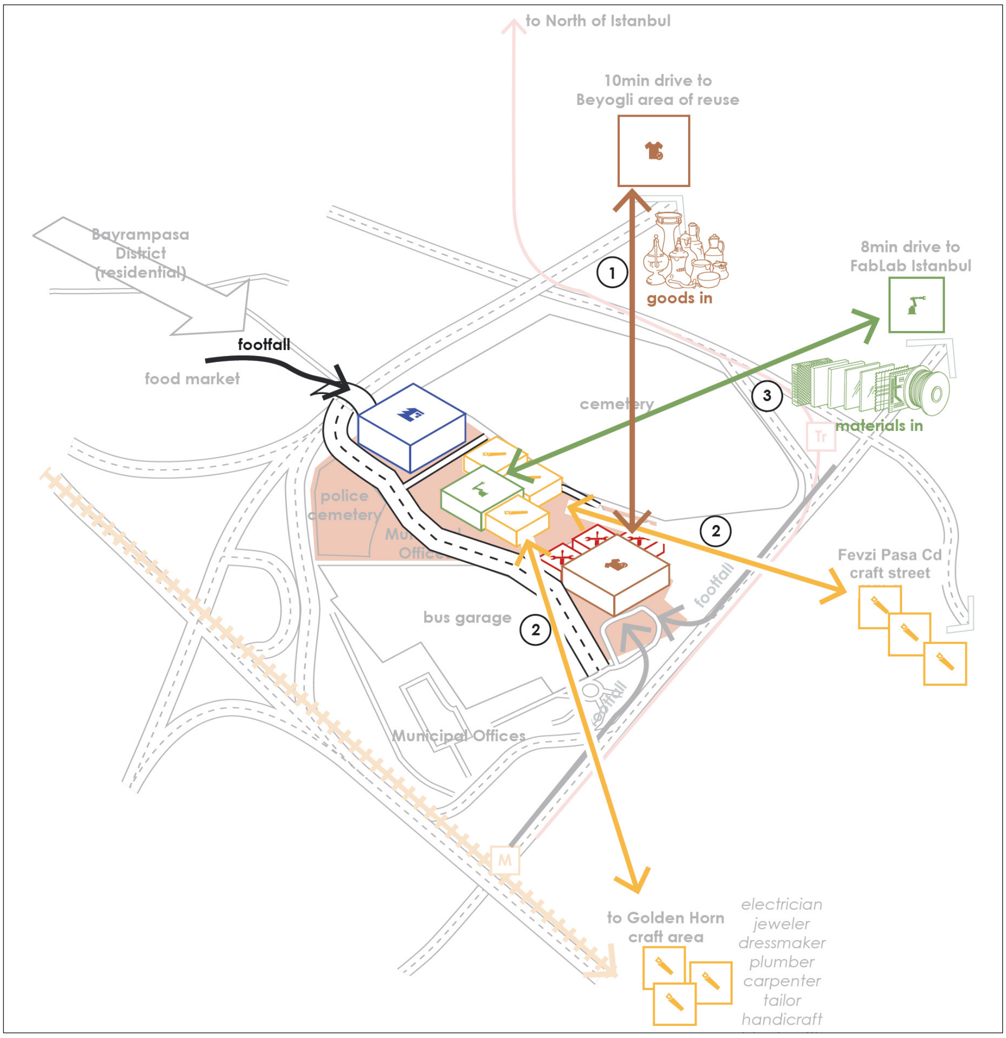

Figure 10. Axonometric sketch proposal (in black/coloured) overlaid on diagram of context (in grey) of Istanbul city incorporating typology hybridity principle. The numbers 1, 2 and 3 represent a phased timelines with arrows indicating key connections: (1) building on the nearby reuse area (Beyogli), (2) linking to the craft areas in the city and (3) incorporating a FabLab satellite.

5. Conclusions

The five circular maker typologies and their spatial character, identified and defined in this study, embody the design nature of an urban circular metabolism in their physical and social contexts.

This study examined existing urban programs centered on makers in relation to the inner loops in CE theory. The case study examples reveal the design characteristics of the circular economy in everyday urban life. Working at an urban, building, and human scale has identified urban mechanisms that can make circular production cycles tangible, accessible, and familiar to potential users.

Spatial and contextual urban factors define the location and characteristics of the five typologies. Neighborhood characteristics, size, and access to transport all contribute to the traditional persistence of these local spaces. The studies suggest that maker spaces hold the capacity to thrive, based on the long history of reuse, repair, and craft maker spaces evident in all the cities. The conjecture is that these maker space typologies have the potential to work symbiotically and as part of a larger circular urban production ecosystem. These connections are tested further in the 'Pop-Machina' project at the level of new and individual maker spaces in order to improve their circular performance. The ways in which maker spaces hybridize—by combining different typologies—increases the range and possibilities of circularity and builds on the social and physical networks that sustain makers.

An understanding of makers and the spaces they occupy, beyond a predominant focus on fab labs, has enabled a more complete recognition of sustainable and circular urban production. A wider definition of this type of urban activity makes these everyday maker spaces available for integration into an understanding of urban metabolism and acknowledges their social and material value. For instance, the 'repair café' sub-typology exists in different forms and has a differing status depending on its context. Two out of seven cities we have studied revealed a prominent repair café culture, but it is clear that Repair spaces are evident in the other cities. Furthermore, such communities of skilled repair expertise are understood as distinct from the digital fabrication and material reuse experts that are based in fab labs.

Our typological study of circular maker spaces has revealed a diversity of examples evident across all seven cities and their potential for productive interdependence. This spatial and typological diversity of circular maker capacity is especially important to consider as we shift towards adopting circular city models and policies. The tendency to emphasize one particular form of making can be limiting if not attuned to local socio-spatial dynamics and opportunities. It prompts an engagement with the existing local circular maker dynamics that can help shape the path towards a circular urban metabolism more suited to a city's culture and place.

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