

Make it a circular city: experiences and challenges from European cities striving for sustainability through promoting circular making

Aykut Coşkun ^a, Julie Metta ^b, Yekta Bakırlıoğlu ^c, Damla Çay ^a, Kris Bachus ^b

^a Koç University-Arçelik Research Center for Creative Industries, Rumelifeneri Yolu, Sarıyer, İstanbul, 34450, Turkey

^b Research Group Sustainable Development, HIVA, KU Leuven, Parkstraat 47 bus 5300, 3000, Leuven, Belgium

^c Middle East Technical University, Department of Industrial Design, Üniversiteler Mah. Dumlupınar Blv. No.1, Çankaya, Ankara, 06800, Turkey

Abstract

A growing number of cities are deploying circular economy practices to contribute to the Sustainable Development Goals (SDGs). Makerspaces are community-driven initiatives enabling collaboration between a city's diverse stakeholders in that objective. These initiatives can enhance citizens' contribution to circularity by engaging them in circular 'making' activities (e.g., reuse, repair, sharing) and by providing them with novel means, skills, and knowledge in these activities. However, cities face various challenges during the process of engaging citizens to create a vibrant circular city. Based on an in-depth analysis of experiences and challenges in seven European cities, which attempted to embrace the SDGs through circular making activities, this paper presents ten engagement-related challenges and five strategies to overcome them. Integrating these challenges and strategies in a strategy-challenge matrix, the paper offers several recommendations for cities striving to address SDGs through establishing and maintaining circular makerspaces.

Keywords:

maker movement, circular economy, citizen engagement, vibrant ecosystem, stakeholder strategies, circular makerspace, sustainable development goals

Highlights:

- The maker movement is pivotal to implement a circular economy transition in cities
- Cities face engagement challenges to create vibrant circular maker ecosystems
- Five strategies to address these challenges and the SDGs were identified
- Inspirational cases holistically embracing the challenges and the SDGs are listed
- A matrix is proposed to guide cities in addressing engagement challenges

1. Introduction

The transition to the circular economy (CE) is essential to tackle environmental issues. Cities will need to play a pivotal role in this transition, as they host the majority of the human population and are responsible for the majority of the world's energy consumption (60-80%) and carbon emissions (75%) (Chen & Chen, 2012; Environment, 2017). The maker movement and maker communities can provide tools for creating sustainable cities (Doyle, 2019; Gershenfeld, 2012; Muñoz-La Rivera et al., 2020; Soomro et al., 2021). This movement entails citizens interested in making activities and willing to engage with products beyond consumption (Anderson, 2012; Doussard et al., 2018). The citizens engaged in the maker movement meet in spaces like repair-cafés, fab labs, or makerspaces (Taylor et al., 2016), which is used as an umbrella term for all these spaces in this paper.

Maker movement can make significant contributions to the Sustainable Development Goals (SDGs). Makers can increase citizens' environmental awareness by promoting circular making activities (reusing, repairing, refurbishing, recycling etc.) (SDG11)¹, and reduce the environmental impact associated with the transportation of goods by enabling on-demand and localised production (Doyle, 2019; Peeters et al., 2019) (SDG12), especially through the introduction of circular makerspaces, which are equipped to enable makers to undertake share, repair, refurbishing, remanufacturing and recycling activities. Maker movement can also reduce inequalities and exclusion in society (Casillas-Martín et al., 2020) (SDG10) and initiate more democratic and bottom-up changes towards sustainability by providing the citizens with the means, skills, and knowledge required for circular making activities (Galuppo et al., 2019) (SDG8).

In a vibrant maker ecosystem focusing on CE, makers from cities collaborate with each other and with other stakeholders (e.g., non-profit organisations, local governments, and small businesses) and engage citizens in circular making activities (Millard et al., 2018). This in turn facilitates communities in creating sustainable impacts at the city scale (Chen & Chen, 2012; Grafakos et al., 2019; Raiden & King, 2021). However, building such an ecosystem is challenging due to reasons like the lack of a space providing resources and infrastructures to makers (Bouwma-Gearhart et al., 2021), the lack of financial support, the difficulty in scaling-up individual projects and products (Doussard et al., 2018), and the lack of knowledge on CE (Bakırlıoğlu et al., 2021; Negash et al., 2021). The overarching challenge that binds all these is the ability to engage individuals with different backgrounds, skills, and perspectives in circular making activities and to sustain this engagement in the long run (Galuppo et al., 2019). Thus, it is critical to identify engagement-related challenges for creating vibrant circular maker ecosystems, understand their causes and devise solutions to address them.

This paper aims to fulfil this need by presenting the experiences and insights from the H2020 European project Pop-Machina, aimed at facilitating Europe's transition to CE by incorporating CE thinking into making activities. It examines diverse narratives of engagement by focusing on the differences and similarities between seven pilot cities (Istanbul, Kaunas, Leuven, Piraeus, Santander, Thessaloniki, and Venlo). These narratives were systematically identified

¹ This paper connects eight SDGs: (1) No Poverty; (4) Quality Education; (8) Decent Work and Economic Growth; (9) Industry, Innovation and Infrastructure; (10) Reduced Inequality; (11) Sustainable Cities and Communities; (12) Responsible Consumption and Production; (13) Climate Action.

through workshops and interviews with city representatives and makers to monitor pilot activities and gather challenges, and through case analysis and close reporting of circular making activities from pilots to identify practices. The paper contributes to the literature by i) showcasing 12 practices of collaborative circular production, ii) scrutinising engagement-related challenges (four intangible challenges in engaging communities and six tangible challenges in engaging through space), iii) presenting five main strategies for overcoming them, and iv) proposing a strategy-challenge matrix for helping other initiatives in addressing these challenges. Along with these academic contributions, the paper reveals several recommendations for cities working on achieving the SDGs.

2. Related work

2.1. The circular economy and the circular maker movement

The past decade has witnessed CE's widespread adoption ever since the Ellen MacArthur Foundation's proposal of the term, building on the life-cycle assessment-based approaches to product development and holistic approaches to social environmental sustainability. CE is an alternative economic model for social environmental sustainability, which tries to better balance the three pillars of sustainable development (environment, society and economy). It calls for a radical shift in supply chain management to achieve zero system leakage through the development of product-service systems closing the material loops to recapture the embedded value of products at the end of their use phases (EMF, 2013). Among many other interrelated approaches to sustainability, CE is regarded as a prerequisite for a sustainable society (Bakker et al., 2019).

Localized production and post-use practices of value recapture (i.e., repair, reuse, refurbishment, remanufacturing, recycling) could facilitate the transition toward sustainable societies (Doyle, 2019). Integrating various scales of production at local, regional and global scales empowers local skills and knowledge, strengthens businesses and encourages citizens to pursue post-use services thanks to the accessibility to such services, all the while sustaining these localities economically (Dogan & Walker, 2008). Coupled with global knowledge exchange, such practices can initiate on-demand production of global designs adapted to local and individual needs, preferences and desires (Ramos, 2017). By narrowing and slowing supply chains, local secondary resources are consumed closer to the production side, eliminating the transport impact of global supply chains, extending the lifetime of products, and contributing to resource efficiency and CE (Geissdoerfer et al., 2018).

The maker movement presents a viable alternative in this regard (Doyle, 2019). The emergence and spread of digital desktop fabrication technologies, along with the formation of a global community of makers, demonstrate the potential of technology accessibility, high-fidelity fabrication possibilities and across-the-globe open knowledge exchange for local, on-demand fabrication of adapted designs responding to local needs. As demonstrated in the "Design Global, Manufacture Local" approach (Kostakis et al., 2015), empowering local stakeholders and supporting local skills, knowledge and resources, has the potential in facilitating cities' transition towards sustainability.

Establishing circular makerspaces (CMS) - makerspaces that promote circular making activities - is crucial for cities striving for sustainability. Depending on the establishment

purposes, makerspaces can have two different governance models: bottom-up commons-based peer production (Benkler & Nissenbaum, 2006; Kostakis & Drechsler, 2015; Söderberg & O’Neil, 2014) and top-down public policy-based governance (Shea & Gu, 2018; Van Holm, 2015; van Holm, 2017). In the former, the makerspace is established and maintained by the people who are given equal rights to govern it, as in the case of Invention Studio (Forest et al., 2014). In the latter, the makerspace is situated and institutionalized in a broader urban governance model at the city scale. Nonetheless, establishing a circular makerspace is only the first step in creating a vibrant circular-making community, and it does not guarantee long-term success. For a CMS to thrive in a city, makers and citizens should be engaged in the long run.

2.2. Engagement-related challenges for creating and maintaining circular makerspaces

Despite being seen as an alternative economic model devised to minimise the environmental impact and improve the environmental benefits of product life-cycles, CE is often criticised for ignoring the social aspects to facilitate the transition towards sustainable societies (Murray et al., 2017). This criticism can be addressed by the promotion of the circular maker movement (CMM) in cities. Makerspaces can support social inclusion by empowering disadvantaged groups in utilising fabrication technologies (Dias & Smith, 2018; Ellis et al., 2021). Besides providing people with essential tools to produce artefacts, they allow different makers to interact with each other to create a community (Einarsson & Hertzum, 2021). For the maker movement, this community-building aspect is regarded as even more important than tools in establishing a makerspace (Kohtala & Bosqué, 2014). Hence, maintaining the community and sustaining the engagement of makers are important elements for realising the idea of a circular city, a city that adopted CE to its core production and consumption systems.

Previously, researchers have identified several challenges for community building and makers’ engagement, and proposed solutions. Analysing the management practices of two circular makerspaces in Italy and Finland, Galuppo et al., (2019) indicate becoming a lively community and a catalyst for individual development is one of the main challenges for managing makerspaces. They report that this challenge stems from two factors: the diversity in stakeholder skills, interests and needs, and the perception of the makerspace as a community or as a place to meet individual goals (Galuppo et al., 2019).

Regarding the first factor, previous research shows that citizens who are unfamiliar with digital prototyping and fabrication tools may be reluctant to visit a makerspace (Meissner et al., 2017; Taylor et al., 2016). This reluctance can be overcome by organising open day events regularly, designing short-term projects with the participation of non-experts, and managing long-term community involvement processes (Dreessen & Schepers, 2018). Regarding the second factor, previous research shows that makers’ engagement with a makerspace can range from individual activities like 3D-printing to collective activities like helping others with 3D-modelling software (Kohtala et al., 2020). To address this challenge, thus supporting community building in makerspaces, Einarsson & Hertzum, (2021) propose a model based on enabling people to engage through personal entry points (e.g., watching making tutorials) which serves as a scaffold for enabling social experiences (e.g., organising workshops).

Although previous work identified some engagement-related challenges for creating and maintaining CMSs and proposed some suggestions, more work is required to realise the potential of CMSs in facilitating cities' adaptation of CE principles and practices. This paper addresses this need based on insights and experiences gained in the Pop-Machina² project, which aims at facilitating Europe's transition to CE by incorporating CE thinking into making activities. Further information on the Pop-Machina project can be found in Appendix A.

3. Methodology

The challenges and strategies were identified via examining practices of CMSs part of the Pop-Machina Horizon 2020 project, which seeks to highlight and reinforce the links between the maker movement and circular economy to promote environmental sustainability and generate socio-economic benefits in European cities. In the remaining of this paper, the CMSs mentioned are all from the Pop-Machina project. Their circular maker ecosystems have diverse characteristics requiring tailored approaches to engagement as illustrated in Figure 1.

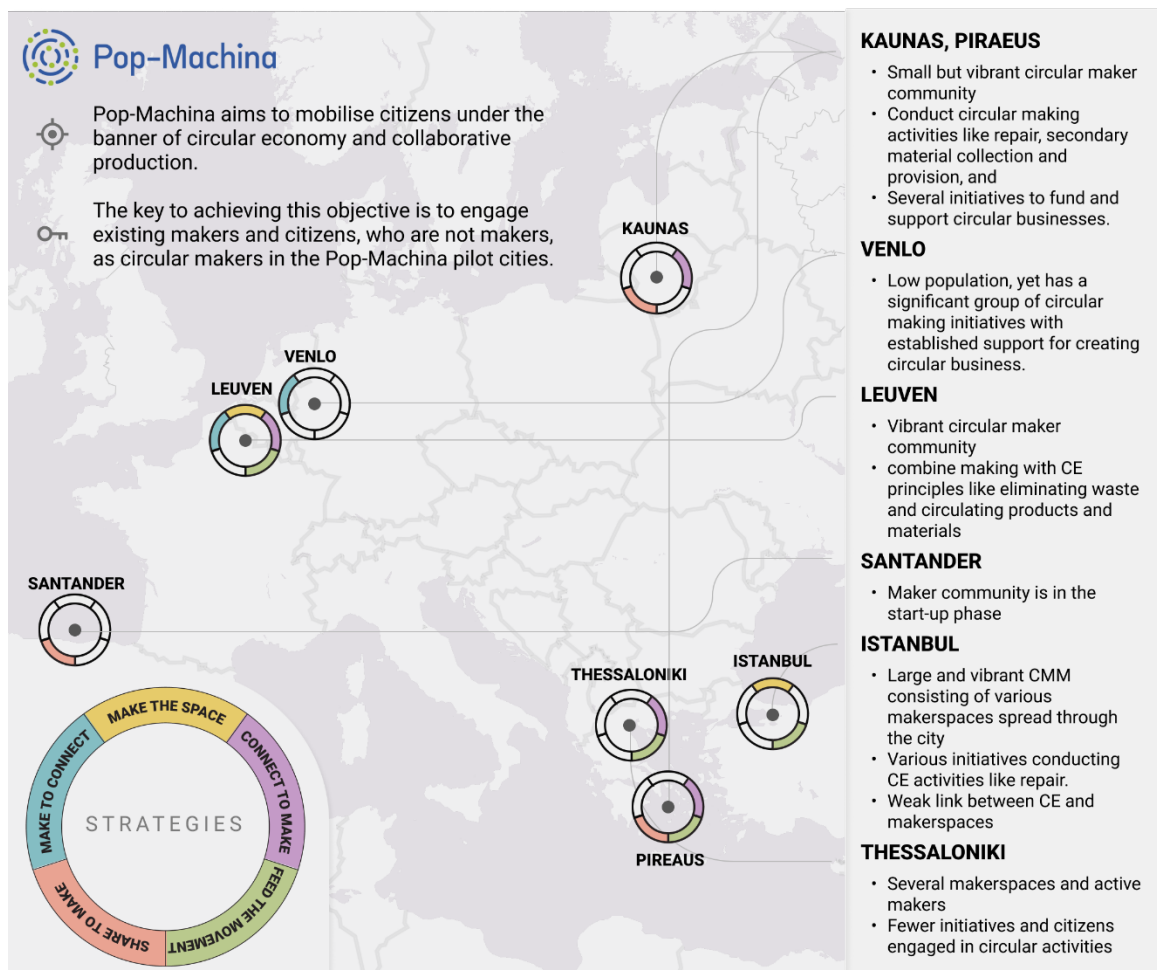


Figure 1 - Pop-Machina project objectives, pilot cities and their maker ecosystem characteristics

² <https://pop-machina.eu>

3.1. Data collection and analysis

The data was collected by the authors over 18 months, through monitoring the studied cities, utilising various techniques and channels as illustrated in Figure 2.

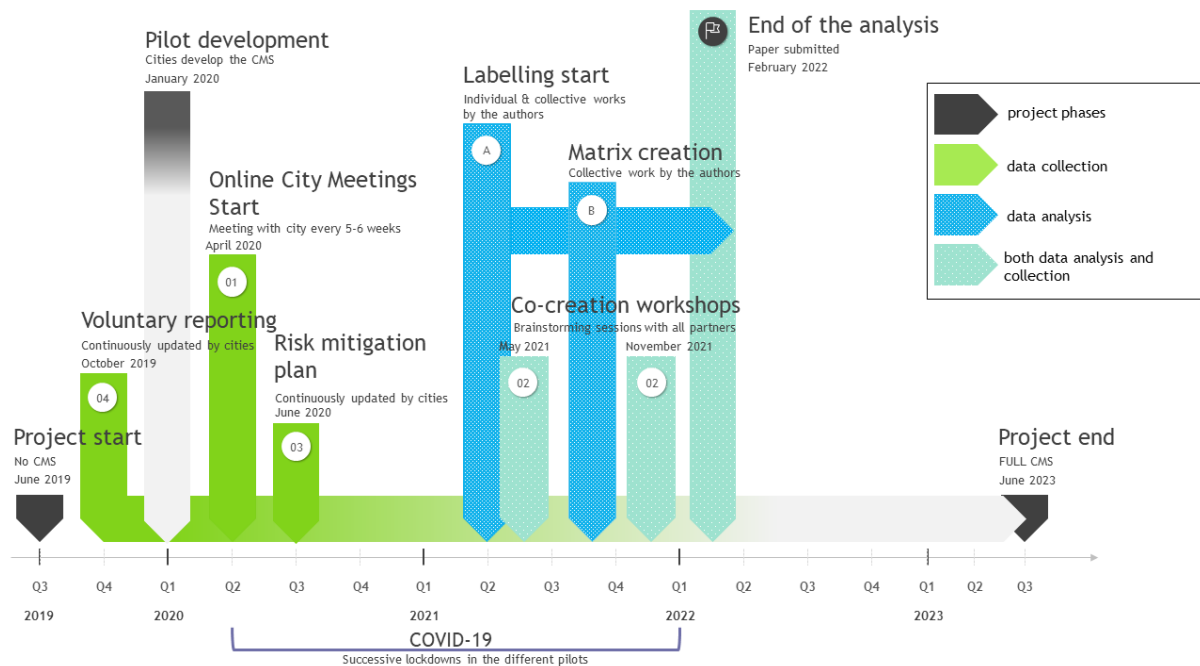


Figure 2 - Detailed timeframe of the project including the data analysis and collection. Most of the actions were developed by the cities in consultation with the researchers to enhance circularity in the cities' maker movement.

The first channel was the online city meetings (01) which were organised every five weeks to assist the cities in the development of their CMS. In these meetings, cities were asked to discuss and elaborate on the current challenges and opportunities regarding their local CMSs. The second channel was two co-creation workshops (02) organised on an online collaborative whiteboard platform with an average of 60 participants (mainly academics and practitioners but also civil servants, which were at least 1 per city). In preparation for these workshops, each city was asked to list at least three challenges they were facing during the development and the activities in their local CMS. During the workshops, Pop-Machina partners, including city representatives, reflected on potential strategies to overcome them. The third channel was the Pop-Machina risk mitigation plan (03) designed to prevent and closely monitor challenges potentially endangering the CMS deployment. The fourth channel was the voluntary reporting of challenges (04) by the cities via emails and phone calls. Further details on these techniques can be found in Appendix B.

For analysis, the minutes from the online city meetings (1), the notes from the online co-creation boards (2), the statements in the risk mitigation plan (3), and the notes from cities' spontaneous reporting (4) (e.g., emails) were compiled. Then, every statement, describing a challenge or a potential strategy to overcome it, was labelled by the authors according to its content (A). The labelling of the challenges and strategies was executed firstly by the different researchers in parallel, illustrated by (A) in Figure 2. Secondly, the labels were compared and discussed among the researchers to delineate the final ten challenges and five strategies. The labels were thirdly presented to the city representatives for validation. Lastly, the labels were cross-checked with related literature described in section 2, guaranteeing the labelling quality.

presented in Figure 4. In this strategy-challenge matrix, the scores given preliminary to each action were averaged (from 0 to 3) to provide scores per strategy.

4. Challenges and strategies for engaging circular makers

4.1. Challenges of engaging communities and spaces

The analysis revealed ten engagement-related challenges represented in Table 1. On the one hand, **intangible community-related challenges** are those pertaining to creating a vibrant CMM, groups of citizens interacting in a genuine, sustainable, autonomous and spontaneous way fostering inclusion and collaboration within cities. The four challenges under this category represent the levels of involvement in the creation of a CMM and the roles they embody in this process. On the other hand, **the tangible space-related challenges** revolve around the spatial aspects of engagement. The space is crucial for engaging citizens at different levels and establishing resilient communities (Bouwma-Gearhart et al., 2021). Thus, the CMS should be well-connected to and integrated with the urban context, enabling various forms of engagement and accommodating varying citizen needs. The first three space-related challenges are about the CMS's relationship to the city (i.e., transportation accessibility, accessibility of resources, and integrative accessibility), and the other three are about its inner aspects (i.e., modularity, disability accessibility, cultural attractiveness).

Table 1 - Engagement related challenges of the studied circular makerspaces
Note: It should be noted that these sets of challenges are neither exhaustive nor strictly separated or static. Rather, the identified roles and responsibilities shift, expand, shrink and coincide according to the context of the local CMM. Furthermore, there is no hierarchical order among these challenges - they are all important elements to create a vibrant CMM and achieve the SDGs.

Intangible community-related challenges	Advocating the endorser of the local CMM	The engagement of experienced makers as endorsers, who have knowledge and expertise in varying foci, to disseminate knowledge, skills and capabilities for local circular economies, to engage aspiring makers to adopt circular making practices.
	Mobilising citizens as circular makers	The engagement of citizens to adopt circular making practices through upskilling, awareness-raising, knowledge transfer, and encouraging and empowering them to deploy projects, organise activities and foster the CMM in the city.
	Engaging underserved communities	The inclusivity of the maker community and the diversity in the engagement of citizens as circular makers.
	Outreaching and raising awareness about the CMM	The wider promotion of the CMM and its potential to establish local circular economies, gain reputation, attract more citizens and grow the movement
Tangible space-related	Providing accessible transportation	The location of the makerspace within the city and how it is accessible through transportation opportunities.
	Enabling accessibility of resources	The makers' proximity to resources (e.g., material sources, services, external knowledge sources) and makers' capability

		to reach these resources (e.g., gaining access, facilitating reachability).
	Promoting integrative accessibility	The ability to bridge people of varying ages, gender, ethnicities, socio-economic backgrounds, levels of education, and disciplines engagingly, facilitated through the location and accessibility of the makerspace.
	Having a modular space layout	The layout arrangement of the space and capacity to be reorganised to accommodate varying needs and preferences of makers for different activities and events.
	Enabling disability accessibility	The design of the space to accommodate citizens with different disabilities and to ensure their access to the space.
	Arousing curiosity through cultural attractiveness	The features of the space that are meaningful and attractive to the citizens and can spark curiosity among them.

4.2. Strategies for creating vibrant circular makerspaces

Twelve practices were deployed in the cities and CMSs to overcome the challenges, which also targeted various SDGs 4, 8, 9, 10, 11, 12 and 13. The practices were categorized under five main strategies addressing different challenges introduced below. Each strategy is illustrated by different pilot cities and CMSs, details of which can be found in Appendix C.

- (1) *Make the space* acknowledges the importance of location, attractiveness and accessibility of a makerspace in engaging citizens in the CMM and thus allows to embody SDGs 1, 4, 8, 9, 10, 11, and 12. The cities of Leuven and İstanbul illustrated this strategy with their strategic choice of CMS location as well as by the integrative design of those spaces.
- (2) *Connect to make* concerns the governance of CMSs and collaborations with external actors for active engagement. By connecting with various actors in a collaborative and mutually nourishing way, the CMM sustainably engages an increasing number of citizens, becoming more resilient and impactful. This strategy is illustrated through the Thessaloniki, Piraeus, and Leuven cases, which by the involvement of and connection with stakeholders in education, business, social economy and waste management, raise not only the accessibility of tools and materials but also the awareness of communities toward CE. The connections allow communities to be truly engaged in and committed to the CMM. This strategy activates SDGs 4, 8, 9, 10, 11, 12, and 13.
- (3) *Feed the movement* addresses the accessibility to resources and specifically secondary materials. A major barrier is the existing waste management practices preventing makers from accessing valuable materials and discarded objects. Thus, re-introducing discarded objects and materials into circular making practices is critical for the CMM. Thessaloniki and Piraeus illustrated this strategy by collaborating with waste management companies in the city, and Leuven and İstanbul as attempts to formalise

such material flows to increase their accessibility and value-added. This strategy tackles SDGs 1, 8, 9, 10,11, 12, and 13.

- (4) *Share to make* aims to overcome barriers against setting up a standalone space where the community can come together, collaborate and flourish, and turn them into an advantage. The cities deployed their CMS in various areas already utilised by other stakeholders not yet involved in the CMM. By sharing facilities and tools, not only the environmental and economic costs are shared but the number of citizens reached by the CMS activities is also expended. This strategy covers SDGs 4, 9, 10, 11, and 12, as illustrated in cases from Santander, Piraeus, and Kaunas (See Appendix C).
- (5) *Make to connect* focuses on outreach and engaging underserved communities and aims to raise the awareness of people who have limited knowledge about the maker movement. Engaging them through making, showcasing their potential, and touching their everyday lives through dedicated activities and programs are the main drivers of this strategy. It addresses SDGs 1, 8, 10, and 12, as illustrated in cases from Venlo and Leuven.

5. Discussion

5.1. The strategy-challenge matrix for facilitating vibrant circular maker movements

This paper aims to identify challenges related to creating a vibrant CMM and strategies to address these challenges while activating SDGs, based on an analysis of circular making practices from the studied cities and CMSs. This analysis revealed ten challenges and five strategies integrated into a strategy matrix illustrated in Figure 4, which shows how strategies were used to address challenges, and to what extent the strategy had an impact on a specific challenge to activate and tackle the SDGs, within the scope of the studied cities. The strategies were coded by the authors based on how well they addressed the challenges for the makerspaces in the studied cities and CMSs.

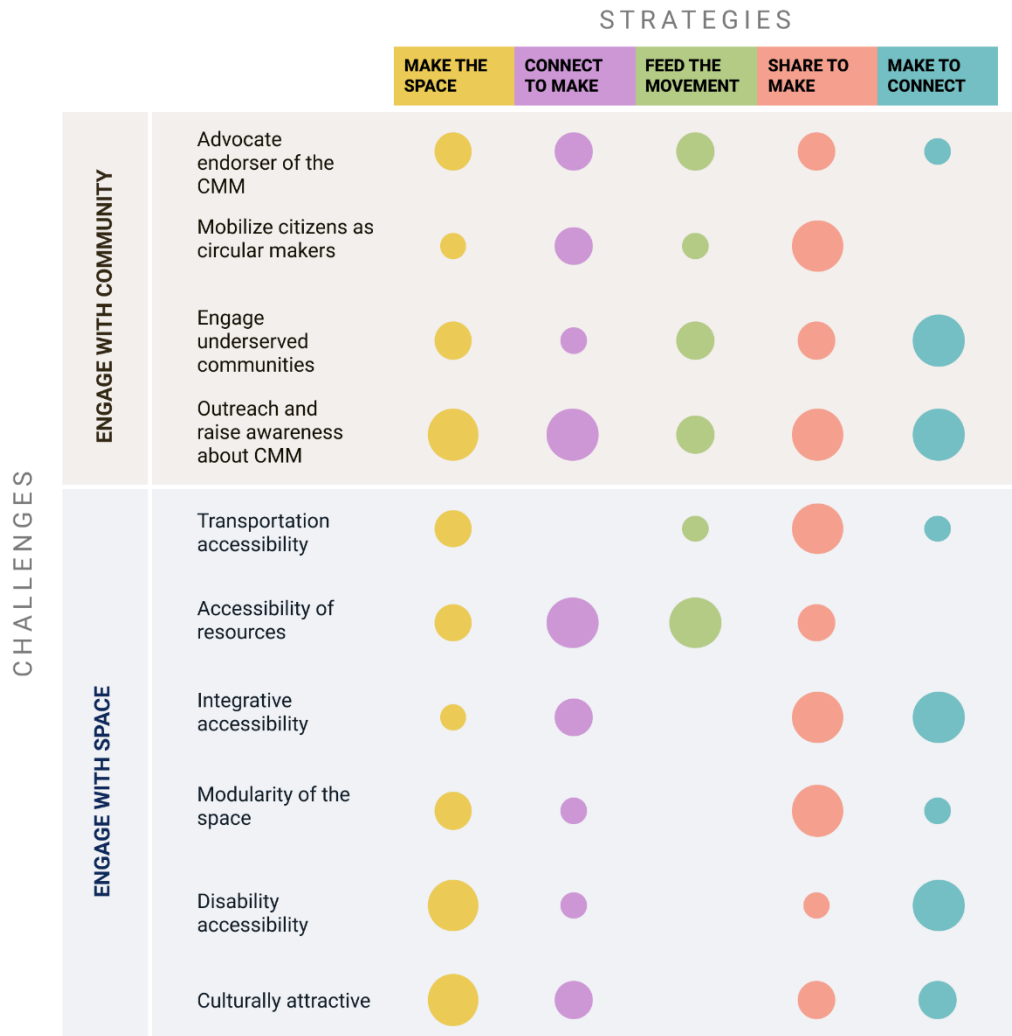


Figure 4 - The strategy-challenge matrix

Note: The circle size demonstrates the ability of the strategy to overcome a challenge. The bigger the circle, the higher the capacity of the strategy to address the challenge. The blank areas are unexplored within the scope of the studied cities and CMSs.

This matrix serves as i) a way to determine engagement challenges and decide on the proper strategies to tackle them, and ii) an analytical tool to identify strategy-challenge gaps, which in turn, help develop an action plan for engagement. To illustrate, from Figure 4, it appears that while the studied CMSs are utilising each strategy for addressing community-related challenges, space-related challenges were less covered. *Feed the movement* strategy was not used to address challenges related to integrative accessibility, modularity, disability accessibility and cultural attractiveness. This information could help prioritise new ways to address these challenges through *feed the movement* strategy, e.g., how secondary materials and other resources are delivered to disabled people. Alternatively, from the most populated challenges, the cities and involved stakeholders can focus on expanding the impact across cities, i.e., how *share-to-make* practices can be transferred to other cities, which seem to address all the challenges with moderate to high impact.

Though this matrix is created based on the studied practices, it could be useful for other projects or initiatives striving for a vibrant CMM and creating a network among cities. For instance, it can be examined by cities struggling with engagement (e.g., of underserved

populations), to define which strategy is relevant and feasible for the local context (e.g., share to make). It can be used as an entry point for them to connect and create a network, identify similar challenges and strategies, and help initiate a dialogue to discuss ongoing challenges and strategies.

5.2. Towards circular makerspaces and sustainable cities

The analysis indicates some unresolved (or overlooked) challenges in the scope of the studied cities and CMSs, which might slow down cities' processes of becoming sustainable. This section emphasises the prominent unresolved challenges and related issues to better exploit the potential of CMSs in contributing to sustainable cities.

5.2.1. Governance actors as facilitators of circular making activities

According to the matrix, the engagement of citizens in the long run is an overlooked challenge. The studied CMSs are administrated by local governments (cities), which sometimes lack the flexibility to allow CMS actors to feel comfortable and enable adjustments for appropriation from the citizens. While cities commonly adopt the top-down approach in city planning, citizens engaged in the CMM prefer bottom-up approaches like grassroots innovation (Wang, 2016). The disconnection between city-civil servants and their bureaucratic institutions, and citizens volunteering creates a mismatch and conflicts in the decision-making processes. CMS management with clear hierarchical power relations leaves little room for makers' empowerment, autonomy and independence (Masters et al., 2019), reducing their willingness to get involved and engaged. This challenge could be addressed by shifting the cities' role from the managers of CMSs to facilitators of circular making activities.

Section 2 discussed the pros and cons of two existing governance models for CMSs, top-down and bottom-up. On the one hand, in a top-down governed CMS, makers could spend more time making activities since maintenance and provision activities are taken care of by somebody else (e.g., repairing and maintaining the tools, materials stock management etc.). On the other hand, a bottom-up governed makerspace could create a sense of belonging and feeling of being empowered, thus increasing citizen engagement in making activities.

The analysis of circular making practices in seven European cities showed that characteristics of both approaches are needed to create a CMS that can engage citizens in the long run. By investigating three makerspaces from China, Fu, (2021) proposes a third alternative to these governance models, named a 'subtle top-down' model, based on a reciprocal relationship between the government and non-government actors to have a governance model aligned with public policy goals. Though this model carries the characteristics of both top-down and bottom-up approaches, it still gives more governing agency to cities. Different from this previous work, within the scope of this paper, the authors suggest a fourth alternative, a *city-supported bottom-up model*, in which cities could adopt a facilitator role rather than a managerial role. In this model, the facilitating role of these stakeholders includes providing makers with prototyping tools, and access to (secondary) materials and space (e.g., meeting space, workshops, website), and letting makers decide on the design of the space (e.g., adding a workshop area for kids) and on the type of circular making activities (e.g., organizing a local repair event to help residents repair their goods). Exploring these alternative CMS

governance models in the scope of engaging citizens, in the long run, appears to be an important direction for future research.

5.2.2. Empowering spaces

The second unresolved challenge is engagement in space, which is related to feeling welcomed and empowered in CMSs. There are several strategies suggested by previous studies to address this need. First, providing free access to public makerspaces could be an invitation for citizens to spend time in a makerspace, which in turn could encourage them and authorities to reconsider their relationship (Diaz et al., 2021). However, empowering space is not only about free access. As demonstrated in this paper, the accessibility of a CMS has multiple challenges to accommodate people's needs (e.g., using suspended electrical outlets to keep wires off the floor for better wheelchair accessibility (Steele et al., 2018)), or design accessible activities and events within the makerspace (Brady et al., 2014). Accessibility of the latter aspects is equally important as the accessibility of the space, as they enable citizens to be equipped with the necessary skills, knowledge and infrastructure to run a circular making project. Without access to the materials, skills, tools and resources, this potential can be hindered (Bakırlioğlu & Kohtala, 2019; Klemichen et al., 2018; Kohtala, 2017; Unterfrauner et al., 2019).

Furthermore, CMSs could allow for alterations of management structures and work environment, and adjust the space to allow for such adjustments, to make makers feel welcomed, motivated and empowered. Hence, the simultaneous activation of both intangible challenges (engagement in governance) and tangible challenges (engagement in space), as well as a balanced involvement of cities and citizens are needed to facilitate the transition towards sustainable cities. This paper is one of the first studies to investigate the relationship between tangible and intangible engagement challenges in CMSs. Future work should further explore how these challenges influence each other and how they would impact the level of citizen engagement in CMSs and sustainability in cities.

5.2.3. Building trust and a sense of belonging in circular makerspaces

For empowering and engaging citizens in the CMM, mutual trust between cities and citizens should be established, as it is a key requirement in distributed decision-making (Pradhan et al., 2021). Building trust could help communities achieve strong resilience (Savolainen et al., 2016), which in turn facilitates cities' transition to sustainability. Such long-term resilience would also allow cities to overcome, more easily, changes and shocks beyond environmental sustainability (Grafakos et al., 2019) (e.g., an economic crisis, a pandemic (Wuyts et al., 2020)).

For trust to be developed in CMSs, the interactions between different stakeholders including employers, administration, regulars, volunteers and visitors are essential. Taylor et al. (2016) found that being connected with other makers increases the sense of community in a makerspace. However, not all interactions and connections are positive. Meaningful interactions are needed to help build trust between makerspace stakeholders. For example, in the case of knowledge and skill sharing, a CMS can teach 3D-prototyping tools, and ask attendees to prototype parts to repair chairs. In this scenario, while volunteers learn about a circular activity, they give design effort in exchange for knowledge. Both parties have a

collective goal of contributing to the makerspace (creating a welcoming space) along with their self-development goals (i.e., learning a new skill; being recognized by the community).

The frequency and type of interactions are also critical in building trust and belonging. By examining the interactions in a university makerspace, Andrews et al. (2021) found that frequent visits to a makerspace and engagement in a making project increased students' sense of belonging to the space and the community. However, cities and citizens should acknowledge that feelings of trust and belonging need time to build. Furthermore, the level of belonging to a CMS can vary among stakeholders due to the different roles and responsibilities these stakeholders have (Bijman, 2017). Hence, cities should not expect immediate results from CMSs to quickly deal with pressing environmental issues, and should not expect the same level of involvement and sense of belonging from each makerspace stakeholder.

5.2.4. Supporting circular makerspace's contribution to SDGs through policy

CMSs have the potential to contribute to the sustainable development of cities (Doyle, 2019). Having a trusted and reliable network of CMSs would allow the cities to exchange experiences and learn from each other. However, to increase the impact of CMSs on sustainability at the city scale, they need to be supported by proper policies (Doyle, 2019; Grafakos et al., 2019). This is also the case for some of the strategies presented in this paper, which require city-level policy action. As an example, *feeding the movement*, which is a straightforward strategy for making secondary resources available to makers and citizens, might be constrained by waste management restrictions. Policies should be adopted at the local (and possibly at national and European) level to remove the barriers that sometimes obstruct intangible and tangible engagement strategies alike (Doyle, 2019). Furthermore, the analysis conducted in this paper revealed that cities are not always equipped to engage with their citizens in the collaborative development of a sustainable ecosystem for their city. The lack of citizens engagement becomes visible especially in cases initiating and sustaining circular making activities. The analysis of the cases suggests that there is a need for policy to allow more citizen consultations and to bring civil servants and citizens to initiate and better collaborate towards urban sustainable ecosystems. Such policies could be developed with considerations and implications for pan-European implementation, i.e., citizens engagement towards the creation of a vibrant circular maker ecosystem in Europe.

6. Conclusion

Based on the work in the Horizon 2020 project Pop-Machina, this paper presented a taxonomy for engagement-related challenges for creating a vibrant CMM and strategies that cities could deploy to tackle these challenges. With this, it demonstrated the potential role a vibrant CMM can play in increasing inclusiveness and promoting steps towards more circularity on the city level, as well as being part of a city's strategy to achieve the SDGs. The paper offers guidance to cities with the ambition to develop a CMS and create and support a vibrant maker community around it, adding to the sustainability and attractiveness of the city.

The activities being rolled out in the studied cities and the matrix developed in this paper can inspire other cities in tackling similar engagement-related issues. However, it is important to stress that the solutions offered in this paper are not a panacea. All strategies need to be tailored to the specific context of each city. The insights should be mainly used as a reflection

on the method cities can apply to tackle challenges linked to CMSs. Lastly, if backed by sufficient facilitating policies on the city, national and European levels, the strategies can be used as guidance by other cities, and as such create a lever towards an upscaling of practices with the potential to contribute to the goals of making cities in Europe more resilient, circular and inclusive.

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A. Appendix - Pop-Machina: building vibrant circular makerspaces

Pop-Machina is a H2020 project (2019-2023). The project supports the CE and collaborative production by establishing CMSs and empowering maker communities in creating circular design projects. There are 23 partner institutions working on Pop-Machina, representing more than 100 direct colleagues. Among them there are about 20 civil servants representing seven cities. In each city, the project Pop-machina involves up to several hundred practitioners and citizens.

One of the objectives of Pop-Machina is to mobilise citizens under the banner of CE and collaborative production. The key to achieving this objective is to engage existing makers and citizens, who are not makers, as circular makers in the Pop-Machina pilot cities including Leuven (Belgium), Venlo (The Netherlands), Istanbul (Turkey), Santander (Spain), Thessaloniki (Greece), Piraeus (Greece), and Kaunas (Lithuania). These cities' maker ecosystems have diverse characteristics requiring tailored approaches to engagement. Leuven already has a large and vibrant maker community including many initiatives that combine making with CE principles like eliminating waste and circulating products and materials. Venlo, despite its low population, has a significant group of circular making initiatives with established support for creating circular business.

In comparison to Leuven and Venlo, Kaunas and Piraeus have small but active maker communities who conduct circular making activities like repair, secondary material collection and provision, and several initiatives to fund and support circular businesses. Istanbul has a large and vibrant CMM consisting of various makerspaces spread through the city and various initiatives conducting CE activities like repair. However, a strong link between CE and makerspaces has yet to be established. Furthermore, while Thessaloniki has several makerspaces and active makers, the city has fewer initiatives and citizens engaged in circular activities compared to Leuven. Lastly, although there are citizens who are engaged in making, the current Santander maker community is in the start-up phase.

The objective of engaging citizens in circular making activities has been realised in the project by integrating inclusivity into engagement strategies. Because the maker movement currently mainly consists of wealthy white young men (Eckhardt et al., 2021), increasing the diversity of citizens in the project is essential to reach the SDGs (particularly SDG10). Vulnerable people⁴ constitute a population of great diversity in terms of causes and context (e.g., including but not limited to women, migrants, and unemployed). The Pop-Machina cities are emphasizing engaging underserved citizens with their activities so that they become members of the CMM.

⁴ To encompass this variety, several workshops were conducted with the Pop-Machina pilot cities and their supporting partners to draw up a strategy for the integration of vulnerable people. As a result of this effort, Pop-Machina partners decided to use the term underserved people to refer to vulnerable communities, and define underserved people as “persons currently underserved by the maker movement and by the urban infrastructure in general”.

B. Appendix – Details of the data collection techniques and channels

The first channel was the online city meetings, illustrated by (1) in Figure 2. The city meetings were organised every five weeks to assist the cities in the development of their CMS. These meetings were organised on an online meeting platform and gathered the seven cities simultaneously. Each meeting started with a brief reporting of the development, the activities and the challenges of the CMS in each city. Cities were asked to discuss and elaborate on the current challenges and opportunities they were facing regarding their local CMSs. CMS managers outside the project were invited to discuss the challenges encountered and concrete strategies that allowed them to overcome them. These meetings offered room for discussion and exchange among the cities and with the project's academic and business support partners.

The second channel was the series of co-creation workshops, illustrated in (2) Figure 2, which were organised on an online collaborative whiteboard platform and discussed through an online meeting platform twice, with the participation of average 60 participants (mainly academics and practitioners but also civil servants, which were at least 1 per city) In preparation for these workshops, each city was asked to list at least three challenges they were facing during the development and the activities in their local CMS. During the workshops, Pop-Machina partners, including city representatives, reflected on potential strategies to overcome them. The talks by CMS managers, both within and outside the project, during online city meetings, and co-creation workshops were sources of inspirational concrete solutions for the Pop-Machina CMSs. Several of them adopted the strategies presented during the meetings and workshops to tackle their local challenges.

The third channel was the Pop-Machina risk mitigation plan, illustrated by (3) in Figure 2. To prevent and closely monitor challenges potentially endangering the CMS deployment, a risk mitigation plan was set by the coordination team, constantly updated by the cities and their supportive partners, and consulted frequently by the partners. This allowed the risks and challenges to be monitored and partners to provide assistance to cities in need.

The fourth channel was the voluntary reporting of challenges by the cities via emails and phone calls, illustrated by (4) in Figure 2. Per its consortium design, each city had a supporting technical and academic partner, and an open communication channel with the coordinator. Cities reported their challenges transparently.

Regarding the labelling of the challenges, the authors, for every statement, described how it was representative of a challenge or a potential strategy to overcome it. For example, the difficulty to keep the community engaged through online meetings during the pandemic was reported. This challenge is mainly due to the hands-on nature of the activities that makers are most interested in. It was labelled as 'difficulty in engaging makers in online environments'. While the challenges, the strategies and the list of initiatives were developed and discussed during meetings gathering up to 50 partners⁵, the labelling of the ten challenges and five strategies for each of the initiatives was conducted by the authors.

⁵ The partners mentioned here are the academic and business researchers, civil servants, citizens, policy makers and business representatives involved in the Pop-Machina project.

C. Appendix – Circular practices from Pop-Machina cities and their relation to strategies to overcome the ten engagement challenges

This appendix details how the different cities and CMSs used the strategies to overcome the challenges linked to space and communities' engagement.

C.1. Make the space

This strategy acknowledges the importance of location and attractiveness of a makerspace in engaging citizens in the CMM and thus allows to embody the SDGs 4, 8, 9, 10, 11, and 12.

Leuven: Leuven's CMS, Maakleerplek⁶, is located inside an old mill building between residential areas, and creative sector companies. The area is cosmopolitan and undergoing gentrification and new cultural development (Challenge 10, SDG9). The space is also at the crossroads of several transportation modes, making it easy to reach with enhanced transportation accessibility (Challenge 5, SDG11).

The place was refurbished by local architects, along with the contribution of local civil society organisations willing to take part in the refurbishment (SDG8). Every space of the building is designed to enhance creation and learning capacities of the various users, providing a certain level of modularity (Challenge 8). The spaces propose raw and recyclable resources (SDG12) as key design elements to stimulate user awareness (Challenge 4). The CMS is composed of six different rooms made to host various activities and invites a variety of stakeholders like companies, schools, artists and residents to learn, make and work together (Challenge 2) while conveying the potential to be reorganised according to different user needs for integrative accessibility (Challenge 7). The CMS organises workshops to discuss and tackle various societal, social, economic, ecological and cultural challenges both locally and internationally for the present and the future (SDG4). All citizens are welcome, and integration is key to the activities proposed in the CMS (Challenge 9, SDG10).

Istanbul: In the dense (2.400 pers./km²)⁷ megacity (16 million people), the CMS's location selection prioritised transportation accessibility (Challenge 5, SDG11), accessibility to resources (Challenge 6) and integrative accessibility (Challenge 7). The city chose a place located in the Istanbul Waste Management Directorate due to its vicinity to discarded materials, main roads, and public transportation, revitalising and reusing a deserted space (SDG12). Furthermore, this location is in the lower socio-economic and immigrant neighbourhoods (SDG10). To increase the accessibility of this space for the general public, as it is located in a governmental building that can only be accessed by officials, the city built a new, private entrance. The whole space is refurbished to accommodate disability accessibility (e.g., mostly flat layout, with ramps where necessary) (Challenge 9). While these refurbishments were considered to facilitate makers' and citizens' engagement with the CMS, the city recognised the limited impact a single makerspace can have in a large city. Hence the idea of creating *CMS Hubs* in various existing makerspaces distributed across the city

⁶ <https://maakleerplekleuven.be/>

⁷ <https://inta-aivn.org/en/481-inta/activities/exchange/roundtables/20122013-inbetween/1983-istanbul-metropolitan-area>

emerged, which are connected to the original Istanbul CMS. The Hubs are devised as small stations where makers and citizens can access the circular maker platform, create new projects (SDG8), request secondary material and realise their projects by utilising the equipment from the original Istanbul CMS.

C.2. Connect to make

This strategy concerns the governance of a CMS and collaborations with external actors for active engagement. By connecting with various actors in a collaborative and mutually nourishing way, the CMM can sustainably engage increasingly more people, becoming more resilient and impactful. This strategy is illustrated through Thessaloniki, Piraeus, and Leuven cases and involves SDGs 4, 8, 9, 10, 11, 12, and 13.

Thessaloniki: The Thessaloniki CMS is collaborating with a local waste management company to organise regular maker visits to their premises and collect waste to be used as secondary raw material (SDG12). In 2020, they collected 800kg of material including old furniture, construction material and discarded kick-scooters to be refurbished. The collaboration improved the accessibility to resources and allowed precious materials to be diverted from landfills and to be used as input for various making activities (Challenge 6). The activity itself enhances waste and consumption awareness among the CMM and is used as a sensibilization campaign (Challenge 4, SDGs 4, 11 and 13).

Piraeus: Piraeus is deploying a collaboration strategy focused on textiles. Though textile as a secondary raw material presents potential, the misconceptions about its recyclability among the general public hinder its collection and reutilization. Perceived as a reusable material through fixing old clothes, there is a tendency to place old clothes in recycling bins where there is no categorization between what is repairable and reusable and what needs to go to recycling. Piraeus partners recognised the necessity for collaboration among the circular makerspaces, other makerspaces in the region and both the local textile and waste management industries in tackling this challenge. They set up partnerships with the recycling centre of the municipality and a private recycling company⁸ (SDG8). The collaboration with the two local institutions allows fabrics and wood to be freely collected for the makerspace uses (Challenge 6, SDG12). While these are mainly from industries in Piraeus and old clothes from citizens, such a strategy has the potential to engage people in the CMM and also strengthen connections among citizens with different backgrounds (Challenge 4, SDGs 4 and 11).

Leuven: Leuven involved citizens in the governance of the space. While the Leuven CMS is facilitated by the City of Leuven, each of the six different workshop spaces is run by local groups, enhancing the endorsement of the CMS by makers (Challenge 1, SDGs 8 and 9). The partners were selected through an open-to-all call for application - not only companies and entrepreneurs but also schools (secondary and tertiary), civil society organisations and citizens for integrative accessibility (Challenge 7). As of December 2021, there are no less than 36 partners involved in the governance of the CMS. The variety and number of the actors allow the makerspace to reach a broad audience, provide a wide range of activities and ensure

⁸ This company is named "Antapodotiki anakiklosi (Rewarding recycling)"

the continuity of the activities by becoming a culturally attractive space (Challenge 10, SDGs 4 and 12). This community engagement in Leuven allows to fully utilise existing competencies and networks and to allow their diversity and integration among the community (SDGs 10 and 11).

C.3. Feed the movement

This strategy addresses the accessibility to resources, specifically secondary materials. A major barrier is the existing waste management practices preventing makers from accessing valuable materials and discarded objects. Thus, re-introducing discarded objects and materials into the circular making practices is critical for the CMM. In the previous section, the cases of Thessaloniki and Piraeus collaborating with waste management companies present a compelling opportunity to feed the movement. In this section, the cases of Leuven and İstanbul are introduced below as attempts to formalise such material flows and illustrate how it tackles SDGs 1, 8, 9, 10,11, 12, and 13.

Leuven: In Leuven, two non-profit organisations⁹, in collaboration with the local public waste management service company¹⁰ and a local social enterprise¹¹, created a place to gather and sell second-hand construction material (SDGs 1 and 10). The ‘Materialenbank’ (Materials Bank) offers discarded materials to any citizens and companies for reuse (SDG12). Selling and reserving material can be operated through their online platform while the storage and pick up of the material is located along the Leuven canal, near the Leuven city centre. This partnership allows waste material to be redirected to citizens as makers for construction purposes (Challenge 6, SDG11). Beyond saving virgin material resources through reuse (SDG13), the Materialenbank offers jobs to vulnerable groups (Challenge 3, SDG8).

Istanbul: In İstanbul, the CMS managers saw an opportunity to utilize a secondary raw material storage area by the municipality-affiliated waste management company, ISTAC. ISTAC had previously set up a low-tech carpentry workshop there (SDGs 8 and 9) and some of the company workers began to re-utilize the secondary raw material accumulated for creative projects. The idea was to set up the CMS next to this warehouse and low-tech workshop, and initiate a material bank service for the makerspace (Challenge 6). However, this service would involve public-owned resources (i.e., secondary raw material), an exchange between two municipality-affiliated entities (i.e., Istanbul Waste Management Directorate and ISTAC) as well as setting up a retail service for secondary raw materials and sources of income that are covered in neither entities’ bylaws. Since the process of establishing such connections takes time, the use of the secondary raw material from this storage area is currently limited to projects carried out at the CMS.

C.4. Share to make

Share to make strategy aims to overcome barriers against setting up a standalone space where the community can come together, collaborate and flourish, and turn them into an

⁹ Atelier Circuler and <https://ateliercirculer.be/> and and Reused <https://www.reused.be>

¹⁰ Ecoverf <https://www.ecowerf.be/leuven>

¹¹ Vites <https://www.dekringwinkel.be/vites>

advantage. This strategy covers the SDGs 4, 9, 10, 11 and 12, as illustrated in cases from Santander, Piraeus and Kaunas.

Santander: In Santander, the originally selected space for the CMS had become unavailable during the project, due to changes in administration. To respond to this challenge, on the one hand, the city turned to online events for engaging the community (Challenge 2). A local citizen-led organisation creating Covid-19 protective face shields joined in the online webinar to collaboratively and remotely produce shields (SDGs 9 and 12). On the other hand, they proposed a way to build a mobile makerspace that allows hosting activities in different locations in the city, which also enables transportation accessibility (Challenge 5, SDGs 4 and 11). The mobile makerspace is brought to distributed places in Santander, which are the places for the development of municipal activities and meeting of neighbourhood groups. It fosters the active participation of the residents in the life of the city and its respective neighbourhoods (Challenge 4). As the mobile makerspace is modular (Challenge 8) and includes all the tools and materials required to host various creativity workshops and innovative learning activities like furniture restoration, they provide access to resources (Challenge 6) and make the space culturally attractive (Challenge 10). Those training courses are held by the districts' citizen associations, and they target diverse citizen profiles (e.g., children, adults, elderly) (Challenge 3), and cultures (SDG10).¹² Lastly, the mobile makerspace is used in these civic centres to conduct workshops and bring the makerspace closer to the citizens through integrative accessibility (Challenge 7).

Piraeus: Piraeus had challenges regarding finding permanent space for CMS. They encountered bureaucratic issues in selecting the final contractor for the makerspace construction and in acquiring machinery. As a temporary solution, the CMM started using the space of an innovation centre¹³ focusing on the blue economy and entrepreneurship (SDG9). This initiative of sharing facilities provided the Piraeus CMM with accessibility to resources and equipment (e.g., 3D printers, ICT tools) to conduct activities (Challenge 6, SDG12). The final CMS will be located in an old textile school building. Since the Piraeus CMM focuses particularly on fashion and the circularity of fabrics, this building, which was initially one of the first textile schools in Greece, is considered a fitting choice that generates cultural attraction (Challenge 10, SDG11).

Kaunas: In Kaunas, the CMS managers organised several workshops in collaboration with local social enterprises to raise the visibility of the CMM (Challenge 4, SDGs 4 and 9) and to initiate a network of endorsers (Challenge 1) and citizens (Challenge 2) that can undertake culturally attractive activities (challenge 10). Such collaborative practices allow for easier access to resources (Challenge 6) and reduce the environmental footprint since resources and means are shared among spaces and stakeholders (SDGs 11 and 12).

C.5. Make to connect

This strategy is focused on outreach and engaging underserved communities and aims to raise the awareness of people who have limited knowledge about the maker movement.

¹² For more information about the Santander Civic Centres, visit centroscivicosantander.com (in Spanish)

¹³ The center is called the Bluelab initiative <https://en.bluelab.gr/about>

Engaging them through making and showcasing their potential, and touching their everyday lives are the main drivers of this strategy. It encompasses the SDGs 1, 8, 10, and 12, as illustrated in cases from Venlo and Leuven.

Venlo: In Venlo, the municipality owns KanDoen¹⁴, a CMS that was established to create job opportunities for disadvantaged citizens including unemployed and disabled people (Challenge 9, SDGs 1, 8 and 10). Citizens living in the neighbourhood can utilise KanDoen's facilities to make new artefacts (e.g., bags, various accessories) by using secondary materials (e.g., discarded clothes) or repair broken artefacts (e.g., bike repair) (SDG12). With this structure, KanDoen provides a good example for engaging citizens with low socio-economic backgrounds in making activities through supporting their livelihood (Challenge 3). However, this focused approach also creates barriers against integrative accessibility. KanDoen's strong emphasis on neighbourhood-level solutions (the local context) creates a challenge for connecting citizens in KanDoen to the makers in the city. Furthermore, the majority of engaged citizens have limited technological literacy, which creates an additional barrier to using digital collaboration and product tools (e.g., Pop-Machina platform) for integrative accessibility (Challenge 7).

Leuven: In Leuven, a movie clip was created and broadcast on TV¹⁵ to emphasise the ongoing collaboration between makers and vulnerable groups (Challenge 3, SDG11). This short movie highlighted several collaborations including engineers providing disability access to buildings (Challenge 9, SDG10). The TV clip reached a large and diverse audience (Challenge 7). This communication campaign was also effective in the sense that various people reached out and joined the local CMM, engaging with a broader audience and connecting people with vulnerable groups (Challenge 4).

¹⁴ <https://www.venlo.nl/kandoen>

¹⁵ For the short movie, visit <https://www.vrt.be/nl/over-de-vrt/nieuws/2020/09/21/lieven-scheire-en-zijn-team-opnieuw-aan-de-slag/>