Cleaner Waste Systems 5 (2023) 100096

Contents lists available at ScienceDirect

Cleaner Waste Systems

journal homepage: www.journals.elsevier.com/cleaner-waste-systems

Exploring eco-industrial development in the global south: recognizing informal waste-picking as urban-industrial symbiosis?

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ARTICLE INFO

Keywords:
Urban eco-industrial development
Informal waste-pickers
Solid waste management
Sustainable urban development
Sustainable construction

ABSTRACT

Industrial ecology (IE) is discussed as a suitable approach to resolve three widespread socio-ecological problems in the so-called global south: waste accumulation, unemployment, and lack of adequate housing. As the IE framework was developed mainly in the global north, its applicability in the global south is uncertain. The issue is discussed along the use of municipal waste as building materials as a concrete application of circular economy (CE) and IE principles, which could contribute to the alleviation of the aforementioned social-ecological problems. The study focuses on San Martin, a district in the Buenos Aires metropolitan areawhich suffers from these problems dispite its industrial capacities. A SWOT analysis that includes all PESTLE dimensions was applied to identify risks for the success of an IE-based strategy, including the main actors and stakeholders of local waste management. Key issues include the informality and low agency of non-profit organizations, fluctuations in the national economy, inefficiencies in waste collection and recovery, and a lack of awareness and policies on waste separation. One major challenge is the undervaluation of the relevance, expertise and efficiency of waste sorting and processing by informal waste pickers and non-profit organizations. These practices should be recognized as a symbiosis of the urban with the industrial metabolism. This way, the epistemic basis for the eco-industrial development (EID) framework can be layed to make it capable to empower them rather than further displace the people involved. In this way, urban EID could become a useful strategy to channel different scientific disciplines, knowledge and actors, knowledge and actors towards sustainable development.

1. Socio-ecological issues of urbanization and industrial ecology approaches for sustainable development

Rapid urbanization often leads to socio-environmental problems, such as marginalized and segregated populations without access to adequate housing, frequently exposed to natural hazards (Bolay et al., 2005; Dovey et al., 2020; Michelini and Pintos, 2016), high rates of unemployment and informal economic activities (Brown and McGranahan, 2016), and environmental risks from industrial and municipal waste (Bocanegra et al., 2001; Bonelli, 2018; Codebò, 2019; Rigacci et al., 2013; Romero-Lankao et al., 2014) These problems pose a threat to the achievement of Sustainable Development Goals (SDGs), and since politics lacks appropriate instruments from the national to the local level and urban planning, aspirations and reality drift further apart (Brown and McGranahan, 2016; Haase et al., 2017; Krausmann et al., 2008; Michelini and Pintos, 2016; Obersteg et al., 2019; Tansel, 2020; United Nations, 2022).

Circular economy (CE)-based strategies to improve solid waste management (SWM) have been developed and implemented in many countries, including Europe, North America and Asia (Nelles et al., 2016; Obersteg et al., 2019; Schroeder et al., 2019). CE contributes directly to some Sustainable Development Goals (SDGs), but is criticized for being too simplistic and short-term, since the CE framework neglects thermodynamic limits and hardly deals with social-ethical aspects of sustainability (Giampietro and Funtowicz, 2020; Inigo and Blok, 2019; Kirchherr and van Santen, 2019; Schöggl et al., 2020; Vanhuyse et al., 2021). In contrast, Industrial Ecology (IE) is suitable for achieving CE targets and for being economically feasible while also

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https://doi.org/10.1016/j.clwas.2023.100096
Received 29 November 2022; Received in revised form 25 March 2023; Accepted 9 May 2023

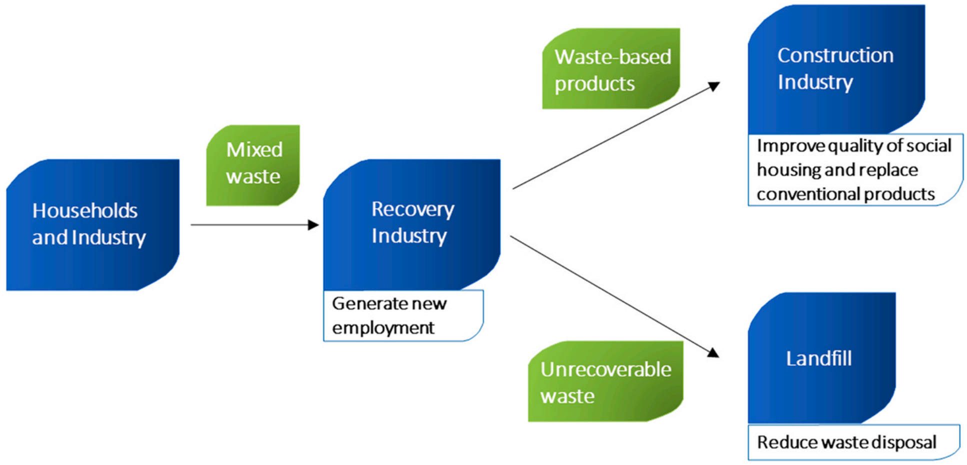

Fig. 1. The strategic objectives discussed in the present study are indicated in white boxes. The arrows correspond to waste flows between actors in the field of solid waste management.

mitigating social problems (Cohen-Rosenthal, 2004). IE combines technical and ecological approaches while simultaneously taking social aspects into account (Cohen-Rosenthal, 2004).

IE considers industrial production systems in analogy to natural ecosystems, borrowing terms, principles and concepts such as symbiosis to design efficiency strategies (Hess, 2010; McManus and Gibbs, 2008; Yang and Lay, 2004). Another important concept is the consideration of material, water, and energy flows as metabolism, whereby a distinction is made between industrial and urban metabolism, especially since the policy instruments are different (Broto et al., 2012; Fraccascia, 2018; Hess, 2010; Krausmann et al., 2008; Newell and Cousins, 2015). The establishment of an urban-industrial symbiosis can lower the environmental impact of cities and be a tool for sustainable development (Dong et al., 2014; Kim et al., 2018; Shah et al., 2020). This can be initiated and implemented by urban and regional spatial planning for instance (Deutz and Gibbs, 2008; Gibbs et al., 2005). Examples of urban-industrial symbiosis include district heating systems that use heat from manufacturing processes, and the use of solid household waste as a substitute fuel in energy-intensive industries such as steel production (Kim et al., 2018).

However, Eco-Industrial strategies for regional and urban development may theoretically but not automatically lead to win-win situations (Gibbs and Deutz, 2005). There are still knowledge gaps that hinder IE strategies for sustainable development. IE applications have been developed mainly in Asia and Europe, but Latin American countries adopt CE legislation from European countries with minimal adaptation to their economic and social conditions (Dong et al., 2016; Fraccascia, 2018; Liu et al., 2014; Shah et al., 2020; Song et al., 2016). Weaknesses that are already known are also adopted (Betancourt Morales and Zartha Sossa, 2020). Studies on using waste residues for building products have been conducted in the context of Circular Economy (CE) but rarely connect with urban metabolism and urban planning (Hossain et al., 2020; Winans et al., 2017). Material flow, life cycle, and carbon footprint analyses are commonly used to evaluate IE projects, but the ex-ante evaluation of sustainability potential, particularly social impacts, is rare (Ohnishi et al., 2017). There is a lack of frameworks for full-scale evaluation of building materials and products that cover IE aspects and analyzes possible links to urban metabolism and industrial symbiosis (Freitas and Magrini, 2017; González-García and Dias, 2019; Hossain et al., 2020). In general, there is a poor connection between social sciences, engineering and natural science approaches in IE literature (Bolay, 2020; Bolay et al., 2005; Boons and Howard-Grenville, 2009; Walker et al., 2021). Open questions remain regarding the potential of IE strategies to counteract urban inequality and how environmental laws affect stakeholders (Broto et al., 2012; McCulligh and Fregoso, 2019). When IE is promoted as part of a regional planning strategy, the integration of environmental, economic, and social aims remains difficult (Gibbs and Deutz, 2005). The framework for establishing IE strategies is provided by the public sector, but the private sector and the populace are important actors in the implementation of such strategies. Therefore the critical aspect for success is widespread public recognition of the urgency of environmental problems and an impetus to seek urban and industrial symbiosis (van Berkel et al., 2009b; van Berkel et al., 2009a).

This article explores the use of industrial and household residues as the backbone of an Eco-Industrial Development strategy to address waste accumulation, unemployment, and housing shortages in the suburban district of General San Martín in Buenos Aires, Argentina, which suffers heavily from these problems despite its industrial capacities. The transferability of IE from countries of the global north to the global south is critically questioned, and the importance of social conditions is emphasized. The aim of this strategy is to meet the strategic objectives of reducing waste, generate employment and provide affordable housing in San Martín (Fig. 1). The article outlines guidelines for planning an IE approach and aims to evaluate the effectiveness of strategies exported from the Global North to address solid waste management issues in Latin America.

2. Study site

2.1. San Martín

The suburban district San Martín, located around the Buenos Aires Metropolitan Region (*Área Metropolitana de Buenos Aires*, AMBA) in Argentina, was the focus of the study (Fig. 2 and Tables 2 and 3). Unemployment and poverty, poor waste disposal and a lack of adequate housing create a cycle leading hundreds of thousands of people in San Martín and neighboring districts to live near a completely polluted river (Rigacci et al., 2013; Salibián, 2006; Topalián et al., 1999; Williams et al., 2017). Quantitative information on the three addressed problem areas can be found in Table 2.

2.2. Waste management

In the following section, an overview of the most important aspects of waste management in San Martin is given, with special emphasis on the roles and perspectives of the different actors and stakeholders.

2.2.1. Regulatory context

In Argentina, SWM is regulated by the national laws No. 25,916 and No. 25,612, both contained in the National Strategy for the Comprehensive Management of Urban Solid Waste. The National

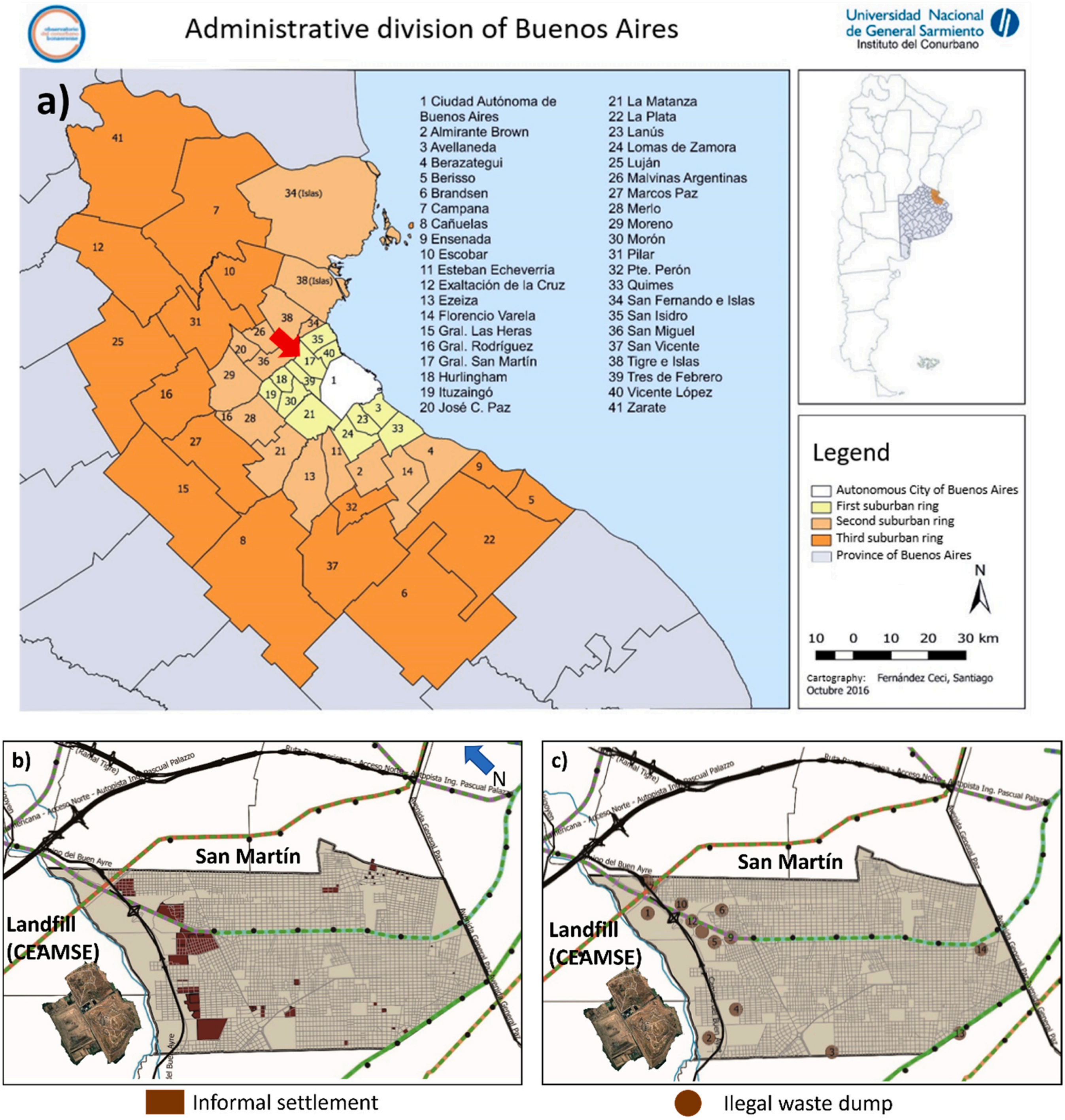

Fig. 2. Maps of the Buenos Aires suburban area next to the Autonomous City of Buenos Aires (CABA), showing a) the administrative fragmentation of the region (Map: Ceci, 2016 (Translated and supplemented), b) the approximate locations of informal settlements and c) illegal waste dumps (Maps: Marta Yajnes, data: Techo 2016), Orthophoto Landfill: GoogleEarth).

Table 1
Planning strategies developed by SWOT issue according to the criteria Relevance and Certainty.

Criteria	Strategy
Relevant and certain	The topic has to be monitored and managed
Relevant and uncertain	The topic has to be further investigated, in order to gain certainty and move the issue to “Monitor and Manage”
Not relevant and uncertain	Make the further planning independent
Not relevant and certain	Monitoring risks, exploit the opportunities

Table 2
Background information on the relevance of the addressed socio-ecological problem addressed suburban district San Martín.

Aspect	Detail	Reference
Population	56 km^2 of surface with a population density of 7396 p/ km^2	Census, 2010
	20 % of the urban dwellers live an informal existence, surviving mainly by selling collected waste	CEEU, 2019;Williams et al., 2017
	Informal settlements heavily affected by the contamination of the Reconquista River (Fig. 3)	Rigacci et al., 2013;Williams et al., 2017
Housing	11.8 % quantitative deficit (the need for new housing) and 6.7 % lack of basic services, inadequate construction materials	CEEU, 2019
Waste	510.4 Tn of urban solid waste (USW) generated per day	Census, 2010
	Buenos Aires province produces 34.6 % of the national waste volume, i.e. more than 16 million Mt/year	Census, 2010
	Argentina's SW production grows by 5 % annually, but only 10 % of the total is recovered	Census, 2010
	USW production reached 1.14 kg/person/day in 2016	Lozupone, 2019

Constitution of Argentina recognizes the sovereignty of local governments to regulate environmental issues. Since 1990, the Federal Environmental Council in Argentina allows provinces and the national environmental authority to agree on and issue environmental resolutions. SWM in San Martín is regulated by the local law No. 992 and by the Provincial Organization for Sustainable Development (OPDS). The local law recognizes waste-pickers as formal actors in SWM. The OPDS plans and coordinates the provincial environmental policy with Law No. 15,164 and regulates the treatment of non-hazardous industrial waste and USW with Laws No. 11,720 and 13,592 and resolution 146/12. The waste generated is classified from harmless to dangerous in terms of how it affects people, property, and the environment, and according to the Environmental Complexity Level (Law No. 11459).

2.2.2. Main actors

The main actors and stakeholders of SWM in San Martín are the waste generators local society and the private and public companies; the municipality and environmental authority (OPDS); So called Sustainable Destinations, cooperatives and private companies that collect, treat, and recover waste; and the Ecological Coordination Metropolitan Area State People (CEAMSE – a state-owned company) and illegal landfills that receive waste for final disposal. Waste-to-energy plants such as incineration facilities are not allowed in Argentina (Pegels et al., 2021; Yajnes, 2020). Informal waste collection is widespread ("Cartoneros"), as well as in non-profit organizations ("Cooperativas"). Detailed information can be found in Table 3. Local academic institutions such as the Universidad de San Martin (UNSAM) are developing waste-based construction products in collaboration with Small and Medium Companies. Table 3.

2.3. Waste-based building products

The core of the eco-industrial strategy is the use of local waste from households (urban metabolism) and industry (industrial metabolism) as novel building materials and products. Because of the great diversity of industries in San Martin and the presence of the CEAMSE landfill, to which household waste from the Buenos Aires metropolitan region is transported and deposited, a wide range of products is conceivable, including corrugated sheets from Tetra Pak or furniture and insulation from textile scraps, among others (Busnelli, 2018). One example highlighted in this article to show the applied principles and some advances of waste-based products are the so-called "molones". This is an insulation system with a wooden frame, which can contain more than 10,000 polyethylene terephthalate (PET) bottles in the construction of a single room. The panel uses economical, easily implemented technology as well as local knowledge, with an open construction system that allows for further modifications. The wooden framework provides for large, flexible surfaces with lower energy consumption in comparison with other locally common solutions (masonry and concrete). They are characterized and certified under the guidelines of the Certificate of Technical Aptitude (CAT) by Resolution SVOA No. 288/90 in Argentina and meet the F60 fire protection standard (Becerra and Busnelli, 2021). This and similar products were designed with the principles of green engineering (Anastas and Zimmerman, 2003) and the material passport (Heinrich and Lang, 2019) by the Institute of Architecture of the University of San Martin (IA-UNSAM) to meet the ecological dimension of sustainable development and avoid potential health risks for manufacturers and dwellers.

3. Methodology

A SWOT analysis is performed to identify **s**trengths, **o**pportunities, **w**eaknesses and **t**hreats of using residues as novel building products for the mitigation of waste accumulation, unemployment and housing shortage. The analysis was combined with the PESTLE scheme, a tool from strategic business planning, which helps to find and/or structure relevant topics. PESTLE stands for **p**olitical, **ec**onomic, **s**ocial, **t**echnical, **l**egal and **e**cological. The procedure was structured as follows:

1) We reviewed literature on similar case studies, circular economy in the global south, industrial ecology projects, and current SWM in San Martín. We also got input from UNSAM and local cooperatives and manufacturers of waste-based products. Issues were assigned to their regarding SWOT field and PESTLE color.
2) All issues were classified further according to two categories:

a) "certainty" of knowledge and
b) "relevance" for achieving the objectives in Fig. 1.

The categorization of "certainty" increased in the following order: "speculation, plausible guess, hard evidence, and knowledge". The "speculation" category was used when observations from the field or comments from insiders raised the question, but little evidence could be found in the literature. "Plausible guess" means that there are indications in the literature, but that the context is, for example, a different country or otherwise not necessarily comparable situation. "Hard evidence" was indicated when examples from Literature are more closely related to the situation in San Martín, for instance, when the study area was another Latin American City. The category "knowledge" was assigned when several studies come to comparable results, or the study area was another district of the Metropolitan Area of Buenos Aires, for instance.

The logic of the relevance dimension is as follows: "added value" means that the issues or risk does not jeopardize the project objectives but are an additional benefit for sustainable development. "Aggravation of the circumstances" means, the issue means hurdles for the project goals, but solutions are known and feasible. "partial steps not possible" means, at least one project goal is endangered if the problem is not considered and solved. "Project not feasible" means that if the problem is not solved, the impact is definitely counterproductive to the sustainability lines in Fig. 1, e.g. if automation jeopardizes livelihoods.

3) From the position in the space formed by the axes "Certainty" and "Relevance", a prioritization and action strategy can be derived on how to proceed with the issues in the future (Table 1).

Table 3
Main Actors and stakeholders of SWM in San Martín.

CEAMSE Landfill and Uncontrolled Dumps
- CEAMSE transports and transfers waste collected by municipalities, treats USW before disposing of it and closes saturated disposal centers (CEAMSE, 2020).
- the biggest landfill of Argentina is located in San Martín, the CEAMSE-run Northern Environmental Complex III (Lozupone, 2019).
- In Argentina, 64.7 % of the total USW goes to sanitary landfills such as those run by CEAMSE, while the remaining USW goes to uncontrolled landfills (34.5 %) or is burned illegally (0.8 %) (Yajnes, 2020).
- CEAMSE will reach its useful capacity in 2023 (Pegels et al., 2021).

Waste Generators in the Industrial Sector
- The industrial labor in San Martín corresponds to 2 % of the Argentinean total, which amounts to 5 % of the national gross domestic product (GGP) and 12 % of the provincial GGP.
- San Martín's GGP comes from the revenues of industry (80 %), commerce (16 %), and services (4 %).
- The main industrial activities are related to metalworking (28.8 %), plastics (14.1 %), and textiles (10.7 %) (Busnelli, 2018).
- OPDS divides waste generators into small and large based on whether they produce less or more than 1 t/day of waste, respectively (Law No. 14273). Large generators must pay for the transport and disposal of waste in CEAMSE facilities and report the waste produced and recovered by a sustainable destination in order to calculate the further recovery rate (Sarandón and Schamber, 2019).
- The waste generators are not yet responsible for waste recovery because the Principle of Extended Producer Responsibility (EPR) law in Argentina is still under development. ERP as an environmental policy is defined by The Organization for Economic Cooperation and Development (OECD, 2016).

Sustainable Destinations and Cooperatives of Waste-Pickers
- Sustainable destinations can be cooperatives, municipal plants, hospital foundations, or any company whose technology is authorized by OPDS (Law No. 14273/2011). There are 71 sustainable destinations in 2021 (OPDS, 2022).
- They collect, separate, and value recoverable waste (Sarandón and Schamber, 2019), so they increase the waste recovery rate and reduce the disposal rate of CEAMSE and prolong its lifespan.
- The cooperatives self-manage resources and services due to the weak presence of the State in areas of social vulnerability (Yajnes, 2020).
- The cooperatives collect the waste under contract with the municipality and sell the waste recovered (EIU, 2017).
- CEAMSE has twelve recovery plants: three private and nine cooperatives, where the latter are in the recycling plant "*Reciparque*" with more than 700 formal waste-pickers working (Ruggerio, 2011). This number of waste-pickers increases during economic crisis in Argentina.
- Informal waste-pickers despite Law No. 992 (Carenzo, 2020; Gutberlet and Carenzo, 2020). They face a market where middlemen make high profits from buying and selling recovered waste and receive low earnings (Yajnes, 2020), along with the police repression due to the unregulated nature of waste picking work along the CEAMSE complex. In 2004, a sixteen-year-old waste-picker died during a police raid of the CEAMSE complex, which caused public sensation (Codebò, 2019; Perelman, 2019).
- A collectively created map designed together with local workers summarizes the problems of formal and informal waste-pickers in the CEAMSE-run Northern Environmental Complex III (Boro et al., 2014; Codebò, 2019).

The Government and Financing of Solid Waste Management
- Cooperation between municipalities and governments (provincial and national) is weak due to jurisdictional fragmentation in the AMBA.
- The municipality of San Martín is responsible for the hiring of actors in SWM and the achievement of recycling goals.
- Municipalities in Argentina must guarantee the collection and disposal of non-hazardous USW. Yet, they lack responsible administrators with the resources, tools, and technical capacity for managing SWM (ACUMAR, 2011) and a regulatory entity on the use of private services in SWM (Lozupone, 2019).
- The financing model for SWM varies between Argentina's municipalities and depends on how organized and interconnected the SWM actors are (Schejtman and Irurita, 2012).
- On total annual budget for SWM, municipalities in Argentina allocate on average more than 60 % to waste collection, 22 % to urban cleaning, and 18 % to disposal of USW (HYTSA Estudios y Proyectos, 2007).
- In 2017, the annual budget in San Martín was insufficient to cover the full cost of SMW (Lozupone, 2019). The municipality expended 14.8 % of the total annual budget for urban cleaning alone (Lozupone, 2019) in 2017. To do this, it spends own funds, receives government funding (Law No. 13,163), and charges private fees (Foglia and Rofman, 2019).
- Argentina's SWM falls under the area of urban hygiene, so is designed with the perspective of a linear and not circular economy (Schejtman and Irurita, 2012). So, the municipalities pay per ton of waste treated (US$7/t in San Martin) and have poor policies on the waste recovery.

Table 3 (*continued*)

- The recovery rate of waste by Argentina's municipalities is less than 30 % (World Bank, 2016).
- In Latin America, the most expensive municipal services are the collection and final disposal of waste, according to the Inter-American Development Bank (IDB) (Becerra et al., 2020). The cost of those services depends on the collection frequency, the collections points per km^2, and the distance from disposal (or transfer) sites, among other factors (HYTSA Estudios y Proyectos, 2007).

People as Producers of Waste
- 94.8 % of households receive regular waste collection services at least twice a week (Census, 2010), but only 5.3 % of them received a differentiated collection service for recyclable waste.
- Households are often unconcerned about the problem of waste disposal, in part because the details of SWM costs are absent from the tax systems (ENGIRSU, 2005). In consequence, households do not know how much they pay to the municipality for SWM.

The Recycling Industry
- In 2020 in the AMBA, the three most abundant products in the USW flow were organic waste (33 %), plastics (18.82 %) and paper/cardboard (13.07 %) (MADS, 2020).
- Only 6 % of the total waste is actually recycled, despite more than 50 % can be recycled (MADS, 2020).
- The composition of USW in AMBA flow from 1972 to 2015 shows that the volume of recoverable waste increased significantly (Savino and Titto, 2020).
- Within the recovery plants of CEAMSE, the private Mechanical-Biological Treatment Plant (MBT) receives waste from the AMBA,Fig. 3.
- MBT is the main recovery plant in this region and can process up to 401.5 kt/year of waste, with up to 60 % recoverable (Savino and Titto, 2020). In 2019, MBT processed around 388.8 kt/year of waste from CABA but recovered less than 1 %, which amounts to 0.1 % of the total waste recovered in CABA (López de Munain et al., 2021).

Local Academia
- The relationship between academia and San Martín is represented mainly by the Universidad Nacional de San Martín (National University of General San Martín, or UNSAM) and its Technical High School. This latter educates students from social-vulnerable neighborhoods and acts as a center for community activities.
- The Institute of Architecture and Urbanism (IA-UNSAM) and the factory unit of the Federal Council of Science and Technology work together to promote the reuse and recycling of waste and thus increase the performance of SWM in San Martín.
- Recently, IA-UNSAM has encouraged other public and academic institutions such as the National Atomic Energy Commission (CNEA) and the National Institute of Industrial Technology (INTI) to participate in the development of Eco-Industrial practices

4. Results

The Strength, Weaknesses, Opportunities and Threats of using industrial residues as an industrial ecology approach to achieve the reduction of waste, lack of housing and unemployment in San Martín are shown in Fig. 4a-d and the corresponding Table A1-A4. In general, in internal conditions (Fig. 4a and 4b), the certainty of SWOT issues was high when related to technical and social issues, but low for economic issues. The uncertainty of a SWOT issue was increased, among other factors, by mistrust between the SWM actors, the lacking depth of study, qualitative data rather than quantitative, and the fluctuating economical-social context of Argentina. For example, "waste resources" in strengths was classified as "relevant and uncertain" (Table A1) because there is a lack of quantitative studies that define the current volume of waste stream types in San Martín. In the area of weakness, "acceptance" and "scalability" appear with very low certainty (Table A2) due to both issues depending strongly on the constant fluctuations of the Argentine market and government, among other variables. In general, greater certainty was observed in threats than in opportunities, as shown in Table A3 and A4.

More than 60% of the weaknesses also have high certainty (Table A2), which shows how well-characterized the barriers are around waste management in San Martin. Such degrees of certainty are important for defining the current and existing ecologies in San Martin. The eco-industrial development requires information that is as realistic as possible and takes into account the changes that may arise locally due to the

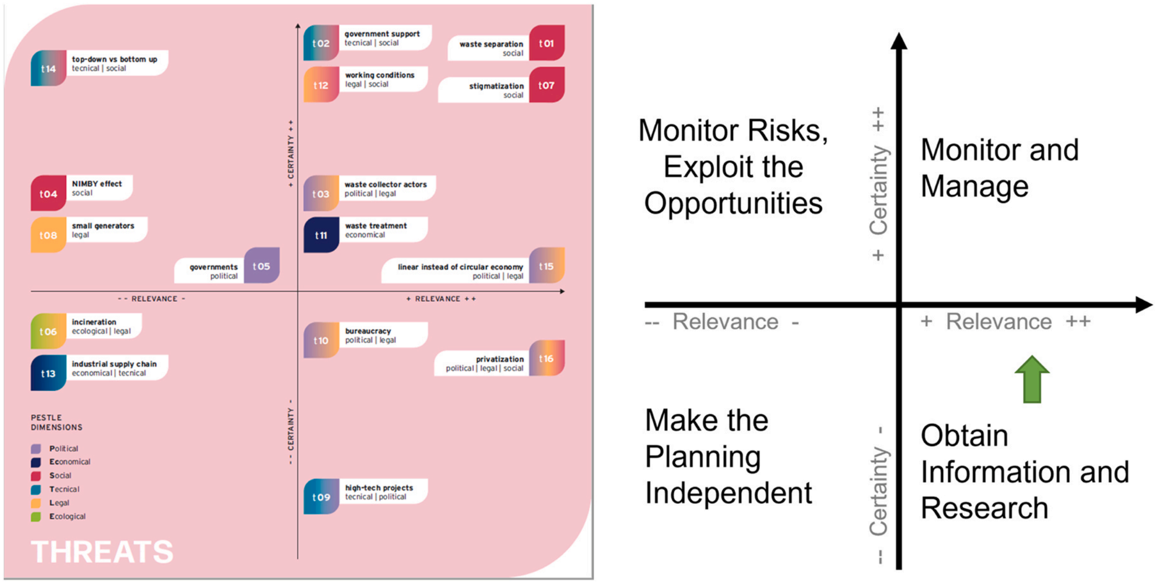

Fig. 3. Visualization of the SWOT analysis (exemplary). Each issue is classified first within the appropriate SWOT field, colors of the issue box refer to the corresponding PESTLE dimension. The issues are then evaluated in terms of their relevance for success of the project and the level of certainty of the knowledge.

presence of these well-defined threats and weaknesses. The urban metabolisms that characterize eco-industrial development can change according to resource availability, technological innovation, and political contingency (Demaria & Schindler, 2016).

The relevance of external conditions (Fig. 4c and 4d) is generally lower compared to internal conditions (Fig. 4a and 4b). For example, "life cycle inventory" is quite useful in the development of environmental product declarations (EDPs) (European Commission DG Environment, 2002) and thus for promotion on the market for their sustainable approach, as is the case in Asia, Europe, and North America (Del Borghi, 2013). But "life cycle inventory" is less relevant compared to other SWOT issues as there are still no laws in Argentina requiring the use of EDP products in construction.

In summary, to pursue the strategic objective of this work (Fig. 1), the most frequent SWOT issues coupled with the PESTLE framework were associated with technical, social, and political aspects (Fig. 4). Fig. 5.

5. Discussion

Few studies address SWM in Latin America with SWOT analysis combined with the PESTLE scheme (SWOT + PESTLE). However, the literature is extensive when SWOT analysis is used as the only tool (Aguilar et al., 2022; Ferraz de Campos et al., 2021; Pardo Martínez and Piña, 2017). Symeonides et al. (2019) combine SWOT + PESTLE and focus on a specific residue (tires) in the SWM of Cyprus, but not on the global spectrum of household wastes. Zorpas (2020) develops a generic strategy of SWM using SWOT + PESTLE, but it is not discussed as part of industrial ecology strategies. When SWM is approached with SWOT analysis, in general CE is included but not IE (Paes et al., 2019; Wikurendra et al., 2022). Freitas and Magrini (2017) investigate IE's contribution to SWM using SWOT analysis in Latin America, but focus on oil and gas industries.

The literature reviewed in this work and the experiences of the Institute of Architecture at the University of San Martín (IA-UNSAM) show that CE strategies alone are insufficient to improve the SWM efficiency in San Martín for sustainable urban development. The different socioeconomic conditions between San Martín and the Global North mean that the SWM strategies of the latter must be adapted to the Argentine context. Differing physical conditions could result in the poor performance of certain SWM technologies from the Global North if they were to be directly implemented in San Martín. Finally, the insufficient consideration of the social aspects of CE strategies (Boons and Howard-Grenville, 2009; Vanhuyse et al., 2021) suggests the need for categories to include this aspect. Such categories relate to the SWOT issues found in this work (Table A1-4).

5.1. *Perspectives on solid waste management in San Martín*

The main SWOT issues found in relation to SWM in San Martín were: 1) the informality/victimization and low levels of agency of non-profit organizations; 2) the fluctuating nature of the national economic crisis; 3) low efficiency in waste collection by municipalities and the recovery of waste by private actors; 4) the lack of awareness and policies about better waste separation at the source; 5) difficulties in developing new waste-based products certification and bring into market; and 6) the lack of cooperation between public institutions at different levels (local, provincial and national) to decide SWM policies. These issues connect with the high frequency of presence according to the PESTLE framework (Fig. 3).

Regarding the first issue of non-profit organizations, the market where cooperatives sell recovered waste material has high levels of intermediation and oligopolistic price regulation. As a result, the cooperative's incomes are unstable and usually unfair, as the government does not recognize the work of waste-pickers as a public service (Carenzo, 2020). Also, technological development in cooperatives is focused on the primary separation of cardboard, metal, and plastics. It is therefore still difficult for cooperatives to perform the more refined waste separation and processing that is necessary to reuse waste in product manufacturing. Hence, training cooperatives in the technical concepts of waste processing will be a key step in empowering them (Carenzo, 2014; Medina, 2007).

Regarding the issue of SWM policies, as long as Extended Producer Responsibility (ERP) law is not implemented, it will likely remain difficult to collect more funds for SWM. In places where an ERP law has been implemented, the volume of post-consumer products managed by municipalities was reduced (Lozupone, 2019). As the waste recovery rate (material resources) increases, progressively fewer funds (financial resources) would be devoted to future remediation. This argument has been used to support the financial value of IE, which promotes the allocation of funds to 1) research and education in industrial ecology; 2) financial assistance to small industries to invest in cleaner and more

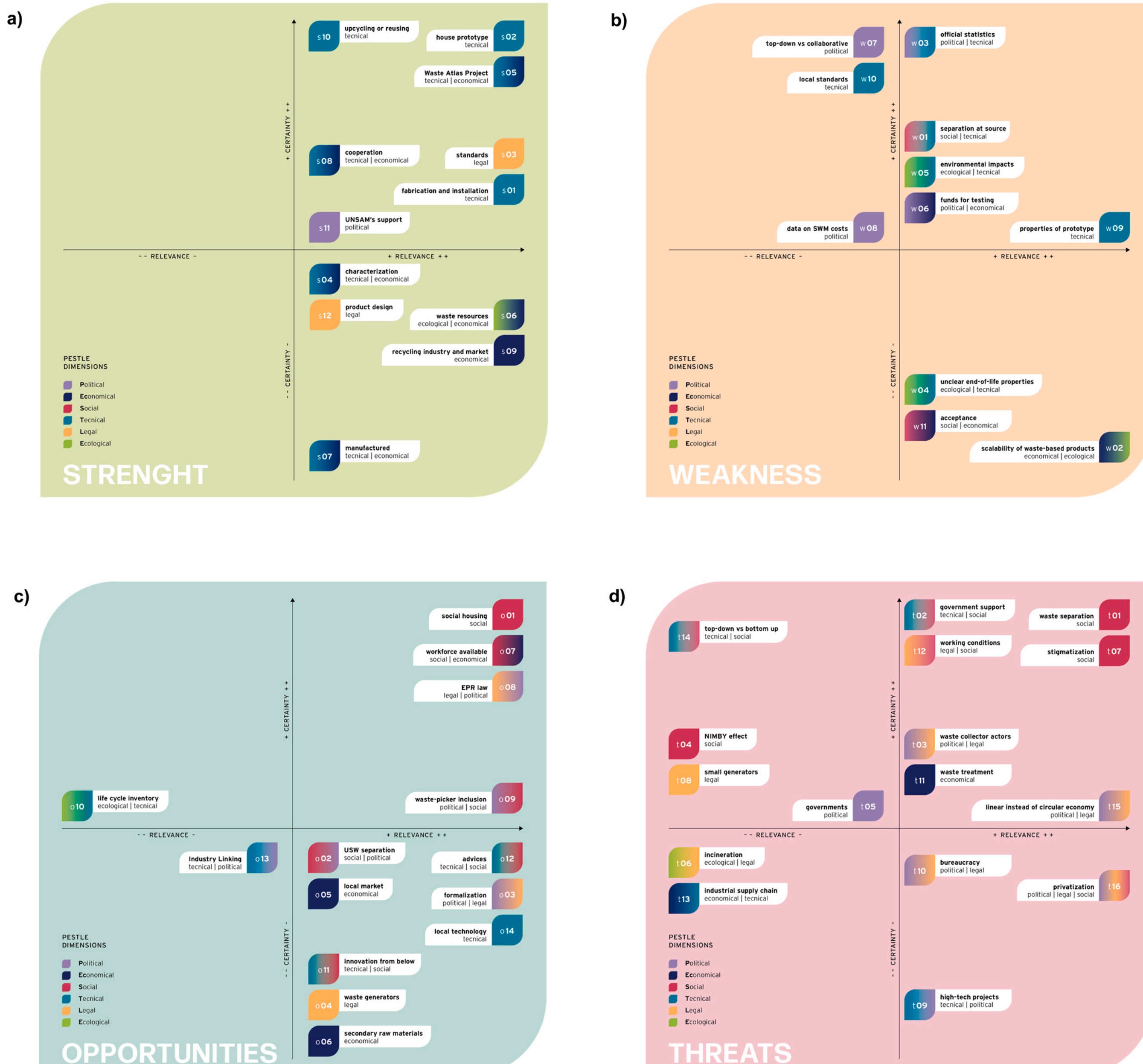

Fig. 4. Issues with solid waste management in San Martín, classified according to a SWOT analysis combined with the PESTLE framework. The information contained in each SWOT topic (grey boxes) refers to the highlighted words, enumeration, and PESTLE acronyms shown in Table A1-4.

efficient technologies; and 3) the monitoring of environmental parameters and human development indicators, the latter being especially relevant for the informal sector (Erkman and Ramaswamy, 2003).

With regards to the poor separation of waste at source and the low rate of segregated collection of USW in San Martín (Table A2 and A4), best practices from the Global North can be beneficial. Also, there is a lack of information on waste flows between SWM actors in San Martín (Table A2).

Some believe that the rate of recovery remains low due to the poor infrastructure and technology of non-profit organizations and suggest more investment in high-tech machinery for collection and recycling, following the practices of the Global North. However, López de Munain et al. (2021) report that high-tech companies in Buenos Aires maintain low efficiency and lower recovery rates than those carried out by non-profit organizations. The waste recovery rate of the MBT was less than 4 % of its capacity. Also, 87 % of waste from the CABA region treated by MBT ended up in CEAMSE landfills in 2019 (López de Munain et al., 2021). In contrast, the cooperatives and informal recyclers of CABA recovered 80 % of what was collected, amounting to 234.6 kt/year or 19 % of the total waste generated in CABA (López de Munain et al., 2021). Other authors also report high levels of manual recovery, which is related to the idea of an "integrated technology" that takes into account economic, sociocultural, and sensory perceptions in practices such as waste sorting (Carenzo, 2016). For example, training of the senses, such as smell, is required to inhibit the perception of nausea that arises in response to unsorted garbage. Such skills of “learned how to know” the materials emerge over time and can be transmitted (Carenzo, 2016). This “learned how to know” also occurs outside of top-down teachings (Carenzo, 2016). Despite these facts, government support for cooperatives and private sustainable destinations is unequal (Carenzo, 2020). In sharp contrast, high-tech companies generally have high levels of automation and require few personnel, which undermines the objective of employability proposed in this work (Fig. 1).

Incineration ("thermal recovery") is another recycling technology, but it is prohibited in Argentina by Law No. 1854/2005. However, there is

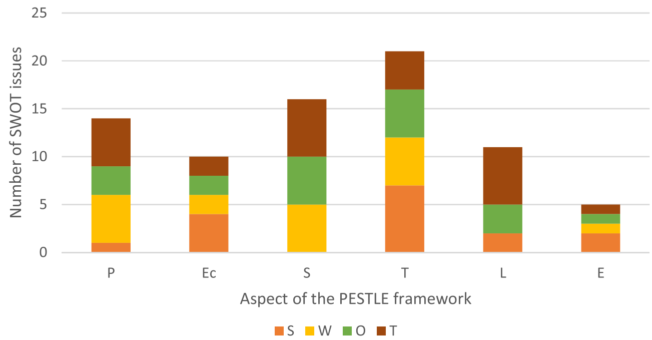

Fig. 5. Overview of the SWOT topics sorted by their affiliation in the PESTLE scheme.

still interest in installing such plants, hence "incineration" is marked as a threat in Table A4. The main barriers to developing incineration technology in Argentina are high investment costs, long payback period, and the high operating and maintenance costs of incineration plants (FARN, 2018). Furthermore, the warm temperate climate of San Martín (IRAM 11603) and the high organic content of USW (MADS, 2020) may contribute to difficulties in maintaining combustion, decreasing the profitability of incineration plants. These issues have already arisen in other areas of the Global South (Medina, 2007). In sum, the private sector and high-tech solutions play a significant role, but it would be naïve to rely on them alone to improve the efficiency of SWM in San Martín.

On the challenge of developing, certifying, and promoting the use of waste-based building products (Table A1-4), several authors have discussed these issues and provided guidelines on overcoming them. Asdrubali et al. (2015), who summarized more than twenty insulation waste-based products for buildings, observed that several products are still in the prototype stage and incompletely characterized. The authors concluded that poor characterization becomes a barrier to achieving certification and acceptance in the market. The certification of non-traditional building products, such as waste-based ones, encounters difficulties when the standards developed for traditional products are applied. For example, the PET bottle-based panel discussed above was characterized by an Argentinean standard (IRAM 11950) that does not cover bottle-shaped geometries for sampling. PET bottles were cut and thus adapted to the shape requirements of the local standard. Non-traditional products face skepticism from stakeholders as these products have less of a track record in the area of construction than traditional ones. On the other hand, the environmental and social benefits promoted by waste-based products have so far not been measured by the local standard in San Martín. The PET bottle-based panel shows additional benefits beyond the merely technical: environmental benefits in terms of soil recovery and emissions reduction, social benefits in terms of jobs creation in a region with low technological development and the improvement of quality of life, as well as economic benefits.

5.2. Developing an "adapted" eco-industrial strategy for sustainable urban development in San Martín

The principles and practices of IE can improve SWM in San Martín by collecting and organizing the data on waste streams treated and traded. IE seeks to achieve a symbiosis between SWM actors and their activities, as it combines the qualitative and quantitative tools of resource flows (Shenoy, 2016). IE could connect with initiatives already present in San Martín, such as industry linking platforms and cooperatives' software (Table A3). In this way, IE would provide a lens through which to understand where the "sharing" is taking place (Sahakian, 2016). Cooperatives can supply secondary raw materials more cheaply than imported options (Table A3), especially during an economic crisis in Argentina where the local currency is devalued (Table A4).

To address the difficulties highlighted above, several authors raised the need for decentralized and integrated SWM strategies to be developed in the Global South with different approaches for low-income neighborhoods and middle- to upper-income ones (Giampietro and Funtowicz, 2020; Saltelli et al., 2016). Among other factors, middle- to high-income neighborhoods tend to have different consumption patterns than low-income ones, with residents of the latter often engaging in waste-picker tasks while the "not in my backyard" (NIMBY) effect (Table A4) is strong in the former. Adaptive strategies on environmental issues should be preferred instead of unique ones, as there is a lack of knowledge on the long-term effects of the current strategies (Giampietro and Funtowicz, 2020; Saltelli et al., 2016). Therefore, the promotion of decentralized, integrated, adaptive, and flexible strategies for SWM should be encouraged. Giampietro and Funtowicz (2020) suggest that instead of imposing top-down plans (technocratic strategies), it is responsible and efficient to adopt flexible approaches that explore bottom-up plans. Cooperatives are a good example in this regard, as they seek mutually beneficial cooperation, encourage collective learning processes, and share and maximize services.

In San Martín, the bottom-up plans for SWM come from non-profit organizations, which can enhance the self-organization of socio-ecological systems and discussions on the role of institutional restrictions (Saltelli et al., 2016). Cooperatives in San Martín as self-organizations are adapted and included into the local socio-economic-technological conditions. IE can promote urban and industrial symbiosis by connecting self-organizing systems (Kaswan, 2014), which function according to principles of social and solidarity economy (SSE) (Sahakian, 2016). SSE focuses on people and power systems (the social dimension) while IE prioritizes biophysical limits, natural laws, and principles (the environmental dimension) (Sahakian, 2016). SSE experiences combined with industry have been developed in the Global North for decades, such as in Greece (Kalogeraki et al., 2018; Lowen, 2012; Poggiolo, 2011), Spain (Kalogeraki et al., 2018; Kaswan, 2014), and Switzerland (Kalogeraki et al., 2018). Practicing waste recovery instead of landfilling can lead to carbon-footprint reduction (Fujii et al., 2016), but this footprint decreases even more when municipal solid waste management (people and government) and local industries are linked (Geng et al., 2010).

It has been reported that the weakness of self-led organizations with SSE is the scalability of their activities, which has been the case with the cooperatives of San Martín (Table A2). This scalability could be encouraged by the "Innovations from below" approach (Table A3) and processes focusing on the "Responsible Research and Innovation" (RRI) approach (Inigo & Blok, 2019). RRI seeks to include all stakeholders and the public in the early stages of research and development through processes that anticipate, reflect, and practice responsiveness (Burget et al., 2017). Several authors highlighted various "innovations from below" developed by cooperatives being successful, some of these innovations are even competitive with inventions made by engineering departments specializing in them (Becerra et al., 2020; Carenzo, 2020).

6. Conclusions and outlook

The main challenges for building products from solid residues contributing to mitigate waste accumulation, housing shortages and unemployment in San Martín were identified with the help of a SWOT analysis combined with the PESTLE dimensions. Weaknesses and threats associated with social, political and legal problems were greater in number than within the other PESTLE dimensions. One of the major challenges is the non-awareness, undervaluation, and underestimation of the relevance, expertise and efficiency of waste sorting and processing by informal waste pickers and non-profit organizations (cooperatives). Recognizing these activities as a symbiosis between the urban and industrial metabolism, which is already taking place, could help to overcome the challenges and barriers (Gutberlet and Carenzo, 2020). The industrial ecology framework should consider these activities as urban-industrial symbiosis - especially, but not only - for global south contexts, which is generally associated with marginalized districts, also in countries of the so-called "global north" (Andrianisa et al., 2016; Wittmer and Parzieau, 2016). Yet, the recognition of this symbiosis "under the radar" in scientific epistemologies is, however, only a first step (Aparcana, 2017; Campos, 2015; Sandhu et al., 2017). The inclusion of the informal sector is fraught with stumbling blocks (Ezeah et al., 2013; Moh and Abd Manaf, 2017; Sandhu et al., 2017). One example is the health risks associated with working with waste (Ferronato et al., 2020; Parizeau, 2015; Raghupathy and Chaturvedi, 2013). The current experiences of social and solidarity economy in San Martín could be useful to support innovations from below and thus contribute to the socio-ecological issues addressed. Such innovations would have to be supported by responsible research and innovation to adapt to the social and economic reality (Burget et al., 2017; Carenzo, 2020; Inigo and Blok, 2019; Kalogeraki et al., 2018; Sahakian, 2016; Shenoy, 2016). An open point is how the public or private households feel about such a framework and whether promoting it locally leads to improved waste separation in private households and micro-, small-, and medium companies (separation at source), for instance. Taking this into account, an Eco-Industrial development strategy can reconcile different disciplines and stakeholders under a common narrative, aiming at sustainable development (Morone et al., 2016). Unlikely alliances between different social groups, like middle-class urban dwellers and informal waste-pickers can emerge (Demaria & Schindler, 2016). Informal waste-picking and yet recycling contributes significantly to greenhouse gas emission reduction, even if this is hardly known and recognized (King & Gutberelet, 2013). This strategy would allow to communicate and discuss the impacts of technical innovations regarding the economic, social, and environmental dimensions of sustainability in a balanced manner, fostering trust and cooperation and giving orientation for the construction of the regarding business models (Bolaane and Isaac, 2015; Carenzo and Sorroche, 2021; Fraccascia et al., 2019; Gall et al., 2020; Madsen et al., 2022).

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This study was supported by the Strategy Fund of Karlsruhe Institute of Technology (KIT), within a project called SPUK (Strategic Partnership UNSAM-KIT), and by a KIT Excellence Fellowship Grant for a research stay. During the research and the writing of the article the authors Danny Tröger and Prof. Dr. Andreas Braun were employed at KIT and like to thank SPUK coordinator Prof. Dr. Blümer for supporting the cooperation and research.

Appendix

See Tables A1-A4.

Table A1
Strengths.

	TOPIC (REF)	Pestle	Relevance	Certainty
S01	**fabrication and installation** Easy fabrication/installation of waste-based products studied by IA-UNSAM (Becerra, 2021)	T	++	+
S02	**house prototype** House prototype according to Argentinean standard (Becerra, 2021)	T	++	++
S03	**standards** Waste-based construction products meet Argentinean standards (Becerra, 2021)	L	++	+
S04	**characterization** Technical facilities for characterization of waste-based products (INTI, UNSAM) (Becerra, 2021)	T|Ec	+	-
S05	**Waste Atlas Project** Waste Atlas Project of IA-UNSAM as a tool for urban planning (Busnelli, 2018)	T|Ec	++	++
S06	**waste resources** Waste resources available at local level (Busnelli, 2018; MADS, 2020)	E|Ec	++	-
S07	**manufactured** Waste-based products studied can be manufactured by cooperatives (Becerra, 2021)	T|Ec	+	--
S08	**cooperation** Current cooperation cooperatives and IA-UNSAM	T|Ec	+	+
S09	**recycling industry and market** Availability of recycling industry and market (EIU, 2017)	Ec	++	-
S10	**upcycling or reusing** Waste-based products promote upcycling or reusing approaches instead of recycling	T	+	++
S11	**UNSAM's support** UNSAM's support in working with cooperatives (Sarandón & Schamber, 2019; Constantino et al., 2016)	P	+	+
S12	**product design** Product design adapted to local building rules/urban legislation/land use planning (Becerra, 2021)	L	+	-

CERTAINTY speculation (--), plausible guess (-), hard evidence (+), and knowledge (++)

RELEVANCE added value (--), aggravation of the circumstances (-), partial steps not possible (+), project not feasible (++)

STRENGHT

Table A2
Weaknesses.

	TOPIC (REF)	Pestle	Relevance	Certainty
w 01	**separation at source** Still weak separation at source of USW, which hinders the further quality of material recovered (EMHO, 2014; Pegels et al., 2021)	S|T	+	+
w 02	**scalability of waste-based products** Scalability of waste-based products (Asdrubali, 2015)	Ec|E	++	--
w 03	**official statistics** Lack of official statistics about the recovered flow of USW performed by waste pickers	P|T	+	++
w 04	**unclear end-of-life properties** Unclear end-of-life properties of waste-based products and eco-toxicological properties	E|T	+	--
w 05	**environmental impacts** Missing information on quantitative environment impacts of new waste-based products	E|T	+	+
w 06	**funds for testing** Lack of long-term and constant IA-UNSAM funds for testing of materials	P|Ec	+	+
w 07	**top-down vs collaborative** Lack of experiences on top-down vs. collaborative approach in San Martín (Carenzo, 2020)	P	-	++
w 08	**data on SWM costs** Lack of reliable data on SWM costs in municipality	P	-	+
w 09	**properties of prototype** Environmental/technical properties of prototype (e.g. house resilient to weathering?)	T	++	+
w 10	**local standards** waste-based products poorly covered by local standards and norms	T	-	++
w 11	**acceptance** Acceptance of new waste-based products. Traditional options vs non-traditional. Industrial inertia. Market acceptance of new waste-based products	S|Ec	+	--

CERTAINTY speculation (--), plausible guess (-), hard evidence (+), and knowledge (++)

RELEVANCE added value (--), aggravation of the circumstances (-), partial steps not possible (+), project not feasible (++)

WEAKNESS

Table A3
Opportunities.

	TOPIC (REF)	Pestle	Relevance	Certainty
o01	**social housing** Demand for social housing (informal settlements along river basin) (AIT, 2019)	S	++	++
o02	**USW separation** Municipal and cooperatives interest on USW separation at source (e.g. educational campaigning from "9 de Agosto" cooperative and "Día Verde" program) (San Martín, 2020)	S|P	+	-
o03	**formalization** Formalization of waste-picker (Law No. 992) and OPDS support cooperatives (Law No. 14273)	P|L	++	-
o04	**waste generators** Large waste generators pay for collection and recovery by OPDS (Law No 14273)	L	+	--
o05	**local market** Interest of local market in secondary raw materials, especially during economic crisis (Pegels et al., 2021)	Ec	+	-
o06	**secondary raw materials** Cooperatives supply secondary raw materials cheaper than imported options (Pegels et al., 2021; Navarrete & Navarrete, 2018)	Ec	+	--
o07	**workforce available** Workforce available at local level, especially during economic crisis (Navarrete & Navarrete, 2018)	S|Ec	++	++
o08	**EPR law** Extended Producer Responsibility (EPR) Law finance and empower waste-pickers (Pelgas, 2021; Grasso, 2021)	L|P	++	++
o09	**waste-picker inclusion** Organizations fostering the waste-picker inclusion (FACCYR, 2021; RITEP, 2022; Carenzo, 2020)	P|S	++	+
o10	**life cycle inventory** Ongoing construction of life cycle inventory (LCI) database for Argentinian products (RACV, 2022)	E|T	--	+
o11	**innovation from below** Experiences from below that improve the cooperative's performance in recovery (e.g., "Reciclando Sueños" cooperative (Carenzo, 2014))	T|S	+	--
o12	**advices** Advice from academia and private companies to improve the technology of cooperatives and thus obtain contracts with companies (Carenzo, 2020)	T|S	++	-
o13	**industry linking** INTI Industry Linking Platform registers and connects local technological solutions and demands of the SME sector. The Executing Unit for Comprehensive Management of Urban Solid Waste (GIRSU) develops a tool to calculate SWM cost and measures its performance. (INTI, 2022)	T|P	-	-
o14	**local technology** Cooperatives develop local technology to recover USW (Carenzo, 2014))	T	++	-

CERTAINTY speculation (--), plausible guess (-), hard evidence (+), and knowledge (++)

RELEVANCE added value (--), aggravation of the circumstances (-), partial steps not possible (+), project not feasible (++)

OPPORTUNITIES

Table A4
Threats.

	TOPIC (REF)	Pestle	Relevance	Certainty
t01	**waste separation** Lack of incentives to separate waste at source. Low perception on separation at source vs. other problems related to economic crisis. Lack of knowledge on separation at source policies. Poor rates of differentiated collection waste from houses (Schejtman, 2012; Lozupone, 2019; ENGIRSU, 2005)	S	++	++
t02	**government support** Poor government support to improve technology of cooperatives (Carenzo, 2020; Villalba, 2020)	T|S	+	++
t03	**waste collector actors** Waste collector actors (cooperatives, informal, and private) with asymmetry of power. Scarce representation of cooperatives in decision-making on SWM and government (EIU, 2017; Pegels et al., 2021).	P|L	+	+
t04	**NIMBY effect** NIMBY effect on the installation of new waste recovery centers (Savino, 2020)	S	--	+
t05	**governments** Low coordination and asymmetric responsibility between governments (local, provincial and national) on SWM (ACUMAR, 2011; Schejtman, 2012)	P	-	+
t06	**incineration** Recent interest in incineration practices that endanger the stream of recoverable waste (Bormioli et al., 2021)	E|L	--	-
t07	**stigmatization** Stigmatization about the work of waste-pickers (EIU, 2017; Pegels et al., 2021; Medina, 2007)	S	++	++
t08	**small generators** Small generators of waste are uncovered by OPDS (Law No 14273)	L	--	+
t09	**high-tech projects** High-tech projects with low employability and low efficiency (FARN, 2018)	T|P	+	--
t10	**bureaucracy** Bureaucracy that hinders the process to become a sustainable destination	P|L	+	-
t11	**waste treatment** Lack of interest in paying for waste treatment, as before Law No. 14273 it was free of charge. Large generators sell recoverable waste. Uninsured waste stream for cooperatives if they charge for their work	Ec	+	+
t12	**working conditions** Poor working conditions in cooperatives and informal sector (EIU, 2017; Pegels et al., 2021)	L|S	+	++
t13	**industrial supply chain** Industry imports primary raw materials instead of use from recycled sources (Murguía, 2022)	Ec|T	--	-
t14	**top-down vs bottom up** Lack of cooperation between bottom-top and top-bottom approaches (Carenzo, 2020)	T|S	--	++
t15	**linear instead of circular economy** Solid waste management focus on linear approach instead of circular one (Becerra et al., 2020)	P|L	++	+
t16	**privatization** High level of privatization when EPR laws appear, which would leave several social organisations out of waste management (Zapata et al., 2021)	P|L|S	++	-

CERTAINTY speculation (--), plausible guess (-), hard evidence (+), and knowledge (++)

RELEVANCE added value (--), aggravation of the circumstances (-), partial steps not possible (+), project not feasible (++)

THREATS

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