Section a: State of the art and objectives

DRAM in a nutshell

The main purpose of this project is to develop a breakthrough and still unexplored methodlogy to systematic Practically, the
of Systemic Distributed Recycling via Additive Manufacturing (SDRAM) is to establish a blueprint methodology for the implementation of micro-value chains of distributed recycling at a urban territorial level. We seek to the achievement of a three-level target: 1) Understand the establishment of a free-open source technical ecosystem that can be printed, 2) to establish a set indicators to possible help decision-makers and in the local implementation of these initiatives in Europe/(America?), 3) .....

Section a. State-of-the-art and objectives

In the current paradigm, value creation chains of industrial products are often globalized. The mass production system, understood as a deep transition[1], requires materials as well as human and physical capital to produce goods. This is the fruit of a complex co-evolution of single unit productions systems, interconnected systems, and industrial modernity that have been gradually intensified various forms of environmental degradation. Plastic waste contamination[2], climate change[3], biodiversity loss[4] are some examples of those degradations qualified as *wicked problems* characterized by their complexity, interdependence and contextual specificity[5]. These elements are majors markups of what is recently disscused as the Anthropocene era[6,7]. The Anthropocene frames the humans not only as biological but as geological force acknowledging the new status of humanity given the different indicators in the natural ecosystems that are impacting the stability of the earth system. Thus, the globalized mass manufacturing paradigm are leading to the transgression of the planetary boundaries[8–10]. Therefore, an new deep transition is needed to addressed for alternative socio-technical productive systems that take into account the natural capital and externalities[11] of human activites' since the fuzzy front-end desing phase of the innovation process.

The entry of the circular economy concept in the policy[12], industrial[13] and scientific[14–16] arenas as an umbrella concept, but also as a contested one[17–19], is bouleversing the design process to make clear that the ecological systems do not have nearly endless capacity to provide resources and adsorb wastes. Working to make cities more circular implies adopting a particular approach, using the concept of "territorial metabolism," designating "the set of energy and material flows brought into play by the functioning of a given territory"[**refBarles?**].
This approach consists of understanding cities as the result of a specific socio-ecological regime, no longer solely through their functions or activities, but through their flows and stocks of materials and resources. Many cities have taken up the resource management discourse to design circular economy action plans, which aim to reduce urban environmental impacts while generating new jobs, social well-being and room for innovation. Indeed, cities worldwide are committed to becoming more circular in their resource use, but whether or not their actions help them to reduce their environmental impacts is unclear. Particularly, the main deep challengue lies in the bridging the boundaries of urban and production systems as towards a one coherent, continuum and multi-scale design process[**ref?**].

Open source and digital commons for 'Design global / Manufacturing local'

The convergence of information and communication technologies (ICT) with digital fabrication capabilities of Additive Manufacturing (AM) is creating the appropriate knowledge-based social environments that enable independent production of modular hardware. This synergy could be transformed into a new disruptive paradigm of means of production for modular hardware[20]. It provides the possibility of mass diffusion of this technology, and consequently, AM is being recognised as a revolutionary technology that could up-end the last two centuries of approaches to design and manufacturing with profound geopolitical, economic, social, demographic, environmental and security implications[**Economist2012?**]

Therefore, as an alternative of globalized manufacturing values chains, a major trend in the development of production systems seeks to establish an urban production model[24,25] with decentralized and distributed characteristics[26,27]. Aiming at a *'design global / manufacturing local'*[28] seems a proto-industrialization[29] transition that is taking place in urban settlements that could a major impact in the next short future. The Open Source Appropriate Technology (OSAT)[30] and peer-to-peer (P2P)[20] approaches have been seen potential drivers to propose an alternative globalisation manufacturing paradigm[31]. The open source (OS) approach has become well-established to provide improved product innovation over proprietary product development[32–35]. The evidence is most mature for software development because free and open source software (FOSS) provides: i) diversification and open innovation[36–38], ii) cumulative innovation[39], iii) development efficiency[40], iv) organizational innovation[38], v) higher technical quality of code[41], vi) encourages creativity[42] and vii) perhaps most importantly, it avoids redundant work[43]. The OS approach is now also gaining traction in free and open source hardware (FOSH)[44–48] and appears to be roughly 15 years behind FOSS in development and adoption[49]. One of the primary drivers, is that all forms of free and open source technology software and hardware (FOSS and FOSH) can provide a substantial cost savings[50–53]. The open source additive manufacturing technology, also know as 3D printing, have played a major role in the idea of democratization of manufacturing means[54]. In particular, material extrusion based units are widely used, thanks to the simplicity of operation, the Do-It-Yourself (DIY) approach and the open-support communities. Thousands of open-source products are shared by the global community from consumer goods to scientific[55] and medical equipment[55,56]. This model has been proven to be effective for emergency manufacturing during the COVID-19 pandemic[55,57]. This is a driver communities to fabricate their own products for less than the price of purchasing them. In that sense, the concept of urban factory is evolving as a disruptive approach and is the materialization of this manufacturing paradigm. The urban factory is defined as "*a factory located in an urban environment that is actively utilizing the unique characteristics of its surroundings*". It creates products with a focus on the local market and allows customer involvement during value creation[24,58].

Major long vision: Circular and convivial production

Today, a major societal issue rely on how to conceived socio-technical 'circular units' for manufacturing that integrates values of sobriety**[ref?]**, resilience[59,60], adaptability[61] and evolutive in urban settlements. The reuse, repairing, recycling approaches will need to converge in a post-growth economy context considering the societal issues of resource scarcity and waste accumulation in the urban settlements[62,63]. Indeed, today the establishment of these socio-technical systems need to include all ecosystem externalitites and the carrying capacity of the ecosystem to claim to sustainability[64,65]. The trend is reinforced by the fact that by 2050, it is expected that about 70% of the world's population will live in urban settlements[63]. Urban cities will be responsible for non-negligible environmental impact[66,67], producing about 50% of global waste, and 75% of greenhouse gas emissions which affects the sustainability of cities[68] and the quality of city life[69].

Distributed recycling for additive manufacturing: a promising inclusion

Since 2014, I have been working on the validation of the open-source 3D printing, filament-[70] and pellet-based[71], as a robust manufacturing system, but also as a potential enabler of the mechanical recycling[72–74] of plastic waste feedstock. Likewise, I have been working on the design of the pertinent closed-loop supply chain[75,76], considering the applicable sustainability indicators[77] based on the scientific literature. In a recent paper[78], I could highthligh a great interest by the scientific community of this topic which is called *distributed recycling for additive manufacturing (DRAM)*. DRAM (See Figure 1) is a breakthrough promise in the constitution of a micro-circular industry units to validate the technical feasibility, and several technological pathways are maturing to allow individuals to recycle waste plastic directly by 3D-printing it into valuable products.

To appreciate the ground-breaking scientific nature of this idea, let me state that the plastic production increased at compound annual growth rate of 8.4%, passing from $2Mt$ in 1950 to $368Mt$ in 2019, but about 9% have been recycled while 79% was accumulated in landfills or the natural environment[79]. Historically, the plastic recycling has been oriented to centralized facilities in order to take advantage of economies of scale through the production of low-value products. However, it is proved to be an expensive process

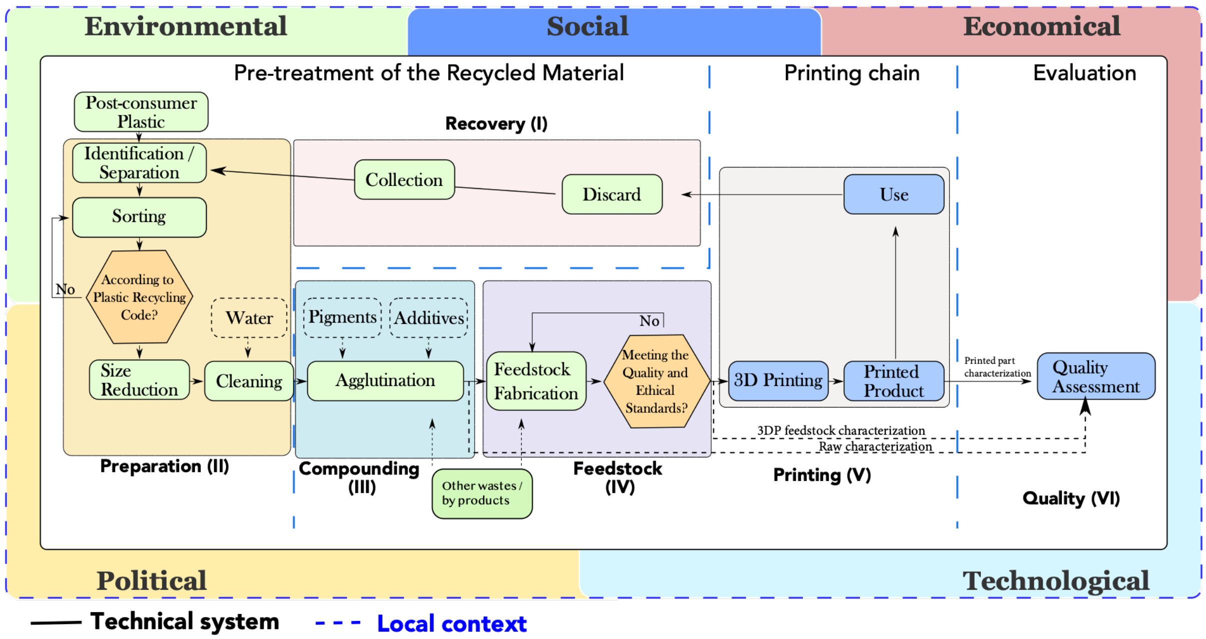

Figure 1: Distributed recycling via additive manufacturing. Source

due to the inherent separate collection, transportation, processing and remanufacturing[80,81]. On the other hand, DRAM can starts with local plastic waste that is produced everywhere from packaging to broken products (*Recovery (I)*). It is washed, dried and then ground or cut into particles using a waste plastic granulator or office shredder (*Preparation (II)*). The raw material for FFF can be manufactured economically using distributed means with a waste plastic extruder (often called a "recyclebot")[82] for mono or composite materials (*Compounding (II) and Feedstock (IV)*). Filament made with a recyclebot costs less than 10 cents per kg, whereas commercial filament costs $20/kg or more. This can produce valuable products at remarkably low costs. For example, using a recyclebot/3D-printer combination can produce over 300 units (e.g., camera lens hoods) for the price of one such item listed on marketplaces (e.g. Amazon). Fused granular fabrication is a recent experimental approach enabling the printing process directly from pellets[83,84], which reduces the degradation cycles of the plastic. For this process, I worked in the desktop format[71], but it seems that this technology could further expand the boundaries of additive manufacturing and eventually recycling[85–87] for larger object[88].

`<!-- OPen source approach -->`

Distributed recycling fits into the circular economy paradigm[89–91], as it eliminates most embodied energy and pollution from transportation between processing steps. Also, it decreases the embodied energy of filament by 90% compared to traditional centralized filament manufacturing using fossil fuels as inputs[92–94]. Additionaly, open-source investment should result in an extremely high return on investment (ROI)[55]. This makes distributed recycling environmentally superior to other methods of plastic recycling systems.

However, I realized that the global system maturity is ambiguous given that not all the value chain for the implementation of a community-driven of plastic recycling are matured[78]. Major efforts in the scientific literature have been only concentrated in the materials and technical validation.
However, the system validation remains to be difficult to implement. More important, the analysis of the holistic impact that this process can have in the context of a city remains not well understood. In the framework of a EUH2020 project called INEDIT[1], I have been leading the implementation of the *Green Fablab* demostrator inside the third place called Octroi-Nancy Association [2] since November 2021[3].

[1]See https://cordis.europa.eu/project/id/869952
[2]See https://www.octroi-nancy.fr/
[3]This demostrator found retard because of the pandemic situation.

INEDIT project aims to create an ecosystem to transform the DYI practices largely documented in FabLabs/Hacker/Maker spaces into a professional approach called Do-It-Together to capitalise on the knowledge, creativity and ideas of design and engineering. The Green Fablab is a distributed recycling demostrator that that use living lab approach[95,96] to experiment in real conditions with citizens, final users and large general public. This experiment is enframed as a design for sustainability at a socio-technical system level[97]. We have collected and recycling around 100kg of plastic waste for the pedagogical and architectural uses given the fact that we are connected with a creative ecosystem of designers and makers participatin in the Octroi-Nancy projet. This hands-on experience confirms the literature that a new recycled resources industry is starting to conceived inside the cities[98]. This industry is seen as driver consists of a series of activities related to recycled resources – e.g., recycling, refining, remanufacturing, etc. – aspiring to mitigate the negative externality caused by the linear economy. The sustainable development of the RRI has thus been highlighted on many countries' agendas to promote the circular society[99–101], as well as the goals of carbon peak and carbon neutralization. In the case of plastic waste, the main difficulty remains to make affordable the use of new secondary material applicability by the industry[102], but more profoundly, how these socio-technical experiments will interact with the urban planning process and policymaking to make concrete the ambition of circular economy inside the urban and regional settlements.

2. Ambition & objectives

The material rarefaction[103], the ecological integration of manufacturing systems[65,104,105] and the urban resilience[106] calls for pushing forward the boundaries of knowledge of the urban production systems to unleash a sustainability transition towards circular economy. Therefore, the main objective of this project is **to establish a systemic methodological blueprint to fully understand how to design, implement and (e)valuate an open source distributed manufacturing/recycling production systems for an urban values chains inspired on the "Design Global / Manufacturing local" principles**. The deployment of circularity marks a return to a more productive conception of the city, that must consider the natural and urban ecosystem services, the strength the resilience capacities and take into account the energy sobriety of european territories. Thus, this project seeks two level targets: 1) The scientific understanding of the design of socio-technical configurations of distributed production/recycling systems as a circular economy strategy in urban settlements. 2) Holistic and pluralistic (e)valuation of the pertinence of the open source appropriate technologies, practices and potential innovation as an assets for urban territorial development. Table XX presents an outline of the three major layers to consider in these project.

Challenge 1: The role of urban system in the deployment of the circularity.

In order to identify the design process of an urban circular production system, some relevant questions are the following:

- What are the acceptability conditions for the deployment of urban circular economy initiatives ?
- How to establish the link to integrate territorial planning priorities with respect to production systems priorities within an urban circular economy context?
- How to dimension production systems to be consistent with the resources and materials (first and second hand) considered as local?
- How to identify the opportunities and barriers from a social, technological, political and legal point of view for the implementation of an urban production network?
- What strategies can be implemented so that socio-technical systems of circular production can be in line with urban needs and their contribution to the SDGs?
- How to establish an open source value chain in order to foster resilience and technological and energetic sobriety of the urban territory?
- How would the implementation of urban production systems affect the functional blocks of an urban territory?

Challenge 2: Understand the open source technodiversity as territorial asset.

To implement an open source appropriate technology ecosystem suitable for circular urban production system, some relevant research questions are the following:

- How to design a technodiversity baseline based on open source appropriate technologies (OSAT) for distributed and circular production?
- How can the design process of an appropriate open source technology be analyzed to avoid what is known as the Jevons paradox?
- How to facilitate the adoption of open source practices and tools, for a public that goes beyond the fablab/makerspaces that have been pioneers?
- What would be the relevant business model for open hardware adoption to allow the introduction of open source tools and practices?
- How to evaluate the degree of maturity of a small company so that within its strategy it can implement the adoption of open hardware as a disruptive practice?
- What open source technologies needed to develop and implement a urban closed-loop suply chain ?
- How open source technologies would allow the development of urban productive systems in coherence to favor the resilience of the territory?
- What are the core competences needed in an open source ecosystem for urban circularity?

Challenge 3: Pluralistic (e)valuation of circular and urban production systems.

In order to (e)valuate in a pluralistic way the development and implementation of urban production units, some relevant questions are the following:

- How to connect ecological and economic indicators within the same evaluation framework?
- Which territorial and production system indicators would make it possible to establish a minimum scale of operation, but also a maximum scale that respects urban ecosystem services?
- How to establish scenarios of evolution and impact so that territorial decision-makers can encourage the adoption and piloting of these initiatives?
- What would be the relevant functional unit to delimit the range of action of the production/recycling system within the urban metabolism?
- What are considerations the necessary to represent the preferences of the stakeholders in the decision-making process of integration urban / manufacturing systems?

Section b. Methodology

3. Introduction the scientific methodology

SDRAM implement a methodology made of four working packages (WP), as illustrated in Fig. 2. The aim of WP1 is to set a baseline for an integrative and critical analysis of urban territory in the frame of micro-value chains for manufacturing/recycling production. This working package gives the insights for the WP2, and WP3, which are key of the project. The WP2 seeks to consolidate systematize a design process for OSAT for a complete distributed manufacturing/recycling process establishing an unit maturity level index for each, but more important, a system maturity level for the integration in a urban ecosystem. The WP3 aims to identify a pluralistic (e)valuation framework for the urban closed-loop system network integrating three essential issues: sustainability, resiliency, and agility into a circular economy praxis.

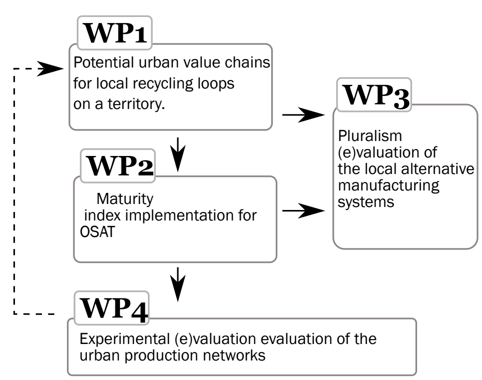

Figure 2: Methodology

Finally, WP4 is dedicated to the experimentation of the several products case studies of the urban circular manufacturing taking into at case studies the implementation of the Green Fablab Project at the third place of OK3 at Nancy-France. The object is to replicate this analysis in other territories such Chile, in collaboration with Prof. Pavlo Santander, and in Canada with collaboration of Joshua Pearce, Grece with , Germenay... Work packages are synthetically detailed hereinafter.

WP 1: Theoretical baseline on urban value chains

WP1 aims at developing a integral methodology that to diagnose, quantify and evaluate the potential urban value chains for distributed recycling loops on a territory considering the ecological priorities of the territory. The achievement to SDRAM target relies the urban spatial analysis and stakeholders characteristics as an entry point of the design of the socio-technical system mapping two major outputs: 1.1) The first output aims to highlights: (a) the identification of the priorities in terms of ecosystems services of the territory at the urban planning level, and how the plastic waste material affects them. (b) the evaluation (technical, economic and environmental) of the current waste management system to identify the ' of the limits of the loop chains , existing plastic 'gaps' that distributed recycling approach can fill, and (c), a stakeholder characterization analysis needs (e.g. sorting centres, recycling centres, schools). Then in 1.2), the second output aims to close the existing data gaps[107] in terms of secondary material availability at the urban level considering its complexity level of revalorization. The goal is to couple *{territory x material}* together as a material flow quantitative analysis to assess the potential to material for a closed-loop supply chain. This is particularly relevant in the context of plastic products where governments worldwide are placing ambitious circularity targets due to the accumulation. The priority is to reveal a list of 'suitable' secondary plastic materials wastes at the urban level that today are not fully understood and valorized. This analysis will be carried out at least every year, and if possible more frequently to see if there is a change or seasonality in the composition of this untreated waste.

WP 2: Maturity level and technodiverstity level of the open source appropritte technology

The WP2 will be focused on the unit- and facility-level to better understand how OSAT can be implemented in urban micro-recycling systems. The main purpose of this task is to leverage a resilient manufacturing[106,108] under the logic of Design Global/Manufacture Local robustness. To do so, three major tasks are seen:

2.1) definition of a scientific literature and critical analysis on the adoption[109] and barriers of the open-source appropriate technologies with particular focus on distributed recycling considering the modularity types[110], gaps in the hardware development and .
2.2) Mapping of new/adapted practices and tools that would be needed to support local manufacturers and local decision makers to navigate and overcome the challenges of distributed recycling manufacturing.
2.3) Identification a system maturity level that enable the constitution of urban closed-loop supply chain . ...

WP 3: Pluralistic (e)valuation of distributed recycling systems

In parallel of WP2, the WP3 aims to consolidate aid-decision tool to reveal and better understand under which conditions these distributed recycling/manufacturing urban chains are pertinent for the local territory. This tool describe and characterize the new value chain to include new form of pluralism valuation[111] and techno-ecological interactions[105,112,113]. More important to avoid Jevons paradox[114], it is determine the scale of action considering the technical maturity, economic viability and environmental respect of the ecosystem services. In (4.1), one strategical point in sustainability relies on explicitly account for their demand and supply of of ecosystem goods and services framework given by the micro-value chains[115]. then (4.2), the main aim is to reveal the components and the structure of the urban circular networks to the combining Material Flow Analysis[116], System Dynamics[117–121] and Circularity Indicators[122].

WP 4: Experimentation and deployment in function of the local territory

The WP4 aims to consolidate a starting point for a longitudinal study[123] to evaluate of the implementation these distributed recycling strategies at a urban territorial level. WP4 is devoted to the iteration and evaluation of the urban production networks to deep understand the evolution. 4.1) Several case studies of distributed fabrication / recycling will be documented and developed in complement with a comparative and contextualized Life Cycle Assessment (LCA) of the new secondary AM material compared to actual materials. 4.2) A strategic roadmap will be a major delivered to understand the possible evolution of

To pass from ecodesign to an operation design for sustainability approach, this WP4 will be based ten different models at operational, tactical, and strategical levels[124].

3. Conceptual risk and fesability assessment

SDRAM is a high operation and conceptual-risk project mainly because the integration of multiples disciplines in a one basis framework need to establish boundary object to have a coherent framework.

Table 4: ss

ID	Risk items	Effect of the risk	Causes of the risk	Grade	Actions to minimize the risk
1	Difficulty to data access to local territorial diagnosis	Constraint to define WP1		Middle	There have been pre-exists between the partners and these territories and recycling actors.
2					
3					

Table 5: Feasible challengues in the methodology

ID	Main challengues	Feasibility
1	Theoretical baseline on urban value chains	
2	Maturity level and technodiverstity level of the open source appropritte technology	
3	Pluralism (e)valuation of the distributed recycling systems	
4		

4. An Impact project

- **Main scientific impacts.** (1) the breakthrough understating of the implementation and evaluation of the design of sustainability of socio-technical systems
- **Main societal impacts.** If the expected modeling are confirmed, the outcome of this pproject will allow urban and technical desicion-makers the implementation of local recycling circuits of available plastic waste by means of small, ro distribed recycling socio-technical units.

5. Resources and budget

The research team

The budget required for the development of SDRAM is XXX €. The most significant cost is the personnel cost (XXXX € - XX %). Minor cost cover the purchase of open hardware equipement (XXXX € - XX %), travels for dissemination of results (XXXX € - XX %), Open access fees for at least 8 publications (XXXX € - XX %). %

	Semester (S)									
Activity	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
WP1:										
WP2:										
WP3:										
WP4:										

Figure 3: Gantt diagram and task allocation

As for me, I will dedicate 42 p.m. of my work to manage this five-year exciting project. I will manage each phase of the project, in the full awareness of the responsibility that I will have in its successful realization, which highly depends on my capability to -humanely and scientifically- conduct, coordinate and supervise the activities carried on by the scientific team.

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