# Section a: Extended Synopsis of the scientific proposal [max. 5 pages]

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| DRAM in a nutshell |
| The aim of Systemic Distributed Recycling for 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) Undertand 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) ….. |

## 1. The State of the art.

### Arriving to the limits for global and mass manufacturing paradigm

Plastic waste contamination[1](#ref-de-la-torre2021), climate change[2](#ref-stoddard2021), biodiversity loss[3](#ref-hermoso2022) are relevants indicators of what is recently disscused as the Anthropocene era[4](#ref-steffen2018),[**steffen2011?**](#ref-steffen2011). The anthropocene frames the humans not only as biological but as geological force acknowledging the new status of humanity given the different markups in the ecosystems that are impacting the stability of the earth system. The globalized mass manufacturing paradigm have played a major role not only as motor for the economic development, but also the transgression of the planetary boundaries[5](#ref-ONeill2018)–[7](#ref-Rockstrom2009). The mass manufacturing socio-technical systems is understood as a deep transition[8](#ref-kanger2022), where a co-evolution of single unit productions systems, interconnected systems, and industrial modernity have been gradually intensified various forms of environmental degradation while not being able to solve recurring issues of social inequality in connection to unequal access to healthcare, energy, water, food, mobility, security, finance, education, and communication. The economic development was often triggered and catalyzed by the introduction of new technologies and concepts for value creation, as shown by the historical industrialization trends.

Manufacturing requires materials as well as human and physical capital to produce goods. Even if the importance of manufacturing as the heart of an economy has not changed, the way of producing goods and the setup of the location start to change dramatically.

The design of manufacturing systems developed the implicit assumption that ecological systems have nearly endless capacity to provide resources and adsorb wastes. This blindness in the engineering vision can be explaining by the fact that at the beginning of the technological industrialization, the human activites’ impacts on the earth remained marginal. This scenario is not true today.

### Major long vision: Circular and production

Today, a major societal issue rely on how to conceived socio-technical ‘circular units’ for manufacturing that are resilient[9](#ref-touriki2021),[10](#ref-VanFan2019), adaptable[**ref?**](#ref-ref) and evolutive in urban settlements. The reuse, repairing, recycling approaches will need to converge in a post-growth economy context need to integrate the related societal issues of resource scarcity and waste accumulation in the urban settlements[11](#ref-kallis2018),[12](#ref-savini2021). Indeed, today the establishment of this socio-technical systems need to include all ecosystem externalitites and the carrying capacity of the ecosystem to claim to sustainability[13](#ref-Bakshi2019a). 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[12](#ref-savini2021). Urban cities will be responsible for non-negligible environmental impact, producing about 50% of global waste, and 75% of greenhouse gas emissions which affects the sustainability of cities and the quality of city life[14](#ref-Riffat2016).

### Open source and digital commons for ‘Design global / Manufacturing local’

As an alternative of globalized manufacturing values chains, a major trend in the development of production systems seeks to establish an urban production model with decentralized and distributed characteristics[15](#ref-Herrmann2020). Aiming at a ‘design global / manufacturing local’ seems a proto-industrialization[16](#ref-sabel1985) transition that is taking place in urban settlements that could a major impact in the next short future [@]. The Open Source Appropriate Technology (OSAT) and P2P approaches have been seen potential drivers to propose an alternative globalisation manufacturing paradigm[17](#ref-Heikkinen2020a). The open source (OS) approach has become well-established to provide improved product innovation over proprietary product development[18](#ref-dibona1999)–[21](#ref-deek2007). The evidence is most mature for software development because free and open source software (FOSS) provides: i) diversification and open innovation[22](#ref-colombo2014)–[24](#ref-alexy2013), ii) cumulative innovation[25](#ref-boudreau2016), iii) development efficiency[26](#ref-hienerth2014), iv) organizational innovation[24](#ref-alexy2013), v) higher technical quality of code[27](#ref-soderberg2015), vi) encourages creativity[28](#ref-martinez2015) and vii) perhaps most importantly, it avoids redundant work[29](#ref-Ardal2016). The OS approach is now also gaining traction in free and open source hardware (FOSH)[30](#ref-thompson2011)–[34](#ref-li2018) and appears to be roughly 15 years behind FOSS in development and adoption[35](#ref-pearce2018). 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[36](#ref-petch2014)–[39](#ref-wittbrodt2013). The open source additive manufacturing technology, also know as 3D printing, have played a major role in the idea of democratization of manufacturing means [@]. Thousands of open-source products are shared by the global community from consumer goods to scientific[@] and medical equipment[@]. This model has been proven to be effective for emergency manufacturing during the COVID-19 pandemic[40](#ref-Pearce2020a). 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[15](#ref-Herrmann2020),[41](#ref-Ijassi2022).

### Distributed recycling for additive manufacturing: a promising inclusion

Since 2014, I have been working on the validation of the open-source 3D printing as a robust manufacturing system[42](#ref-CruzSanchez2014), but also as a potential enabler of the mechanical recycling[43](#ref-Cruz2015),[44](#ref-CruzSanchez2017) of plastic waste material. This scientific topic is called distributed recycling via additive manufacuturing (DRAM) (See [Figure 1](#fig-DRAM)). DRAM is a breakthrough promise in the constitution of a micro-circular industry units to validate the technical feasibility, and several technologic pathways are maturing to allow individuals to recycle waste plastic directly by 3D-printing it into valuable products.

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| Figure 1: Distributed recycling via additive manufacturing. Source |

### DRAM:

To appreciate the ground-breaking scientific nature of this idea, let me state that the most adopted form of additive manufacturing is fused filament fabrication, which is a material extrusion process [@]. DRAM starts with waste plastic that is produced everywhere from packaging to broken products. It is washed, dried and then ground or cut into particles using a waste plastic granulator or office shredder. Next, the particles are either converted to 3D-printing filament using a recyclebot or printed directly. 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 Amazon.com. The raw material for FFF can be manufactured economically using distributed means with a waste plastic extruder (often called a “recyclebot”)[45](#ref-Baechler2013). Recycling of plastic waste into 3-D printing filament decreases the embodied energy of filament by 90% compared to traditional centralized filament manufacturing using fossil fuels as inputs[46](#ref-Kreiger2013),[47](#ref-Zhong2017). Distributed recycling fits into the circular economy paradigm[48](#ref-Zhong2018)–[50](#ref-Despeisse2016), as it eliminates most embodied energy and pollution from transportation between processing steps. Additionaly, open-source investment should result in an extremely high return on investment (ROI) in free and open source hardware[**ref?**](#ref-ref). This makes distributed recycling and additive manufacturing (DRAM) environmentally superior to other methods of plastic recycling.

However, from a scientific perspective using a systematic literature review, I realized that the global system maturity the technical value chain for the implementation of a community-driven of plastic recycling is ambiguous[51](#ref-CruzSanchez2020). 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 in deep, the analysis of the holistic impact that this process can have in the context of a city remain not treated at all. Moreover, I have been leading the implementation of the demostrator Green Fablab in the framework of an European project which is a sustaiability trasition for the urban plastic in a living lab approach.

In particular, this will is important if a recycled resources industry (RRI) is starting to conceived inside the cities. RRI 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[52](#ref-wang2019b). The sustainable development of the RRI has thus been highlighted on many countries’ agendas to promote the circular society[53](#ref-leipold2021)–[55](#ref-jaeger-erben2021a), as well as the goals of carbon peak and carbon neutralization. The main difficulty remains to make affordable the use of new secondary material applicability by the industry[56](#ref-klotz2022), but at the end, for urban planning and polycimaking to make concrete the ambition of circular economy inside the urban and regional settlements.

## 2. Ambition & objectives

The material rarefaction[57](#ref-hultman2021), the ecological integration[**ref?**](#ref-ref) and the resilience of production systems[**ref?**](#ref-ref) remains a systemic problem and it calls for pushing forward the boundaries of knowledge in the fuzzy front-end design phases of socio-technical manufacturing configurations. There is a urgent necessity to better understand how to develop, implement and evaluate socio-technical circular demonstrators at urban levels to unleash a sustainability transition towards appropriate and inclusive micro-manufacturing and recycling values chains inspired on the *“Design Global / Manufacturing local” principles*. By exploring the case of Green Fablab At Octroi Nancy, **the purpose of SDRAM project is create a systemic blueprint methodological approach to fully expand the frontiers of the design socio-technical manufacturing systems as a sustainable transitions in urban settlements.** To do so, the SDRAM project aims to deep understanding of the three major layers and the boundary objects between them:

1. Urban space in the lens of material rarefaction and the urban manufacturing opportunity.
2. Design for a technodiversity baseline based on open source appropriate technologies (OSAT) for distributed recycling, and
3. Pluralism (e)valuation of socio-technical system alternative to mass production in frame of a urban sustainability transition.

#### Manufacturing and an urban priority for resilience and agility.

The significance and main challengue of sustainable urban production lies in the bridging of disciplinary boundary of urban and manufacturing systems fields[58](#ref-Tsui2020). One major drawback is the lack of holistic and shared framework to connect. There is an opportunity to create a City-Factory-Product nexus understanding that aims to be adaptable, relient and considering the carrying capacity of the ecosystem.

#### The open-source appropriatte technology (OSAT) as alternative.

The OSAT relies on small-scale, economically affordable, decentralised, energy-efficient, environmentally sound and easily utilized by local communities to meet their needs [@]. This approach have been valuable for scientific equipement to reduce the cost with equal of quality [@], and having implication in national policy for research equipment at national level[17](#ref-Heikkinen2020a). Therefore, this strategy to complete the technodiversity is a breakthrough to possible open up the valorization of material loops inside urban settlements fostering the creation of closed-loop supply chains. The establishment of development of a technological open source maturity level focalised on the distributed recycling of the design of an open source appropriate technical ecosystem (OSAT) is part of the technical blueprint.

#### Systemic design thinking to identify major feedbacks in the strategic, the tactical and the operational decisional levels.

Reconciling urban development and industrial development is not an easy task. Thus, the type of information that decision-makers take into account is relevant at the moment to put in place industrial systems.

#### Pluralism valuation for emerging industrial micro-values chains that integrate ecosystem characteristics.

The integration of ecological aspects in the decision-making seems not evident given the complexity to define the boundaries and interactions of industrial and ecological systems. However, It is urgent to expand the boundaries for engineering design from the lowest molecular level to the process level, and from individual process to the higher levels of value chains, ecosystems and the planet[59](#ref-Martinez-Hernandez2017). We need to integrate ecological carrying capacity since the fuzzy front end phase of an industrial systems.

The ambition of this project is to open up the possibilities of a new field of socio-technical design of distributed and circular urban production systems to the scientific community.

### A challenging task for a systemic blueprint

The major gap that currently prevents from exploring the potential of alternative distributed and circular manufacturing relies on a knowledge gap in terms of the maturity in the connection between the unit-facility-urban levels including the respective boundaries objects that needs to be considered between the layers. From a design for sustainability[60](#ref-Ceschin2016),[61](#ref-SousaRocha2019) perspective, this implies the aid-decision tools to help makers, practitioners and decision-makers in the implementation phase considering the technosphere (molecule, material, process unit) but also the also to the ecosystem impact. Therefore as a systemic blueprint, I aim to make linkage of the micro-meso-macro levels of the technical, system and valuation layers embed in a urban spatio-temporal context (See Figure network)

Rethinking the design of efficient and effective production system under the perspective of small and modular machines in combination with the means provided by rapidly increasing digitalization can support the development of sustainable and competitive urban production systems.

Urban production systems can be developed in a way that is sustainable and competitive by rethinking the design of efficient and effective production systems from the perspective of tiny and modular machines in conjunction with the tools afforded by rapidly rising OSAT.

## 3. The Methodology

SDRAM implement a methodology made of four working packages (WP), as illustrated in Fig. .

The aim of WP1 is to set a literature baseline for an integrative and critical analysis of urban territory in the frame of micro-value chains for local recycling loops. 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 establishing an unit maturity level index that could foster the consolidatation of the OSAT, but more important, a system maturity level for the integration in a urban ecosystem. The main goal is to establish a complete OSAT ecosystems to valorize the waste niches opportunities identified in WP1.  
 The WP3 aims to identify a set of (e)valuation framework for the urban closed-loop system network integrating three essential issues: sustainability, resiliency, and agility into a circular economy praxis. 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. Work packages are synthetically detailed hereinafter.

### WP 1: Theoretical baseline on urban value chains

WP1 aims at developing a integral methodology 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 possible identify 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 unused waste niches affects them. (b) the evaluation (technical, economic and environmental) of the existing valorization loop chains identifying the limits of the current system, and (c) 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 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 problematic in all ecosystems but is particularly relevant in the context of plastic products where governments worldwide are placing ambitious circularity targets due to the accumulation. This task priority is to reveal the list of ‘suitable’ secondary materials niches 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 found the recycling maturity level of the complete distributed recycling technical chain, thus two major tasks are seen: 2.1) definition of a scientific literature and critical analysis on advantages and barriers of the implications of the open-source appropriatte technologies with particular focus on distributed recycling for additive manufacturing. 2.2) Identify a system integration level that enable the constitution of closed-loop supplying chains. gavras2021

### WP 3: Pluralism (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 micro 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[62](#ref-gunton2022) and techno-ecological interactions[63](#ref-Liu2020c)–[65](#ref-Saladini2018). More important to avoid Jevons paradox, 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[66](#ref-Diwekar2021). 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 [22], System Dynamics [21,22] and Circularity Indicators [39].

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

The WP4 aims to consolidate a starting point for a longitudinal study 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 undertant 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[61](#ref-SousaRocha2019).

## 3. Conceptual risk and fesability assessment

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

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| 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 |  |  |  |  |  |

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 |  |
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## 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 %). %

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