

ERC Starting Grant 2023
Research proposal [Part B1]

My project title

ACRO

- Principal investigator (PI): My Name
- Host institution: My University
- Full title: My project title
- Proposal short name: ACRO
- Proposal duration: 60 months

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

i 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 contamination¹, climate change², biodiversity loss³ are majors markups of what is recently disscused as the Anthropocene era^{4,5}. 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. 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 boundaries⁶⁻⁸. The mass manufacturing socio-technical systems is understood as a deep transition⁹. Manufacturing systems requires materials as well as human and physical capital to produce goods. The co-evolution of single unit productions systems, interconnected systems, and industrial modernity have been gradually intensified various forms of environmental degradation^{ref?}. This co-evolution remains not to solve recurring issues of social inequality in connection to unequal access to healthcare, energy, water, food, mobility, security, finance, education, and communication^{ref?}. 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 circular economy concept entry in the policy¹⁰, industrial¹¹ and scientific¹²⁻¹⁴ arenas as an umbrella concept, but also as a contested one¹⁵⁻¹⁷, aiming to change the societal conciousness that the ecological systems have nearly endless capacity to provide resources and adsorb wastes. Engineering science needs to integrate that the externalities¹⁸ of human activites' impacts on the earth systems since the fuzzy front-end phase of the innovation process.

■ Paragraph à developper sur les systemes de Manufactures

Major long vision: Circular and production

Today, a major societal issue rely on how to conceived socio-technical 'circular units' for manufacturing that integrates values of sobriety^{ref?}, resilience^{19,20}, adaptability²¹ 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^{22,23}. Indeed, today the establishment of these socio-technical systems need to include all ecosystem externalities and the carrying capacity of the ecosystem to claim to sustainability^{24,25}. 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 settlements²³. Urban cities will be responsible for non-negligible environmental impact^{26,27}, producing about 50% of global waste, and 75% of greenhouse gas emissions which affects the sustainability of cities²⁸ and the quality of city life²⁹.

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^{30,31} with decentralized and distributed characteristics^{32,33}. Aiming at a 'design global / manufacturing local'³⁴ seems a proto-industrialization³⁵ transition that is taking place in urban settlements that could a major impact in the next short future. The Open Source Appropriate Technology (OSAT)³⁶ and peer-to-peer (P2P)³⁷ approaches have been seen potential drivers to propose an alternative globalisation manufacturing paradigm³⁸. The open source (OS) approach has become well-established to provide improved product innovation over proprietary

product development^{39–42}. The evidence is most mature for software development because free and open source software (FOSS) provides: i) diversification and open innovation^{43–45}, ii) cumulative innovation⁴⁶, iii) development efficiency⁴⁷, iv) organizational innovation⁴⁵, v) higher technical quality of code⁴⁸, vi) encourages creativity⁴⁹ and vii) perhaps most importantly, it avoids redundant work⁵⁰. The OS approach is now also gaining traction in free and open source hardware (FOSH)^{51–55} and appears to be roughly 15 years behind FOSS in development and adoption⁵⁶. 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^{57–60}. The open source additive manufacturing technology, also know as 3D printing, have played a major role in the idea of democratization of manufacturing means⁶¹. Thousands of open-source products are shared by the global community from consumer goods to scientific⁶² and medical equipment^{62,63}. This model has been proven to be effective for emergency manufacturing during the COVID-19 pandemic^{62,64}. 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^{30,65}.

Distributed recycling for additive manufacturing: a promising inclusion

Since 2014, I have been working on the validation of the open-source 3D printing, filament⁶⁶ and pellet-based⁶⁷, as a robust manufacturing system, but also as a potential enabler of the mechanical recycling^{68–70} of plastic waste feedstock. Likewise, I have been working on the design of the pertinent closed-loop supply chain^{71,72}, considering some of the sustainability indicators⁷³ needed in the based on the literature. In a recent paper⁷⁴, I could highthligh a great interest by the scientific community of thi topic which is called distributed recycling for additive manufacturing (DRAM). DRAM (See Figure 2) 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.

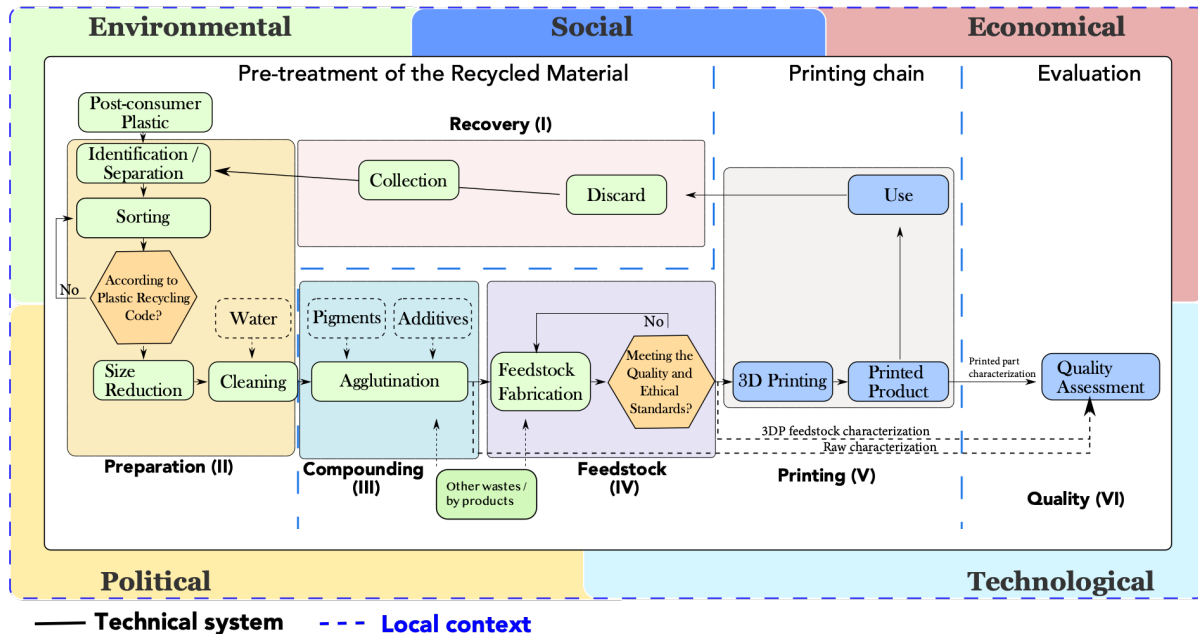


Figure 1: Distributed recycling via additive manufacturing. Source

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 (FFF), which is a material extrusion process [40]. DRAM starts with waste plastic 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”)⁷⁵ 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 Amazon.com. Fused granular fabrication is a recent experimental approach enabling the printing process directly from pellets^{76,77}, which reduces the degradation cycles of the plastic. For this process, I worked in the desktop format⁶⁷, but it seems that this technology could further expand the boundaries of additive manufacturing and eventually recycling^{78–80} for larger object⁸¹. Distributed recycling fits into the circular economy paradigm^{82–84}, 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^{85–87}. Additionally, open-source investment should result in an extremely high return on investment (ROI)⁶². 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 matured⁷⁴. 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 INEDIT¹, I have been leading the implementation of the *Green Fablab* demonstrator inside the third place called Octroi-Nancy Association² since November 2021³. INEDIT project aims to create an ecosystem to transform the *Do-It-Yourself* 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 demonstrator that that use living lab approach^{88,89} to experiment in real conditions with citizens, final users and large general public. This experiment is enframned as a design for sustainability at a socio-technical system level⁹⁰. 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 recycled resources industry (RRI) is starting to conceived inside the cities⁹¹. 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 . The sustainable development of the RRI has thus been highlighted on many countries’ agendas to promote the circular society^{92–94}, 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 industry⁹⁵, but more profoundly, how these socio-technical experiments will interact with the urban planning and polycimaking to make concrete the ambition of circular economy inside the urban and regional settlements.

2. Ambition & objectives

The material rarefaction⁹⁶, the ecological integration in the fuzzy-front end design of manufacturing systems^{25,97,98} and the resilience of production systems⁹⁹ 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 design, orchestrate¹⁰⁰ and evaluate the 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 methodological blueprint 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

¹See <https://cordis.europa.eu/project/id/869952>

²See <https://www.octroi-nancy.fr/>

³This demonstrator found retard because of the pandemic situation.

the three major layers and the boundary objects between them:

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

Manufacturing and an urban priority for resilience and agility. The significance and main challenge of sustainable urban production lies in the bridging of disciplinary boundary of urban and manufacturing systems fields¹⁰¹. One major drawback is the lack of holistic and shared framework to connect the urban and manufacturing development. There is an opportunity to create a City-Factory-Product nexus^{102,103} understanding that aims to be adaptable, resilient^{104,@ 105} and considering the carrying capacity of the urban ecosystem.

The open-source appropriate 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 needs¹⁰⁶. This approach have been valuable for scientific equipment to reduce the cost with equal of quality^{107,108}, and having implication in national level^{38,109}. Therefore, a OSAT technodiversity is a breakthrough to possible open up the valorization of material loops inside urban settlements fostering the creation of urban closed-loop supply chains. The establishment of development of a technological open source maturity level focalised on the distributed recycling is part of the technical blueprint.

Pluralistic (e)valuation for emerging industrial micro-values chains that integrate ecosystem characteristics. Reconciling urban development and industrial development is not an easy task (wicked problem). Thus, the type of information that decision-makers take into account is relevant at the moment to put in place industrial systems. From systemic design thinking and ecological economics fields^{110@,111}, it is needed to new forms of (e)valuation beyond the economics¹¹² to identify major feedbacks in the strategic, the tactical and the operational decisional levels. The integration of ecological aspects¹¹³ 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- / process-level, to the higher levels of value chains, ecosystems and the planet^{114,115}. 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 boundary objects¹¹⁶ that needs to be considered between the layers. From a design for sustainability^{90,117} 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 embeeded 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.

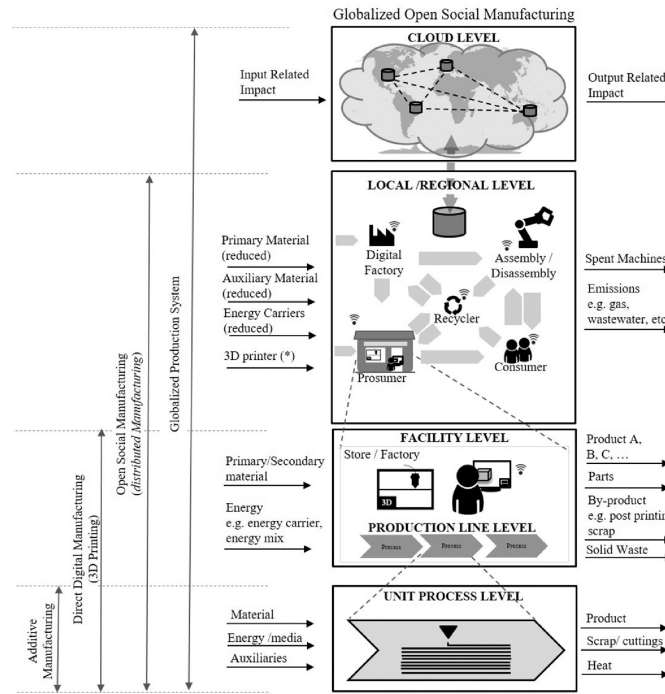


Figure 2: Gráfico a faire basé sur celui-là Source XX

3. The Methodology

SDRAM implement a methodology made of four working packages (WP), as illustrated in Fig. 3. 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 for a complete distributed 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 main goal is to establish a complete OSAT ecosystems to valorize the waste niches opportunities identified in WP1.

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. 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 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 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,

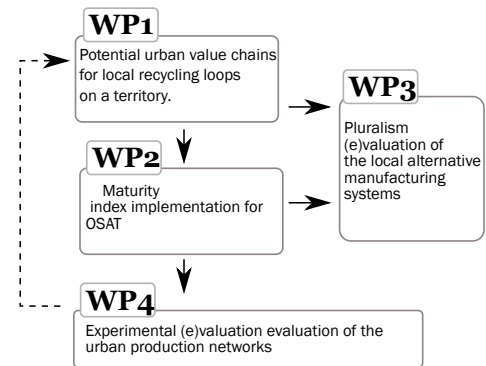


Figure 3: Methodology

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 gaps¹¹⁸ in terms of secondary material availability at the urban level considering its complexity level of revalorization. The goal is to couple $\{territory \times material\}$ 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 technodiversity level of the open source appropriate 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^{99,119} 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 adoption¹²⁰ and barriers of the open-source appropriate technologies with particular focus on distributed recycling considering the modularity types¹²¹, 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

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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 valuation¹¹² and techno-ecological interactions^{98,122,123}. More important to avoid Jevons paradox¹²⁴, 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 chains¹²⁵. then (4.2), the main aim is to reveal the components and the structure of the urban circular networks to the combining Material Flow Analysis¹²⁶, System Dynamics^{127–131} and Circularity Indicators¹³².

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

The WP4 aims to consolidate a starting point for a longitudinal study¹³³ 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 levels¹¹⁷.

3. Conceptual risk and feasibility 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 1: 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 2: 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 devel-
opment 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 4: Gantt diagram and task allocation

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