THE URBAN BIO-LOOP

GROWING, MAKING AND REGENERATING

ARUP

About Arup

Arup is an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services. From 90 offices in 38 countries our 13,000 employees deliver innovative projects across the world with creativity and passion.

This report is the combined effort of multiple Arup teams including Materials Consulting and Masterplanning and Urban Design as well as other consultants, designers and engineers across our Global offices.

Contact

Guglielmo Carra

Europe Leader Materials Consulting

Guglielmo.Carra@arup.com

Released October 2017

ARUP

Corso Italia 1

20122 Milan, Italy

Emilan@arup.com

Contents

THE BIOLOOP

Nature becomes an endless source of feedstock for the built environment

01 A New Paradigm for Materials in Construction

1.1 Context

It is well known that the so-called “business as usual” scenario does not represent a viable option for a sustainable future and that different development models have to be identified for our society to continue growing and prosper in the future. The construction industry must reflect this urgency of change – probably more than others. In fact it is still permeated by a number of detrimental factors such as the use of high impact materials, non-reversible building solutions, low efficiency processes and manufacturing.

The development and use of alternative materials to improve the sustainability and the quality of construction products is central to the current debate.

Use of natural materials would trigger a different approach in construction by allowing a number of benefits respect to traditional materials options by having lower CO_2 content, reducing health risks and cost. Intercepting current low value organic waste streams - both from the countryside and our cities - would reveal an opportunity to issues such as organic waste streams, that represent a costly problem in both economic and environmental terms.

The principles of Circular Economy would provide the rationale for a shift form a linear - disposal model - towards a circular value chain where natural waste(1) is the main resource. In this context new business models could be identified and developed to enable alternative use of organic waste streams as opposed to the current value chain. This approach could also help supporting local and rural economies with benefits for both existing and new stakeholders.

Diagrams hereafter are built or adapted from generic Circular Economy principles.

60%

Raw materials consumed

by construction and operation of the built environment in the UK (2)

30%

Waste from constuction

Up to 30% of EU waste comes from construction (3)

1) In present publication natural waste is defined as the organic content
2) Built environment Circular economy WRAP, 2013 [Online]
3) Construction and Demolition Waste European Commission, 2016 [Online]

1.2 Our Aim & Vision

0.6BT

Organic solid waste
produced Globally in 2012 [4]

5%

Global green house gasses
coming from the decay of post-consumer organic waste [4]

This publication aims at demonstrating that a different paradigm in construction is possible.

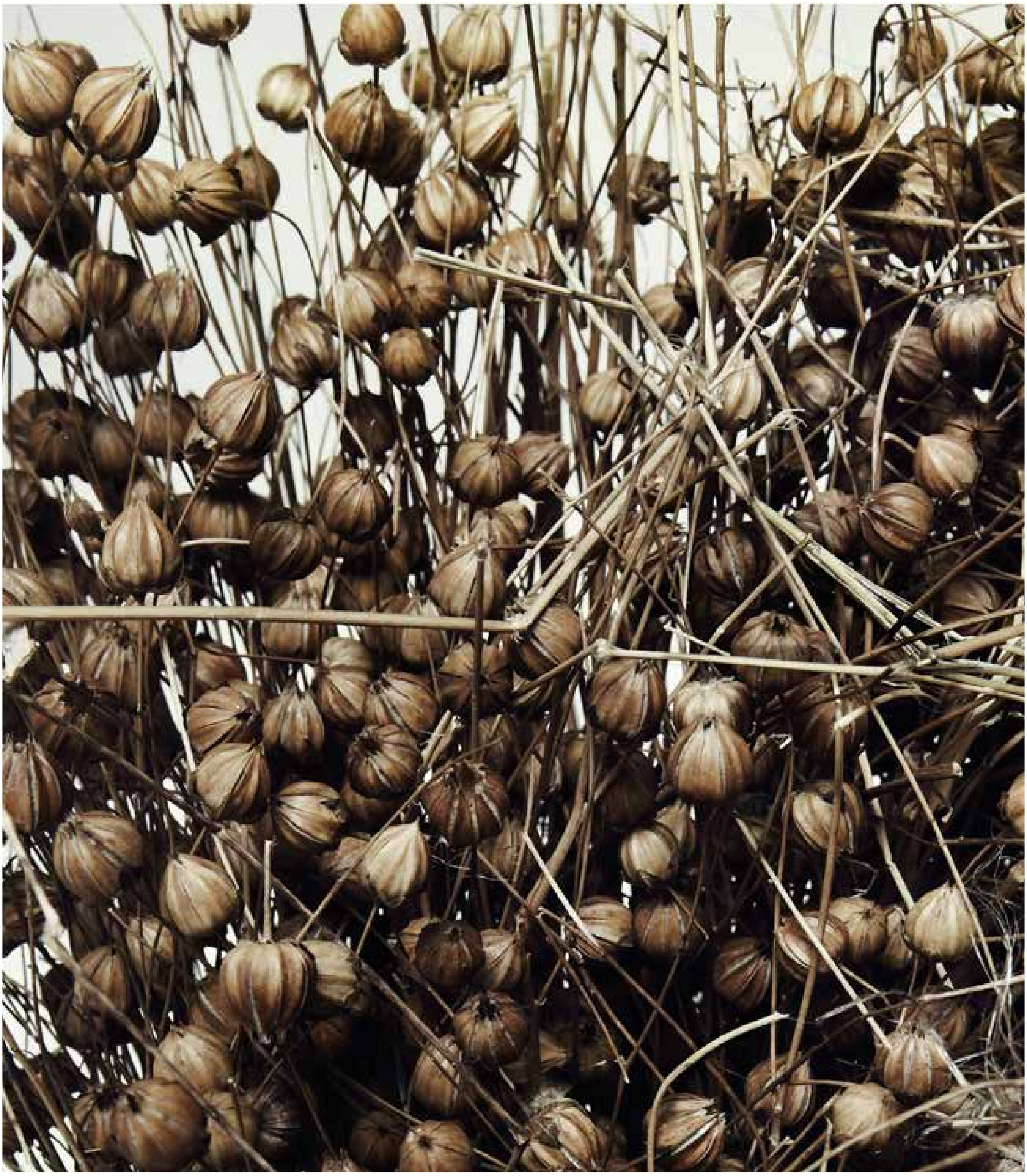
Organic waste from our cities and the coutryside, traditionally managed through landfill, incineration and composting could be diverted – at least in part – to become a resource for the creation of construction engineering and architecture products before being fed back in the biological cycle at the end of their service life.

The use of organic waste in construction would possibly allow the exploitation of its untapped value with a positive impact not only from an environmental perspective but also from a technical, social and economic standpoint. In this document a number of organic waste streams have been identified, together with their applications in building construction as products. Some of them are already certified products used in some markets at global level. Some others need further research and investment before being ready to market.

In the short term these examples are a guideline for designers and practitioners for replacing some of the traditional architectural products with equivalents made with organic waste as a resource.

For the long term we explored to which extent both our cities and urban districts could become self-sustaining – at least partially - from a feedstock point of view. This would be through the active implementation of organic waste streams into the supply chain of building construction products. This vision entails on the one side cities and urban districts that could implement more effective recovery systems and processes to turn organic waste into a source of value, while on the other side they can be planned for growing natural construction materials. All this could have an impact and contribute to the development of local economies.

4) Urban Biocycles. Ellen MacArthur Foundation 2017



© GXN Innovation

FLAX PLANT

Flax fibers are used to make high performing technical fabrics used as reinforcement in biocomposites

1.3 Arup's Background

Year 2013

BIQ Hamburg

First ever algae facade panels successfully implemented in a building

Year 2014

Mushroom tower

Use of mushrooms bricks for structural walls

In recent years Arup has been involved in a number of projects where alternative materials have been utilized for realizing building systems. This provides a sufficient level of confidence that high value technical solutions can be created relying on the embedded potential of natural resources.

The BIQ Hamburg(5) is the first façade system in the world to cultivate micro-algae to generate heat and biomass as renewable energy sources. In this project structural glass photo bioreactors are used as external cladding elements and dynamic shading devices. These are fully integrated in the building services system to harvest, distribute, store and use the solar thermal heat on site. This system has been adopted in a pilot project at the International Building Exhibition (IBA) in Hamburg in 2013. The bio-reactive façade generates renewable energy from algal biomass and solar thermal heat. The integrated system - suitable for both new and existing buildings - was developed collaboratively by Arup, Strategic Science Consult of Germany (SSC) and Colt International.

The Mushroom tower (6) is the first example of a structure - albeit temporary - made by using mushrooms as base materials. In fact mushrooms bricks have been used to create the structure of three towers for an installation for the MoMa in New York City. The mycelium, the base material for the bricks, is a microscopic, fibrous fungus that binds itself to its food source to create a strong, resilient matrix in any shape desired. The raw materials needed to produce them — mushrooms and corn stalks (waste material from farms) that the spores feed on — are as eco-friendly as they come. Bricks can be grown in just five days, and the process produces no waste or carbon emissions. When the structure is taken down at the end of the summer, they can be composted and turned into fertilizer.

5) http://www.arup.com/projects/solarleaf
6)http://doggerel.arup.com/engineering-a-mushroom-tower

© Arup/Colt

© International/SGG

BIQ HAMBURG

Facade panels filled with algae contribute to net-zero energy buildings

© Arup

© Barkow Photo

MUSHROOM TOWER

Mushrooms can grow from organic waste and be used for building purposes

Year 2015

BioBuild

Completed mock ups of facade components in biocomposite

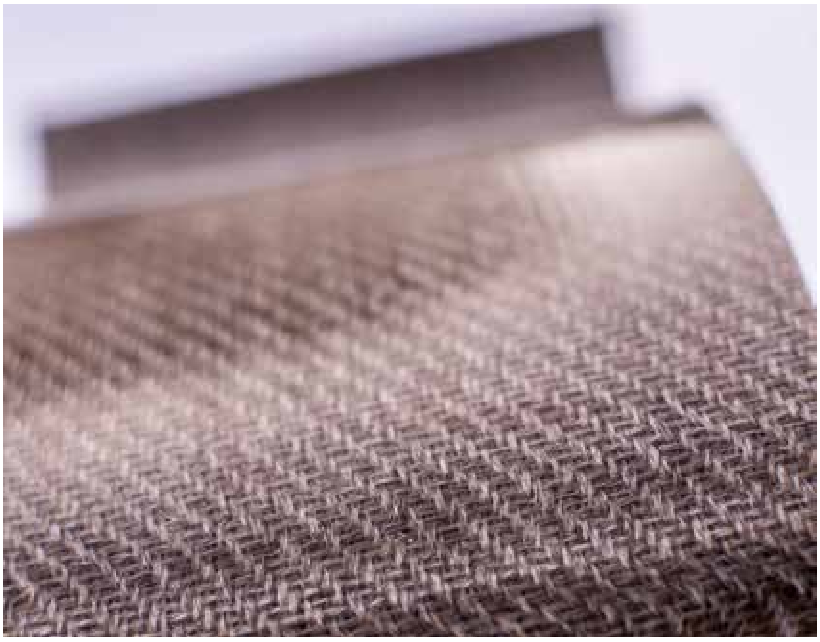
The BioBuild project(7) explored the use of natural based composites to create the first worldwide biocomposite system for structural facades. Biocomposites are composed of natural fibers such as flax, hemp and jute and natural resin derived from residual waste from sugar cane and corn harvesting. These are fast growing plants that regenerate in short cycles. With appropriate processing they can be converted into lightweight and durable products with good mechanical behavior. Additionally biocomposites can reduce the embodied energy of building components when compared to conventional construction materials, and produce no increase in cost. At the same time, they increase the thermal performance of the building.

The project was developed by Arup together with other 12 European Institutions. The project highlighted the need for developing bio-based materials that are better than existing ones. In particular avoiding chemical additives that impact on opportunities for these materials to be re-introduced within the biological loop.

These three project examples outline a trend that needs to be enhanced and supported in the upcoming years to transform early stage applications into a well consolidated practice. Implications of availability of raw materials and considerations on costs are key. In parallel, it is important to consider some technical challenges that are still partially unresolved – such as low materials durability and physical performance.

A process of constant implementation and engineering would allow overcoming some of these critical issues in natural materials technology and allow reproducibility and scaling of the solutions to wider use in construction.

7) http://www.arup.com/projects/biobuild_facade_system



BIOBUILD

Biocomposites made of natural textiles and biopolymers can be used to stiff components for construction

"It is time to move beyond the worn out make-use-dispose models in our sector. We have the ambition, capabilities and mind-set to decouple economic growth from resources consumption."

Carol Lemmens

Director and Global Lead Management Consulting

Arup

02 Current Use of Organic Waste

2.1 Organic waste in numbers

European data have been reviewed to identify the overall amount of organic waste, and therefore, the potential feedstock supply for the production of construction products. The definition of organic waste is as follows:

"Vegetal wastes from food preparation and products, including sludges from washing and cleaning, materials unsuitable for consumption and green wastes. They originate from food and beverage production, and from agriculture, horticulture and forestry. Vegetal wastes are non-hazardous."

Latest statistics - referring to the year 2014 – show that about 2.6 billion tonnes of general waste have been generated in Europe, with about 43.4 million tonnes having natural origin[8]. Amongst European countries Germany is the largest producer of organic waste, followed by the Netherlands and United Kingdom. Italy accounts for about 2.8 MT.

The definition of organic waste does not include the streams coming from post-consumer organic waste produced within cities as well as hazardous organic waste coming from processing of tomatoes and citrus. Thus it represents only partially a much bigger resources stream.

The global amount of post-consumer Solid Organic Waste (SOW) collected in 2012 is equal to 0.6 billion tonnes. Thus this would be an even larger stream when compared to organic waste. For the purpose of present publication the SOW has not been discussed.

43.4MT

European amount
of dried organic waste collected in 2014 [9]

2.5%

Landfill
percentage of organic waste managed through landfill [8]

8) Eurostats Manual on Waste Statistics
9) Eurostat (Online statistics)

2.2 The current waste management model

On a global level it is evident a growing demand for biological feedstock to supply different uses ranging from biofuels, biomaterials and pharmaceuticals.

Cities in particular are undertaking procedures to collect post-consumers organic waste that might reveal pivotal to allow growth of the so called bioeconomy.

On the other side organic waste in the European context is disposed as follows:

1. Recovery. This corresponds to about 90% of the organic waste stream equal to 38 MT. It includes recycling and reclamation of organic substances which are not used as solvents such as composting and other biological transformation processes - as well as some backfilling[9]. For this category the available data do not provide a clear indication of the percentage of waste that is backfilled as opposed to the stream that goes to composting.
2. Incineration. This corresponds to about 5% of the total stream. It accounts for both incineration on land and incineration with energy recovery, for subsequent use as a fuel or other means to generate energy.
3. Landfilling. This corresponds to about 2.5% of the total stream, equal to about 1 MT. It includes the deposit into or onto land – as well as other forms of disposal - including biodegradation of liquid or sludgy discards in soils, and surface impoundment as well as release into a water body except seas/oceans.

The image on the following page showcases how the current waste management model works.

5%

Inceneration

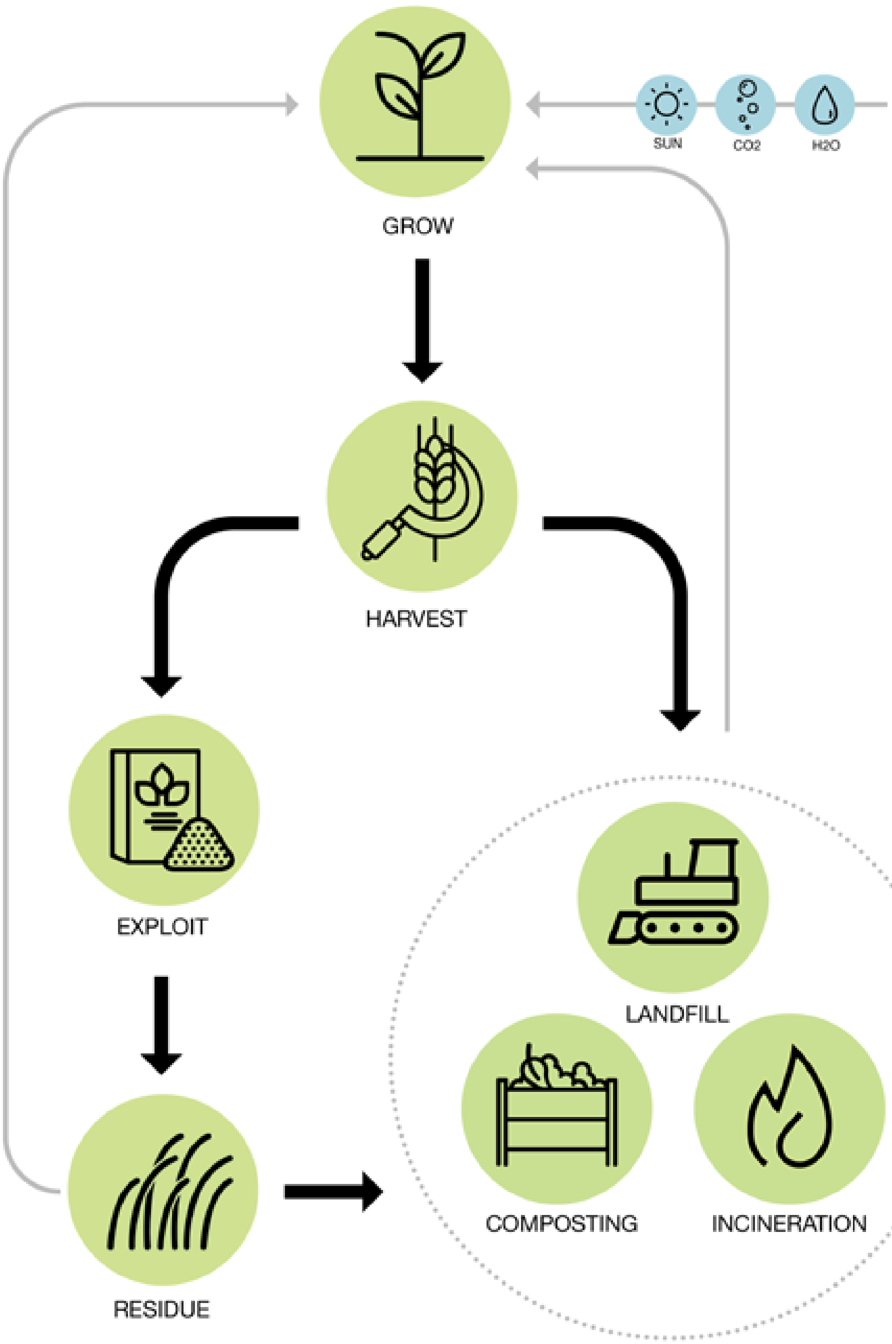
Percentage of organic waste currently disposed through incineration [10]

90%

Recovered

Percentage of organic waste currently recovered through composting and transformation[10]

9) For a definition of backfilling please visit: http://ec.europa.eu/eurostat/documents/342366/4953052/Guidance-on-Backfilling.pdf/c18d330c-97f2-4f8c-badd-ba446491b47e
10) Eurostat (Online statistics)



CURRENT MODEL

Biological loop considering traditional disposal options

2.3 Environmental impact of organic waste

0.15 $kgCO_2eq/kg$

Composting

Environmental impact associated to composting[11]

2.15 kgCO2eq/kg

Incineration

Environmental impact associated to incineration[11]

2.75 kgCO2eq/kg

Landfill

Environmental impact associated to landfill[11]

A Life Cycle Assessment (LCA) approach has been used to assess the impact of the different waste management processes for organic waste. Datasets related to each of the three waste management categories have been compared in terms of their environmental footprint. The main conclusions are:

- Composting of biological and green waste generates about 0.15 kgCO2eq/kg - much less than landfilling it.
- If the waste was incinerated rather than landfilled, data for incineration of waste food - the most similar dataset to vegetal waste - indicates that 2.15kgCO2eq/kg waste could be saved.
- Landfilling of organic waste generates about 2.75 kgCO2eq/kg as an average across the European countries. If this waste could be used as fertilizer in agriculture this value reduces to about 0.005 kgCO2eq/kg.

When comparing the reference values in terms of environmental emissions it appears that composting has the least impact while landfilling – when not used for agricultural purposes - has the highest impact. The point is to assess whether diverting such a waste in alternative processes would make sense from an environmental standpoint.

A relevant aspect to be considered relates to the the need to maintain an effective cycling of nutrients in the biosphere. Thus when considering alternative uses of organic waste it is also important to consider that such products - as nitrogen, phosphorus, potassium - shall return to the soil where both plants and animals can take it again for their own benefits.

11) SimaPro software database

The production and fate of straw in the UK has been investigated as an example to assess such opportunity. It can be concluded that it is reasonable to consider using straw as a resource for construction products for the following reasons:

- It has already been identified as suitable by DEFRA[12].
- Of all the straw produced in the UK just under half is used for animal bedding, and a similar amount is ploughed back. The rest is used to overwinter carrots, for electricity generation, mushroom compost and export. The ploughed back portion is a significant material flow – 5.7Mt that could be better used.
- Carbon sequestering by ploughing back straw is not that efficient, sequestering 733kg CO_2/ha. This compares to 1ha baled wheat straw generating the same energy as 2.4tonnes of coal, and saving over 5000kg CO_2. Therefore straw could be better used [13].
- Whilst it does fertilize the soil when ploughed back, it should be used with added urea to balance nitrogen levels [14].
- It is a less efficient feedstock for liquid biodigesters of animal wastes than corn stalks, on account of its high lignin content [15].
- It can be used to produce raw materials for paper and pulp [16].

5.7 MT

Straw waste

currently ploughed back in UK

12) https://cereals.ahdb.org.uk/media/165158/3351-annual-project-report-2008.pdf
13) http://www.ahdb.org.uk/projects/straw.aspx
14) http://maxwellsci.com/print/crjbs/v4-673-675.pdf
15) http://ec.europa.eu/environment/waste/framework/
16) Electricity prices in Europe, Eurostat

"The Circular Economy forces companies to redesign in depth their business models, from the relationship with customers to the suppliers' networks, thus creating opportunities for disrupting many industrial sectors"

Davide Chiaroni

Co-Founder Energy & Strategy and Mentor of the Ellen MacArthur Foundation

Politecnico di Milano

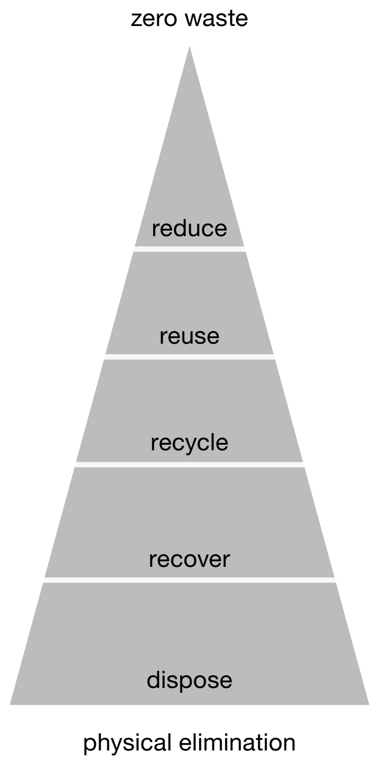
03 An Alternative Exploitation Model for Organic Waste

3.1 The economic logic

Most organic waste currently has useful end of life scenarios from an environmental impact perspective. On the contrary just a small part of organic waste – used for backfilling - could be better diverted into different exploitation models that would realistically reveal to be a better use from an environmental standpoint - such as the production of biological construction products.

The theory of the waste hierarchy indicates that once the production of organic waste has been avoided or reduced its use as a product is equivalent to reuse and recycling, which is preferable to composting and landfilling. The vast majority of organic waste is already reused in some form, or converted to energy, with only a small proportion going to landfill. On this basis the waste hierarchy is working well.

However when considering other factors - in addition to the environmental profile– alternative exploitation models could become more attractive from an economic standpoint. Organic waste – when used to make building construction components – is exposed to a functional upgrade that increases its value. This due to the higher commercial price associated to a kilogram of material used for construction purposes respect to compost or incineration for energy recovery.



The waste hierarchy showcases the methods of waste management from least (top of the pyramid) to highest impact (bottom of the pyramid)

3.2 Capturing the embedded commercial value

0.85€/kg

Commercial value for incineration

Selling price of one kg of organic waste when incinerated

5-6€/kg

Estimated commercial value for construction

Selling price of one kg of organic waste used as cladding in construction

Several aspects shall be considered when moving towards a model based on Circular Economy principles. From an economic perspective it would be relevant to accurately price biologically derived materials in order to determine whether they are commercially viable.

A kilogram of waste incinerated for energy recovery would have a commercial price of about of 0.85 €/kg [17]. On the other hand the same material used, as an example, for interior cladding would have a selling price somewhere between 5 and 6 €/kg. This depends on a number of factors, including the quality of the cladding, its physical features, the market maturity and more.

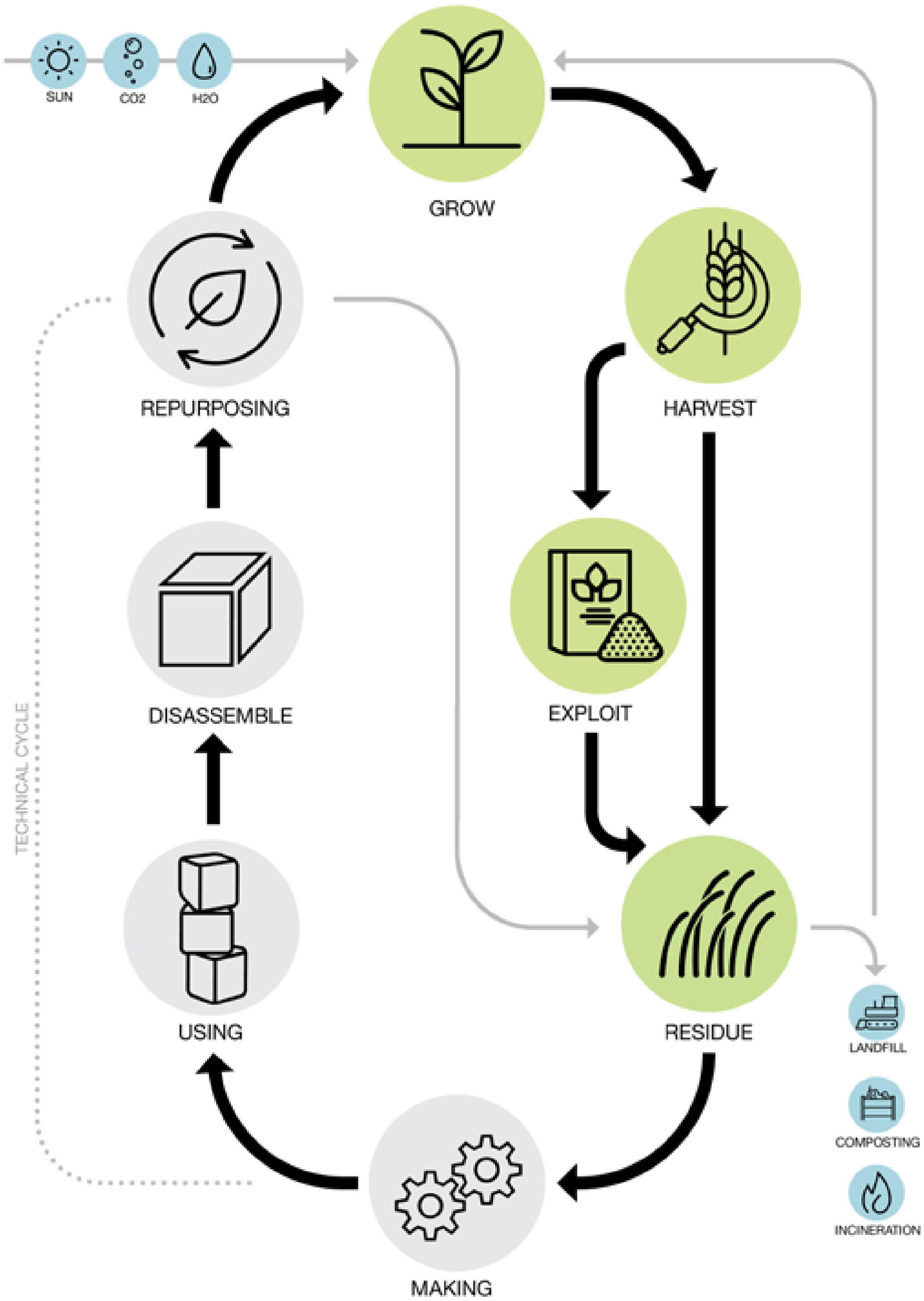
This gap between the commercial value of organic waste in the current disposal scenario with respect to the proposed one could trigger the flourish of an entire new economy. In fact more competitive business models could be identified to capture and maximize the embedded value of these waste streams when used for construction purposes.

It is important to stress that the potential increase in value for organic waste would not come at the expenses of the traditional end of life models for landfill, incineration and composting. Natural resources transformed into construction products will get back in to the biological loop - at the end of their engineering service life. They can actually get even more loops into the technical cycle when repurposed or remanufactured, therefore prolonging their life and generating exponentially more value through several loops.

Some limitations apply to products made of organic waste to be re-introduced in the biological loop after technical exploitation. These materials should be free from chemical contamination after manufacturing and use.

The next page showcases how the alternative exploitation model for organic waste would work.

17) http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics



ALTERNATIVE MODEL

Organic waste acquires value through technical exploitation

"We have a fantastic opportunity to both sequester carbon and reduce waste by using more biological material in construction. We must capitalise on this opportunity by developing suitable materials and putting them into production."

Tristram Carfrae

Arup Fellow and Deputy Chairman

Arup

©Ronald Tilleman and ©Studio Marco Vermeulen

04 Organic Waste for Construction

4.1 Acceptance and limitations for use

Technical performance and competitive price range will be key in determining the potential success of construction products based on organic waste. Additionally codes, standards and regulations will be instrumental in supporting product adoption and allow wide market acceptance.

Currently the use of waste in products in Europe is governed by the Waste Framework Directive (2008/98/EC). It states that certain specified wastes shall cease to be a waste and obtain material or product status only when it has undergone a recovery or recycling operation and complies with specific criteria, known as end-of-waste criteria, which have been agreed with the environmental regulator.

End-of-waste criteria must be developed considering that materials or products are commonly used for specific purposes. Additionally there needs to be an existing market or demand for them. Their use shall be lawful, meaning that materials or products shall meet the technical requirements for the specific purposes and meet the existing legislation and standards applicable to the products. Finally their use will not lead an increase in adverse environmental or human health impacts.

It will be necessary to liaise with governance groups and potential stakeholders at many levels to allow organic waste to comply with the end-of-waste criteria– where this compliance is not proven yet. The use of Health Product Declarations, or the Declare label could be beneficial to demonstrate appropriate health and safety requirements with respect to the absence of harmful toxic constituents. Moreover products performance shall be as good as or better than traditional materials with respect to relevant issues such as durability, fire and insect resistance to prevent their use leading to potential premature failure.

Competitive price range

shall be defined to compete with benchmark products on the market

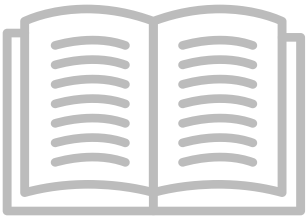
Suitable technical performance

shall be defined to be implemented in actual projects

4.2 Building applications

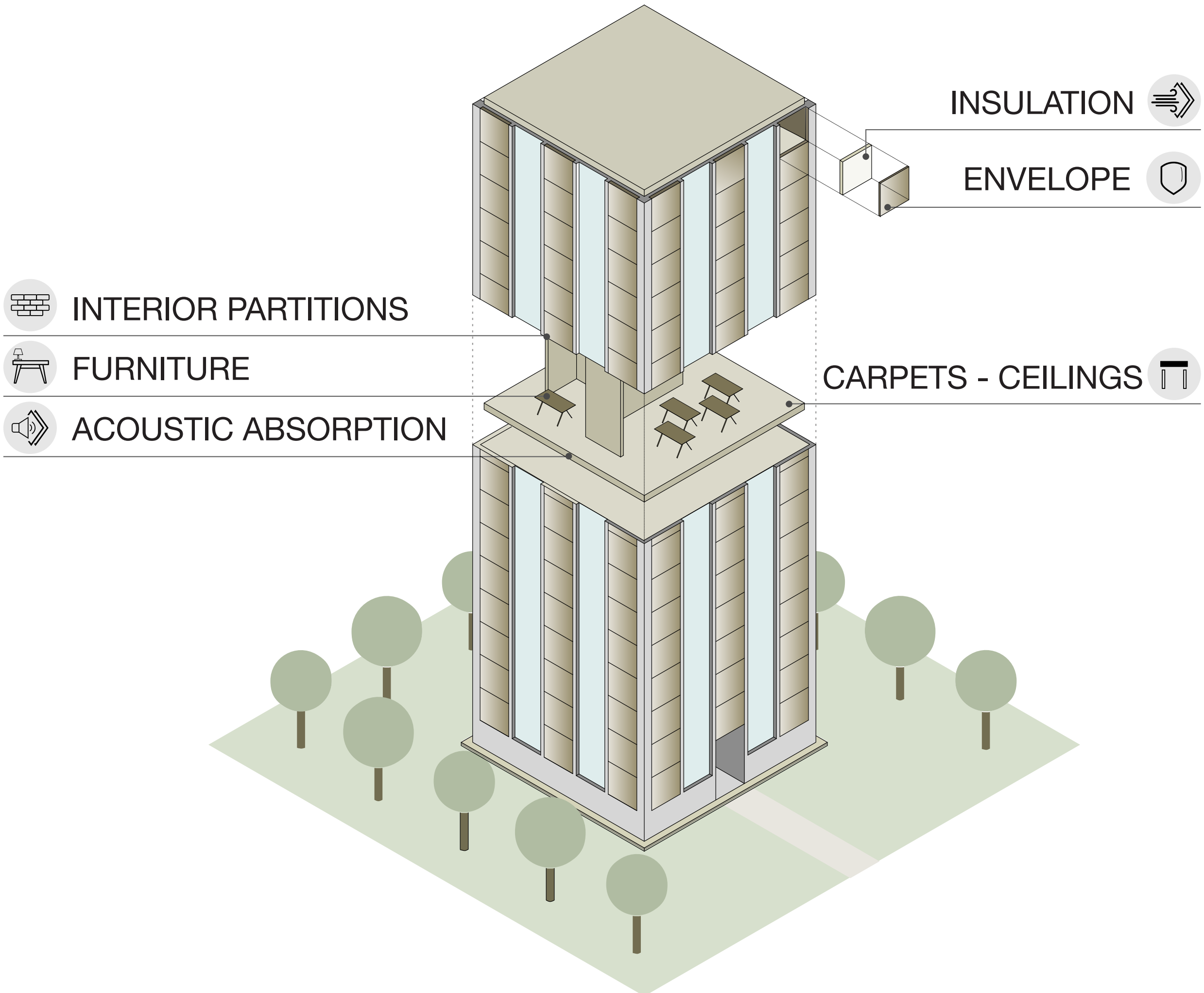
A number of applications currently exist for products based on natural resources. Six main fields of applications have been identified:

- Interior partitions and finishes. These are flat boards - featuring decorative layers where needed. A number of organic waste streams could be used for such applications as bagasse, cellulose, seeds, stalks, or peanut shell. These products are generally characterized by low specific weight - therefore are easy to handle – and are sufficiently stiff to ensure appropriate resistance to impacts.
- Furniture. Natural fibres and small residual particles can be shaped in complex forms for chairs, tables and more generally for any interior application. A variety of surface finishes would provide a strong aesthetic appeal.
- Acoustic absorption. High porosity materials – such as bio-foams – can be obtained from soy residue. Moreover fibres of different types can be combined to create insulation material with good sound absorption properties.
- Thermal insulation. A number of natural fibres obtained from agricultural harvesting can be used. These provide low thermal conductivity and some of them are characterized by good fire performance and are water repellent such as potato peelings and cork.
- Carpets and moquette. These are based on a large variety of natural fibres such as those obtained from residue of bananas or pineapple harvesting, and other flexible, strong and lightweight fibres.
- Envelope systems. To some extent natural fibres can be combined with biopolymers to obtain stiff end-products that can be employed for both interior and exterior applications In this last case chemical additives – that are likely to be required to improve durability and fire properties – might jeopardize the re-introduction in the biological loop.



Codes and standards
shall provide a basis for products to be utilized

Healty products
could enhance likelihood for application



BUILDING APPLICATIONS

Fields of application for products made out of organic waste

5+

Potential applications
of organic waste for construction products

100+

Companies involved
in developing natural products for construction at the present

4.3. Case studies

The following pages includes a collection of case studies for construction products where organic waste has been used as a resource. These are mainly obtained from agricultural waste however some waste streams can be identified at city level from leaves, grass and stalks collected from green areas.

The products are generally produced with local reach but it is important to note that the availability of resources applies at global scale. Therefore reusing organic waste for construction purposes is a global opportunity that can be exploited locally depending on country specific and regional circumstances both from an environmental standpoint - such as climate – and a socio-economic standpoint – when considering the supply chain. It shall be noted that data collected in this report refer to the European context rather than the global one. So the global perspective is addressed form a qualitative standpoint rather than quantitative.

As previously stated in the paper additional opportunities could be identified when considering SOW from cities that might be employed to produce biopolymers and other base materials for construction.

The case studies are assessed depending on a number of factors such as their likelihood for application in the construction sector, the availability of resources at global scale, the complexity of the production processes and the opportunities for the materials to be reintegrated within the biological loop at the end of the product's service life.

© Tamara Orjola - Forest wool

INTERIOR FURNITURE

Table made of natural fibres

Global distribution of crops used for production of building products

The diagram showcases the presence and distribution of organic waste depending on regional and local peculiarities and crops.

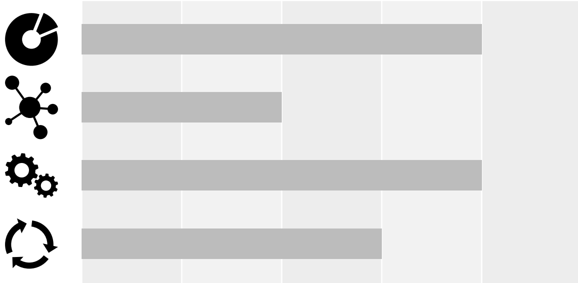
MAP KEY

- sugarcane
- cellulose
- maize
- sunflower
- peanut
- seeds / stalks/leaves
- banana
- potato
- hemp / flax
- rice
- wheat
- pineapple

ASIA
EUROPE
AFRICA
AUSTRALIA

Sugarcane

Crustell B.V., NL



Manufacturing

Bagasse is generated from harvesting of sugarcane. When mixed to binders it can be pressed to generate stiff boards.

Technical Properties

- High strength
- Excellent durability
- Flawless finish

Information

http://msonsgroup.tradeindia.com/

Application in construction

Internal use, floors, fiberboard and furniture

Resource availability

Only in tropical and subtropical areas

Manufacturing process

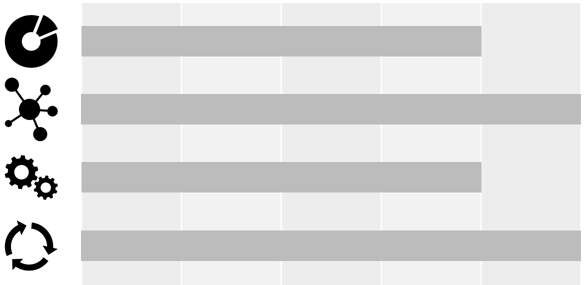
Easy manufacturing

Recyclability & remanufacturing potential

Depending on binders might be limited

Cellulose

Ecor



© JR Delia Photography

Manufacturing

Cellulose sourced from both our cities and the countryside can be used to produce panels with different shape and features by adding water, heat, pressure and no additives.

Technical Properties

- Flexible shape
- High stiffness to weight ratio
- Non-toxic

Information

http://ecorglobal.com/

Application in construction

Internal use, wall panels and celling

Resource availability

From both urban and rural areas sources

Manufacturing process

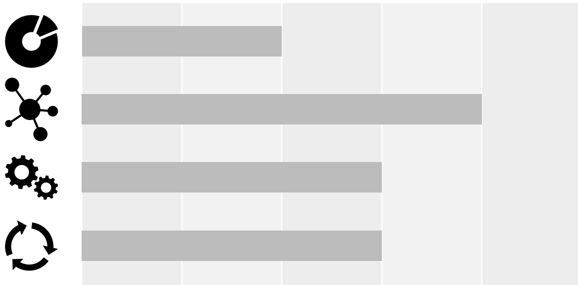
Requires laboratory

Recyclability & remanufacturing potential

Recyclable, no additives

Maize

Wood KPlus



© Wood KPlus

Manufacturing

Residual waste from corn cobs can be used to make a stiff core for sandwiches. These can be combined with flat boards obtained from other organic waste.

Technical Properties

- High strength
- Good insulation
- Low cost

Information

http://www.wood-kplus.at/de

©Enactus

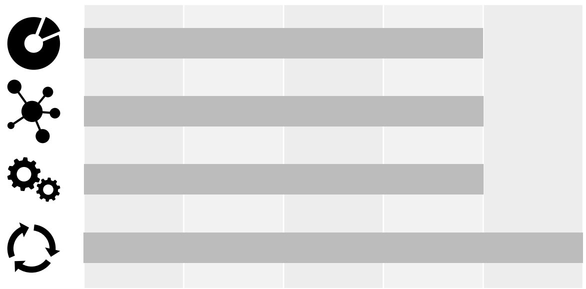
Application in construction
Internal use, lightweight walls, furniture, doors

Resource availability
Despite being a global resource corn grows only in summer

Manufacturing process
Some hand operations required

Recyclability & remanufacturing potential
Biodegradable, but hard to divide the core from the boards

Sunflower



Kokoboard Co. Ltd.

Manufacturing

These boards are made by the repurposing of waste from sunflower harvesting. They are made by just adding water, heat and pressure with no additives.

Technical Properties

- High strenght
- Non-toxic
- Low cost

Information

http://www.kokoboard.com/

Application in construction
Internal use, floors, ceilings, walls

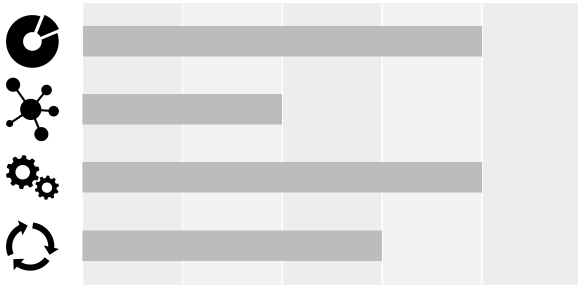
Resource availability
Seasonal product

Manufacturing process
Easy manufacturing

Recyclability & remanufacturing potential
Recyclable, no additives

Peanut

Kokoboard Co. Ltd.



Manufacturing

These boards are made by the repurposing of waste from peanut shells. Peanuts shell are turned into particle boards by a hot press procedure and the use of a formaldehyde-free adhesive.

Technical Properties

- Resists to moisture
- Flame retardant
- Low cost

Information

http://www.kokoboard.com/

Application in construction

Internal use, floors, ceilings, walls and furniture

Resource availability

Only grow in tropical areas

Manufacturing process

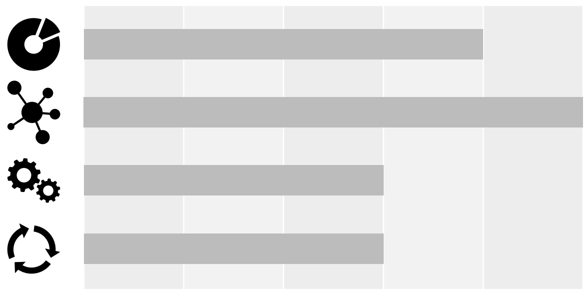
Easy manufacturing

Recyclability & remanufacturing potential

Formaldehyde free

Seeds, Stalks & Leaves

Organoid



© Organoid

Manufacturing

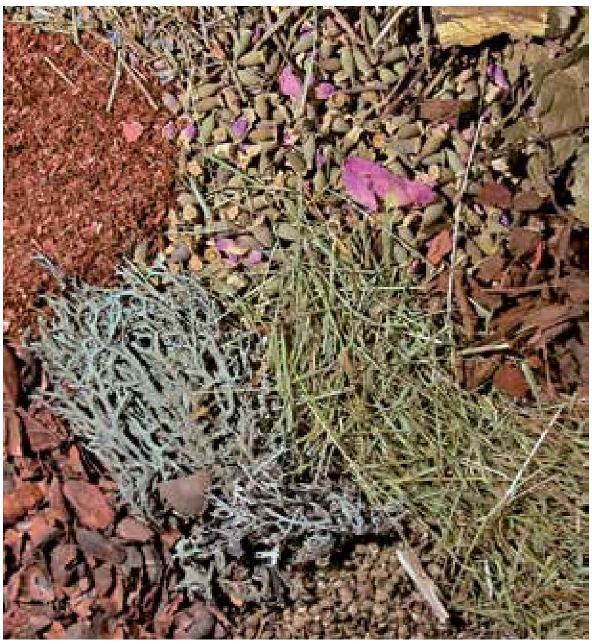
These products are made using a wide range of organic waste converted into both stiff and flexible boards for acoustic ceilings. The products use eco-friendly binders for manufacturing.

Technical Properties

- Low flammability
- Flexible system with stiff surface
- Largely available with low cost

Information

http://organoids.com/



© Organoid

Application in construction

Decorative finishes for walls and furniture and flexible acoustic panels.

Resource availability

Leafs, seeds and stalks of any plants

Manufacturing process

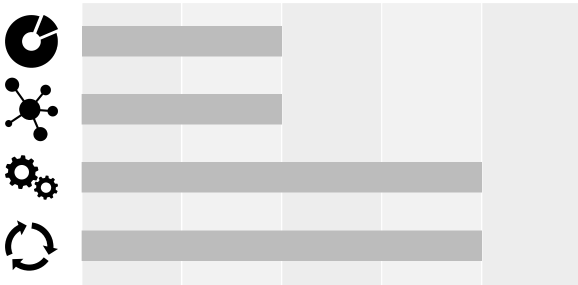
Industrial press moulds

Recyclability & remanufacturing potential

Use of eco-friendly binders

Banana

Leoxx



© Leoxx

Manufacturing

Banana fruit and leaves can be used to obtain rugged textiles. These can find application as carpets and fibers for composite applications. The material is 100% biodegradable.

Technical Properties

- High strenght fiber
- Good acoustic absorption
- Durable

Information

http://leoxx.nl/

©IKEA today

Application in construction

Internal use, carpets

Resource availability

Only grow in tropical areas

Manufacturing process

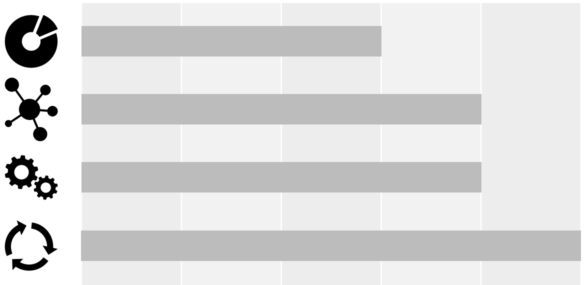
Fibre extraction, spinning & weaving

Recyclability & remanufacturing potential

Fully biodegradable

Potato

Crustell B.V., NL



© Crustell B.V., NL

Manufacturing

These are completely bio-based products made by mixing the peeling of potatoes that are hygenised, pressed and dried. Main constitutens are lignin, cellulose, hemicellulose and proteins.

Technical Properties

- Low specific weight
- Fire resistant
- Insulation and water repellent

Information

https://materia.nl/material/potato-cork/

©Crustell B.V., NL

Application in construction

Internal use, insulation and acoustic absorber

Resource availability

Widely available, low seasonal constraints

Manufacturing process

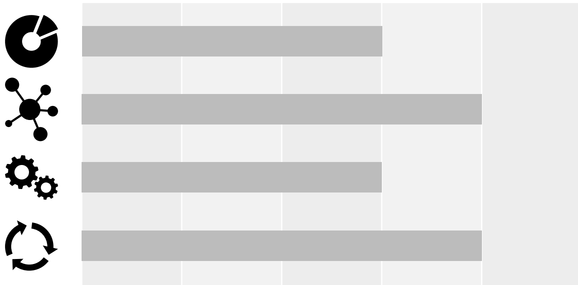
Pressing and heating

Recyclability & remanufacturing potential

Biodegradable and compostable

Hemp & Flax

HempFlax



© HempFlax

Manufacturing

These products employ natural textiles and fabrics from previous production. These are shredded and pressed to obtain panels.

Technical Properties

- Low thermal conductivity
- Low cost
- Reusable/Remanufacturable

Information

http://hempmaterials.com/
http://hempflax.com/

© DIMA bioedilizia S.r.l.

Application in construction

Insulation for walls, doors and ceilings

Resource availability

Rapid growth in appropriate climate conditions

Manufacturing process

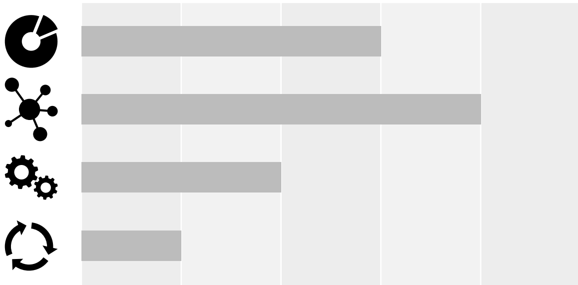
Easy manufacturing

Recyclability & remanufacturing potential

Highly recyclable and reusable

Rice

Watershedmaterials



© Watershedmaterials

Manufacturing

Products are made by mixing rice husks ash with cement to reduce the need for fillers.Rice can be also used as raw material for boards production as showcased with other plants previously.

Technical Properties

- Lower density respect to traditional concrete blocks
- Better environmental footprint
- Highly durable

Information

http://ecorglobal.com/
https://watershedmaterials.com/

© Composition Materials Co.

Application in construction

cement, bricks, ceramic glaze, insulator

Resource availability

Rapidly harvested due to growth speed

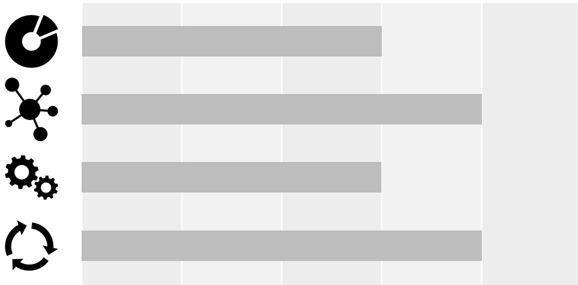
Manufacturing process

Combustion of husks, mix with concrete

Recyclability & remanufacturing potential

Low recyclability, downcycling

Wheat



Enviro Board

© Novofibre

Manufacturing

These panels are produced through a continuous extrusion process and cut to the desired length. They can be covered with a waterproof paper membrane. Panel density and thickness can be adjusted.

Technical Properties

- High stiffness
- Flexible dimensions
- Resistant to water

Information

http://enviroboard.com/

© Paulick Report

Application in construction

Envelope and internal walls, acoustic insulation

Resource availability

Largely available on the Earth North Hemisphere

Manufacturing process

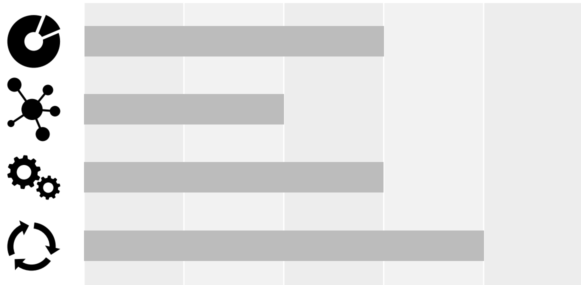
Continuously extruded

Recyclability & remanufacturing potential

Biodegradable, fertilizer

Pineapple

Ananas Anam



© Vegemoda

Manufacturing

These are natural fabrics made by using fibers extracted from pineapple by-products from harvesting. The aim is to get Cradle to Cradle approach in textiles without impacting on food supply chain.

Technical Properties

- High strength
- Soft
- High pilability

Information

http://www.ananas-anam.com/

© Ananas-anam

Application in construction

Internal cladding and furniture

Resource availability

Rather localized

Manufacturing process

Fibers extraction

Recyclability & remanufacturing potential

Biodegradable, fertilizer

"The Circular Economy represents the challenge of the future. Intesa Sanpaolo is strongly committed in promoting this disruptive transition, supporting open innovation and new business models that create sustainable value and regenerate the natural capital."

Massimiano Tellini

Global Head – Circular Economy Project

Intesa Sanpaolo

05 An Opportunity at many Levels

5.1. Innovation as key enabler

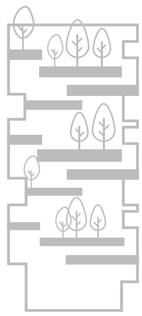
Organic waste is widely available and it is constantly generated regardless of human intervention. It is there, regenerative by nature.

Organic waste is not restricted to the countryside but it extends more significantly to the urban environment. Cities aggregate a large amount of resources. This includes both a high concentration of biological nutrients coming from rural areas as food - that rarely return to the agricultural system thus causing damage where they are discharged - as well as resources directly produced at urban level - as the biological waste coming from parks, trees, urban agricultural systems, community gardens, green roofs and facades.

As recently reported by the Ellen McArthur Foundation[18] new urban farming methods and technologies represent an emerging multi-billion sector of development for the future. The waste stream associated with these increasing green opportunities does not have yet a clear disposal process. Therefore they might be diverted towards alternative exploitation models such as biofuels, pharmaceutical products and biomaterials for building construction.

Innovation can act as an enabler across the entire supply chain by generating new opportunities and business for waste handling, refurbishment, reverse logistics and development of new materials.

Manufacturing process innovation will be an additional enabler. A number of ongoing technological advancements in construction – such as 3D printing of bio-polymers and recent developments in algae and mushrooms technologies applied to buildings- might work well as trigger to develop product innovation.



Green facades and urban farming
will increase organic waste streams

New technologies
will enhance opportunities for manufacturing

18) Achieving Growth Within, published January 2017. The Ellen McArthur Foundation

6x

Increased value

for organic waste when used to make construction products

1Bm²

Cladding surface

produced exploiting 1 MT organic waste

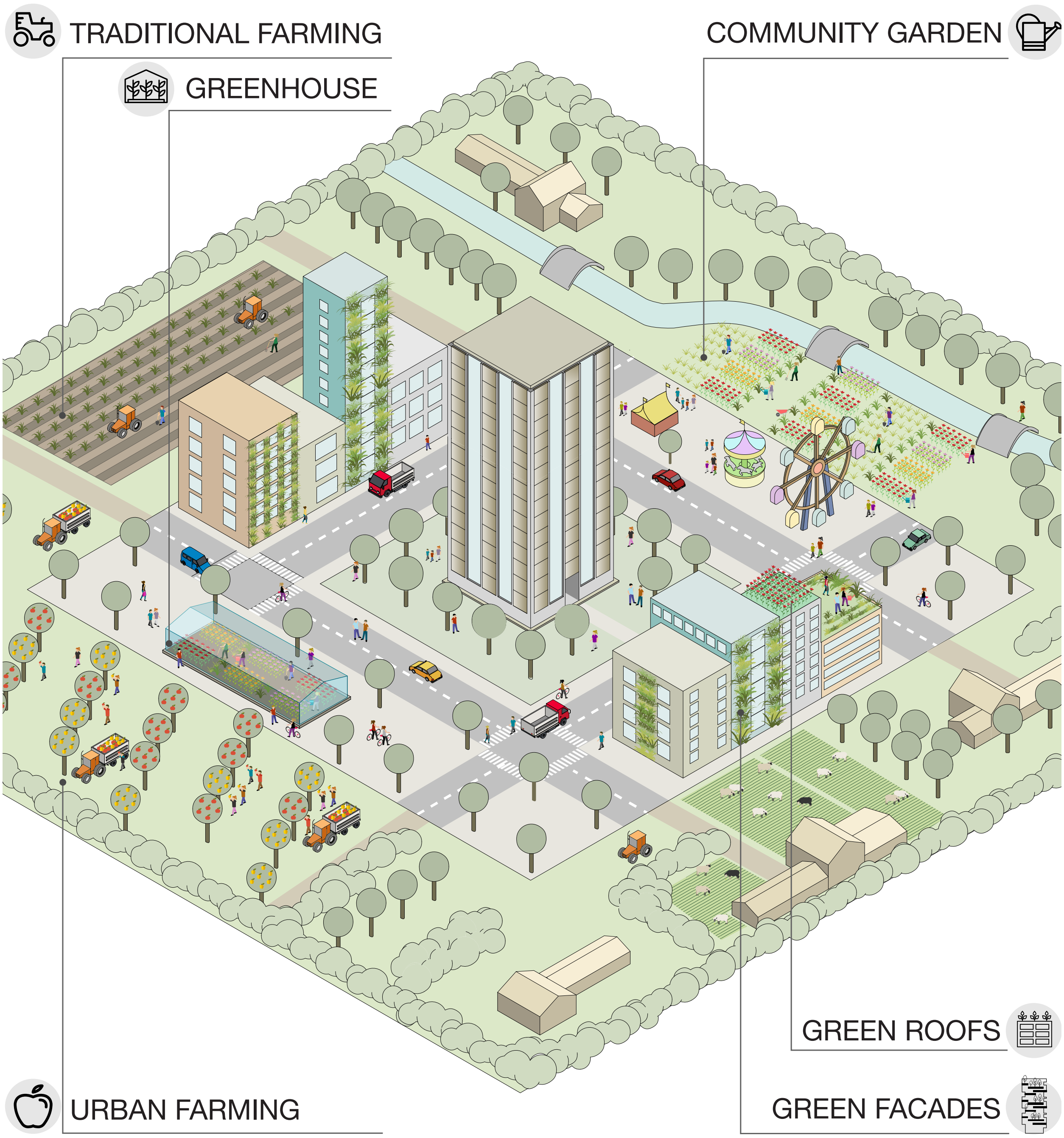
5.2 New business models and stakeholders

As discussed in Chapter 3 a kilogram of waste material used for construction purposes would allow exploiting far higher economic value respect to the value generated in traditional waste management models. When willing to size the potential production for organic waste based products, it shall be considered that with 1 tonne of waste it could be produced about 1000 m^2 of thin cladding boards.

A number of potential business opportunities could grow around availability and accessibility of organic waste, such as:

- Tools to control the waste streams through the value chain so that the added value can be identified and captured;
- Novel manufacturing and re-manufacturing processes for reuse and recycle of natural products within the value chain;
- Creation of services to enhance a "servitisation" approach, meanly shifting from selling products to selling product-service systems. These would fit particularly well for natural products with a rather limited service life such as those applied for buildings interiors;
- Enhanced collaboration within the supply chain amongst all actors.

The coexistence of both new sources within our cities and the need to develop novel production methods would trigger the inclusion into the value chain of a number of stakeholders.



OPPORTUNITIES AT URBAN SCALE

Crops could grow within cities thanks to new food supply chains and green facade systems

Start-up and SMEs

shall exploit economic potential
and alternative use of waste

Investors

shall finance the development of
new business opportunities

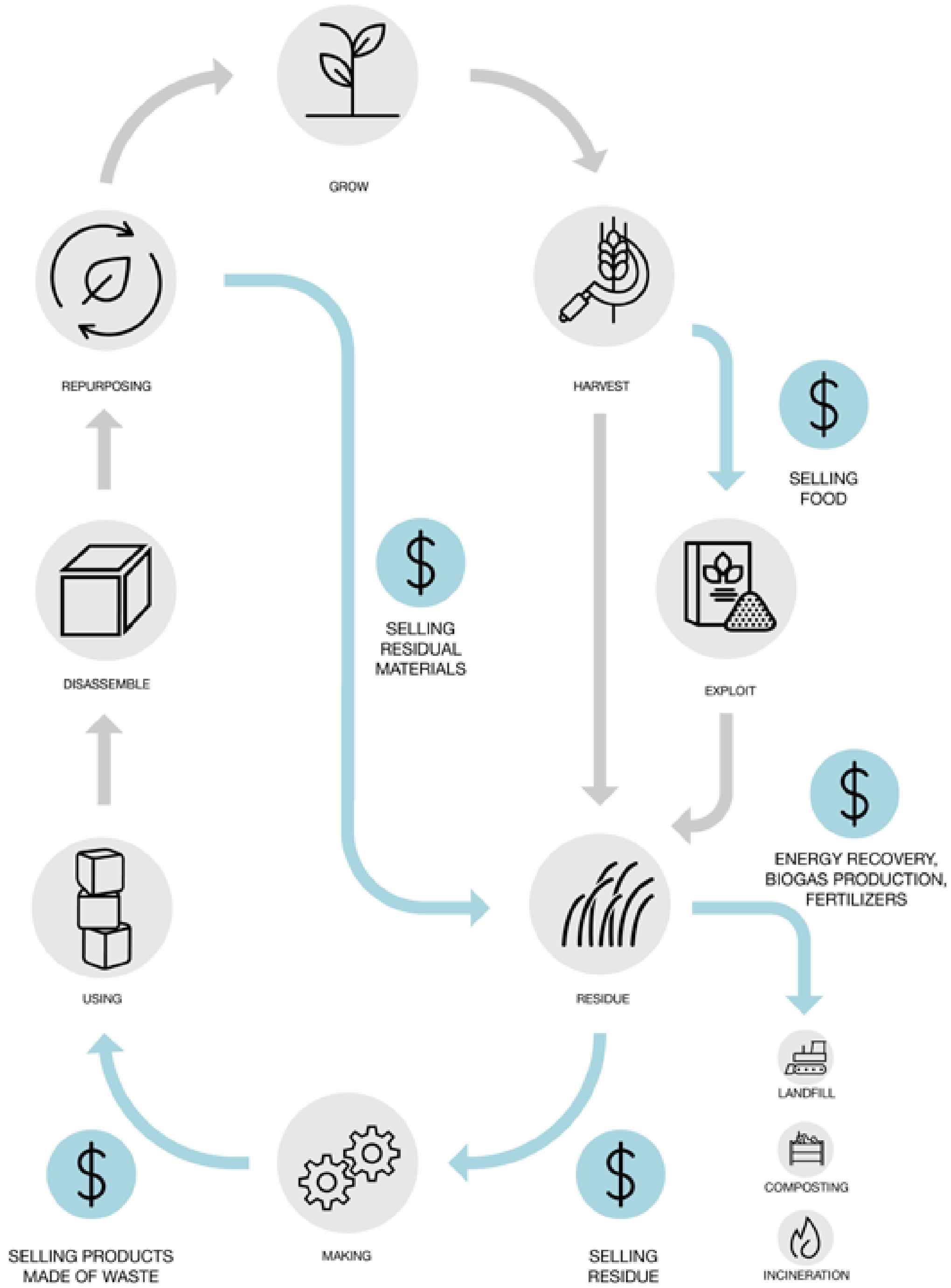
The value chain could largely differ from the current one, by including new start-up companies, as well as SMEs willing to invest in circular bio-based products. Additionally, maker labs will be involved in developing products and services that suit the building sector - alongside agrocompanies - involved in processing and collection of organic waste. Research centres and academia to refine and improve materials properties.

In parallel to that the stakeholders traditionally involved in the construction supply chain shall be persuaded and educated to the opportunities offered by bio-based products and the benefits that a circular approach to construction would provide to them from a technical, social and - more importantly - financial perspective.

The seasonality of organic waste and potential shortage due to climate issues, would represent a significant risk for the supply chain. This can be mitigated by either appropriate storage of resources or the production processes shall be able to support a larger variety of waste rather than a single crop.

Risk mitigation would be essential for investors, such as banks and financial institutions to possibly finance new ventures in the field of organic waste.

Next page image showcase how the value chain for organic waste should modify to sustain the development of construction products and the inclusion of new stakeholders.



GENERATING MORE VALUE

New stakeholders shall populate the value chain ensuring exploitation of higher value for waste

“The City of Amsterdam is convinced that the circular economy carries enormous economical and ecological potential for the city and the region. Especially when focusing on the value chains of construction and biomass in the built environment. We see the need for new paradigms in the governance for the circular economy. Gaining insights through `Learning by doing’ is key to new governance in companies, governments and society”

Esther Agricola

Director Urban planning and Sustainability

City of Amsterdam

06 A Global Reach with Local Impact

6.1 A variable landscape

Cities are aggregators of organic material due to the unbalanced ratio of inflows and outflows leading to concentration. While this makes cities the source of large amount of waste and negative externalities in the current economic model, these resource streams would be captured and valorised in the circular economy model.

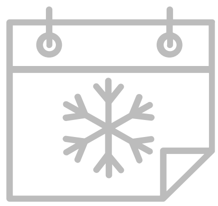
Cities present a relevant opportunity to implement circular principles in the management and exploitation of bio-based and natural resources due to their characteristics that include a large scale supply, a high proximity amongst stakeholders and a tech-savvy workforce[(19)].

Opportunities for exploitation of organic waste would vary according to local and regional circumstances that will change considerably depending on different areas globally.

From an environmental perspective the climate constraints and specific amount of crop that shall be sufficient to scale production up and sustain a potential market. The need for appropriate manufacturing processes would also have an impact depending on the location, whether it is an industrial or rather rural area a specific supply chain need to be developed when not existing yet to exploit the organic waste.

Climate constraints

will have an impact to scale up waste use



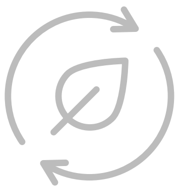
Seasonality

will impact on availability of resources and production capacity

19) Urban Biocycles. Ellen MacArthur Foundation, March 2017

Local regulations

Might impact on use of waste as a feedstock



Recycling

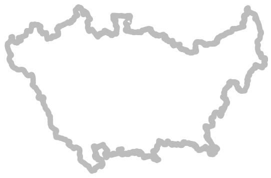
Collection procedures will impact on the quality and amount of waste recycled

Also important are the local regulations related to the use of waste and its management. Some countries might consider organic waste as hazardous materials which risk polluting the soil and water. Therefore it might become complex to divert waste toward models other than incineration. All these are variables to the actual implementation of alternative business models for exploitation of organic waste in construction that shall be assessed on a case by case basis.

Cities around the world have recognized the value embedded in organic and natural material flows and some have put systems in place to capture that value. However the implementation is rather sporadic and the approaches vary significantly. A systemic change would be needed to deal with urban organic waste and realize its full value.

Some cities might be more able to operate virtuous recycle procedures relative to others, for example both San Francisco and Milan already have public organizations in charge of collecting solid organic waste and its disposal. On the other hand cities like Melbourne and London have significant expanses of green areas and parks - that might be an important source of waste – but recycle less.

6.2 Case study: Milan Metropolitan area



Milan metropolitan area
equal to 157.560 Ha

77 %

Total green area / total area
equal to 122.000 Ha

70 %

Agricultural area/
Total green area
equal to 85.000 Ha

Starting from 1995 the city of Milan has worked with large producers of solid organic waste (SOW) - such as restaurants - to institute in 2012 a process of separate collection from households. The collection program now covers about 130.000 tonnes of organic solid waste per year. This makes Milan the top city in the World for recycling of SOW with a population exceeding one Million inhabitants. The collected material is currently used for production of biogas and compost.

Considering Milan a best practice in relationship to the SOW, it has been selected to qualitative assessment of the opportunities offered by its large metropolitan area in terms of amount of organic waste generated from sources other than SOW and its relationship to new opportunities of reusing organic waste for construction applications.

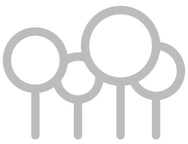
The research started with a territorial analysis, identifying and distinguishing the main natural resources avaliable at the city area in order to understand what kind of processes are currently in place and the opportunities of implementing new disposal models.

The analysis found that 77% of the metropolitan area of Milan - equal to 122.000 ha – consists of green areas. These areas are occupied by three main use types. The prevailing one is agricultural fields – equal to 85.000 ha - the second is urban parks – equal to 13.605 ha. Last comes areas occupied by forests and trees – equal to 8.755 ha.

With respect to the green areas, 70% of it is covered by crops, this implying that the biggest source of organic waste in Milan's Metropolitan Area comes from agriculture.

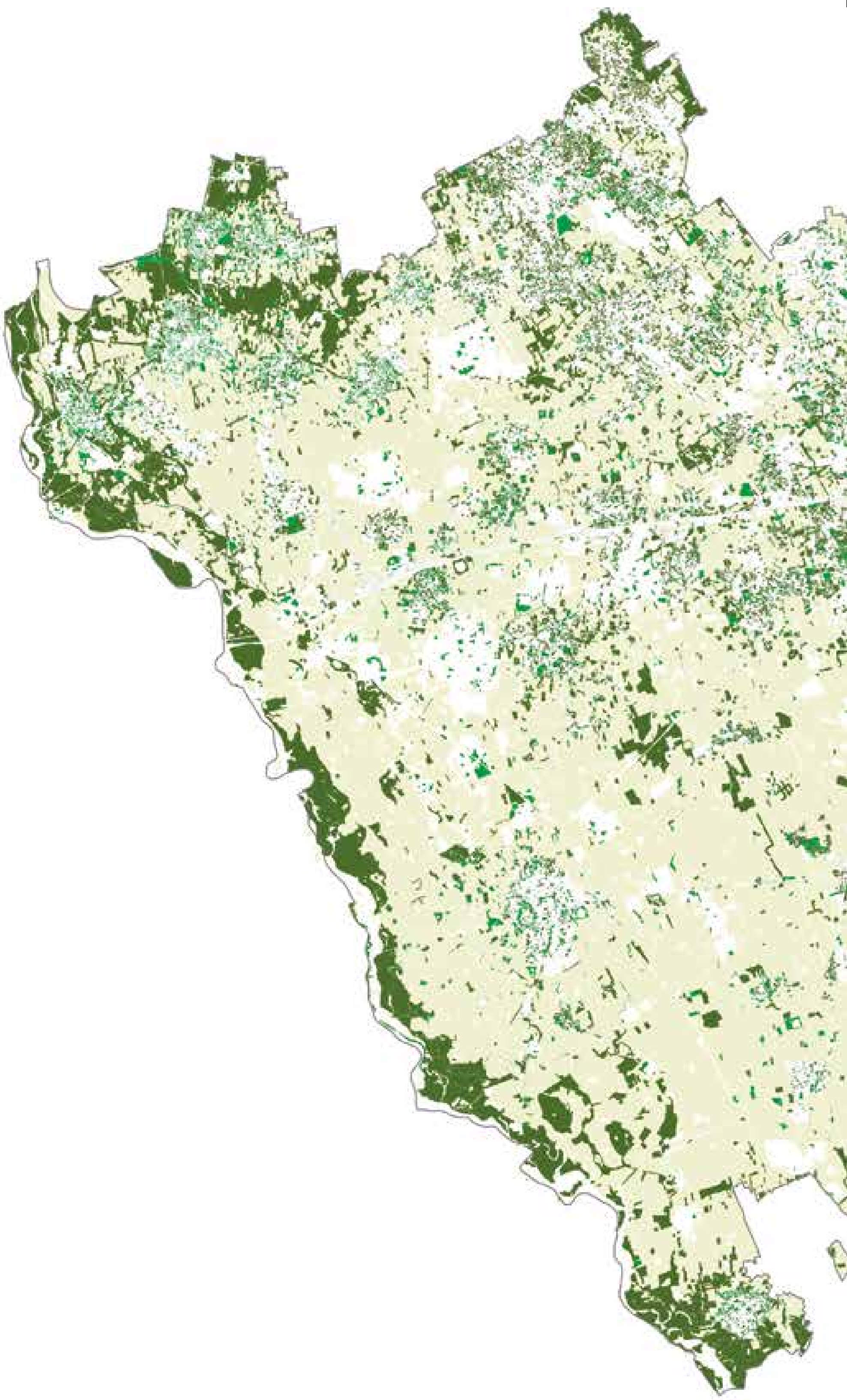
Natural resources in Milan Metropolitan Area

13.605 ha
Urban parks



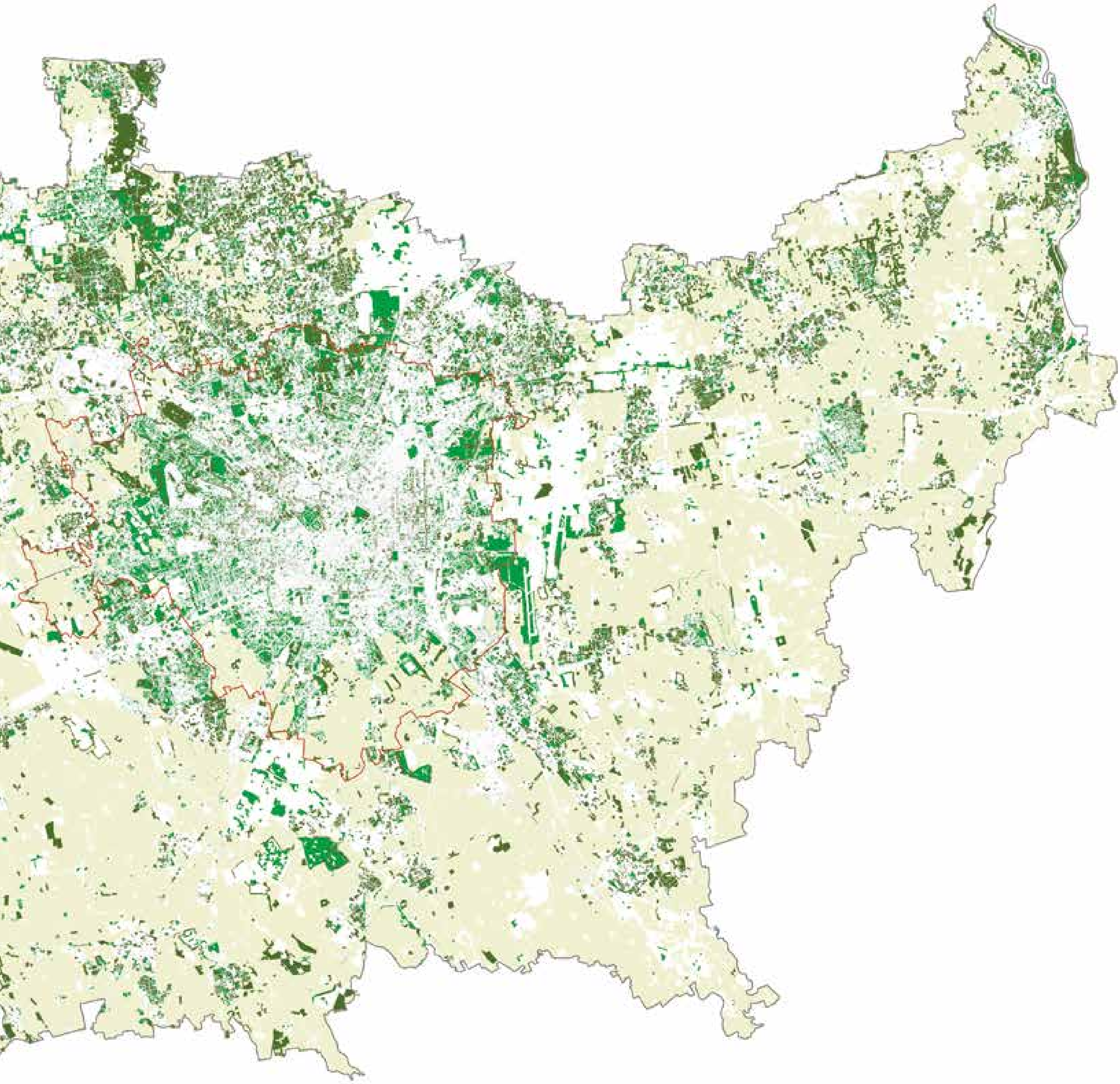
8.775 ha
Forests & trees

85.000 ha
Agricultural area

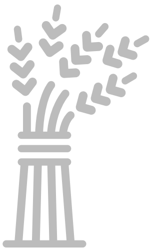


MAP KEY

- urban parks
- trees
- agricultural fields
- infrastructure



6.3 Waste residue as a resource



Harvest index
equal to 0.5

Up to 8M m^2 cladding surface
when using 10% of the waste generated in the Metropolitan Area

Main organic waste streams for the Milan's Metropolitan area come from cereals, vegetables and fruit.

In all these cases the average harvesting index for crops and other organic waste is equal to 0.5. This means that during harvesting operations half of the mass for the crops is left on the ground with no direct return in terms of commercial value.

Considering the Metropolitan area of Milan about 215.000 tonnes of maize waste are collected, while 85.000 and 17.000 are for rice and wheat respectively. To this add about 60.000 tonnes of other organic waste collected from other sources in agriculture and other green ares through the city.

Such waste stream represents a very interesting opportunity for construction purposes. Considering that 10% of the overall organic waste could be diverted to construction and an average use of about 0.5 to 1.0 kg/m^2 of waste for millimeter of thickness for flat boards, this would result in an annual availability in 8 million m^2 of thin boards, only for the city of Milan.

The following pages present the bio-loop that describes the opportunity of using organic waste for different building applications.

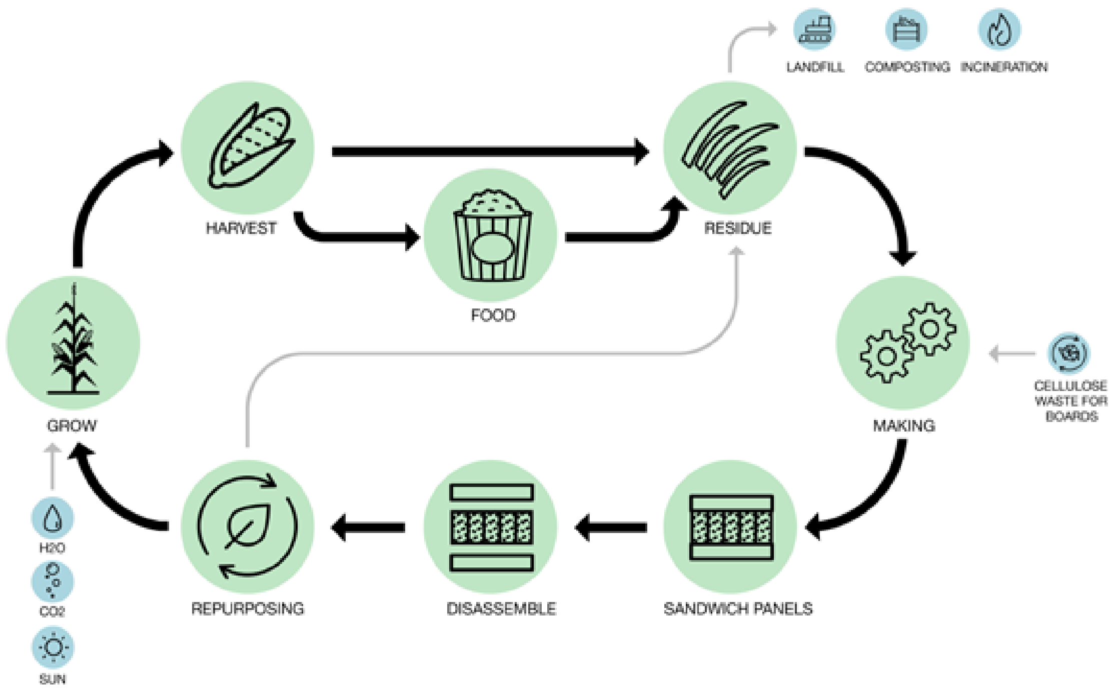
Crop	Maize	Rice	Wheat	Σ of all other natural waste
ha[20]	18.450	13.501	4.855	32.404
Actual crop (t)[20]	216.305	84.770	23.496,5	60.393
Harvest index[21]	0,5	0,5	0,57	0,5
Residue yield (t/ha)	11,75	6,27	3,627	1,86
Residue (t)	216.787,5	84.770	17.609	60.393

MAIN CROPS AND RESIDUE

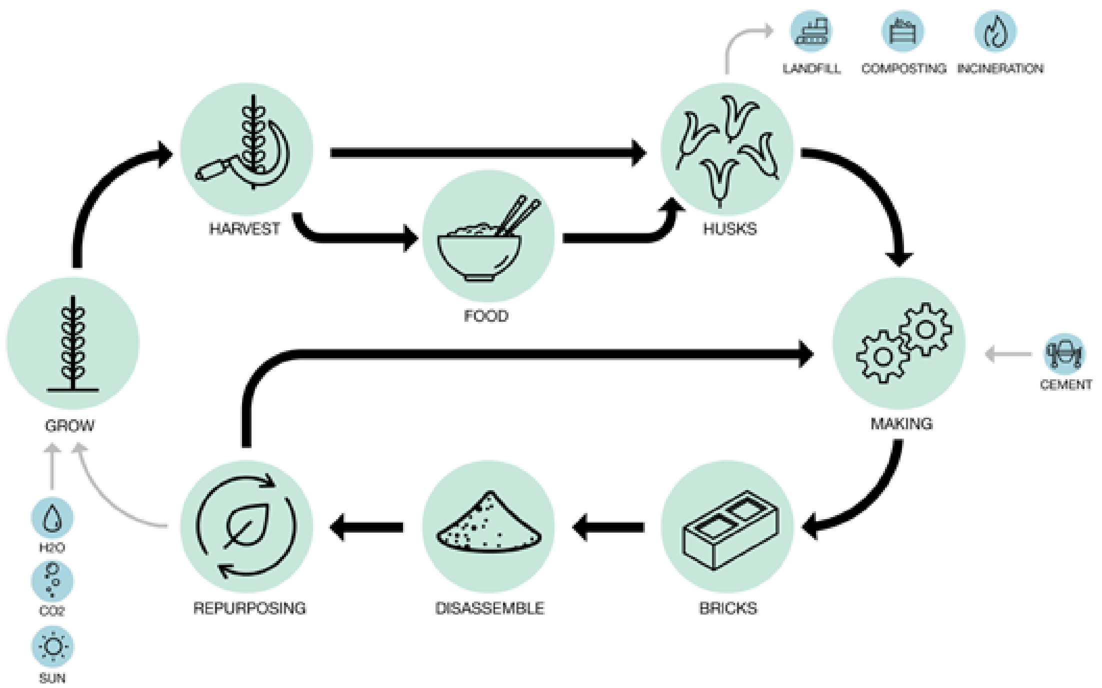
Describing the main waste streams for the city of Milan

20) Source: ISTAT, Censimento dell'agricoltura 2009, 2011
21) Source: General Directorate for Energy European Commission Report on Maximising the yield of biomass from residues of agricultural crops and biomass from forestry, 2016

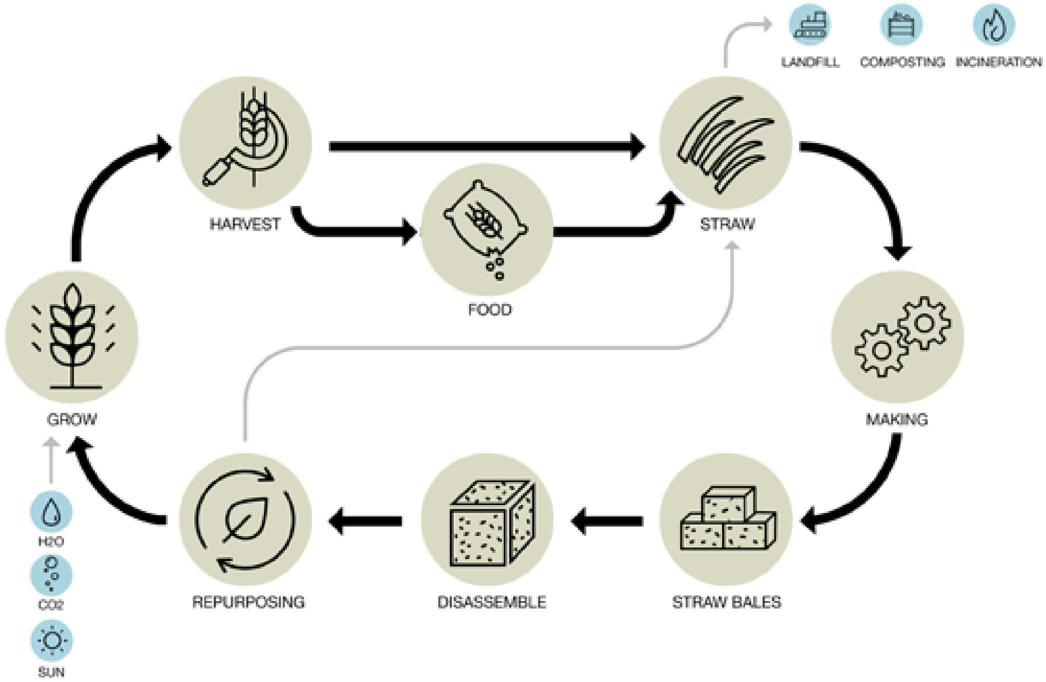
Maize for sandwich panels



Rice ash bricks

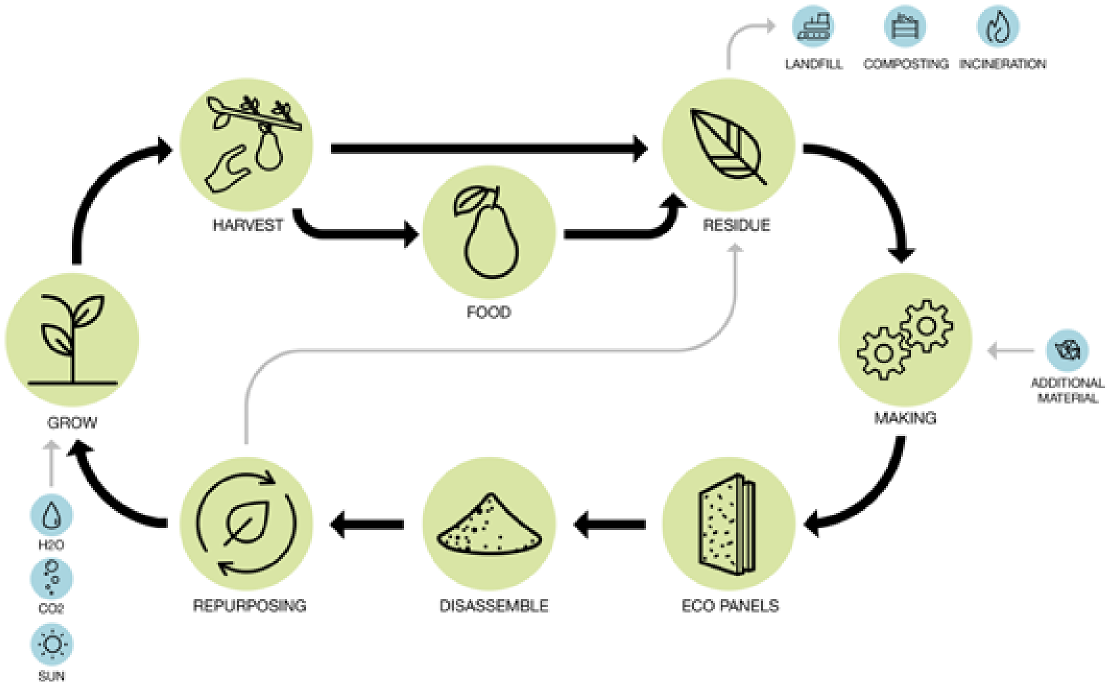


Straw bales bricks



© Arup

Urban organic waste board



© Arup

1143

Number of farms
and agro companies in Milan area

5

Agricultural
knowledge centres
in the City of Milan

6.4 Enabling a local economy

A number of stakeholders shall serve the purpose of creating a local value chain for organic waste to be locally exploited with success. In particular:

- Suppliers of waste such as agricompanies and consortiums;
- Producers - both SMEs and start-ups-to create products out of it;
- Designers and makers to create systems for construction.

Interviews have been undertaken with some of potential stakeholders to better understand their view on concerns and expected potentialities in a new supply chain for exploitation of organic waste.

The interview process involved both companies currently involved in handling of organic waste and companies potentially contributing realizing the additional value embedded in organic waste through alternative exploitation models.

An interesting case emerged for the orange industry, where the business model is traditionally plain with a large amount of residual waste concentrated in a limited period of the year. In recent years forward looking scientists and entrepreneurs realized that additional value was embedded in the wasted portion. Nowadays oranges waste is diverted into a new supply chain where the skin is used to extract pectin – extremely useful for the pharmaceutical sector – as well as innovative processes have been established to use the pulp to create fashion textiles (find an interview to Orange Fibers textiles later in the publication).

Very interestingly exploitation of organic waste in alternative models, might reveal beneficial when large quantities of waste are created in short time periods and in localized areas. This is typical of seasonal cultures such as those of tomatoes and citrus in the southern regions in Europe. This waste is generally treated as special waste that needs to be handled with care and disposed with high costs for the companies involved in the harvesting process and first use. In this case new exploitation models would both allow realizing a financial plus and reduce the implications related to handling hazardous waste.

Milan Agricultural District (DAM)

Local consortium of companies involved in agriculture in Milan's Metropolitan Area.

New financial opportunities

'Reuse of organic waste for purposes other than agriculture and farming would be very interesting for the Milan Agricultural District. In particular when considering the commercial opportunity of creating higher value for waste and having it returning to land. However to ensure that the product will close the loop it is essential that construction products will be free from any chemical contamination.'

Managing and controlling the waste stream

'The process of collection and selling could be made at a consortium level with the Agricultural District managing waste streams and connecting to the different makers and producers depending on the crops. It is essential to keep control of resource streams and their applications.'

Andrea Falappi

President of Milan agricultural district

http://consorziodam.com/

The consortium was established in 2011 to give support to the agricompanies operating in the municipality of Milan and enhance their activities. The consortium is composed of 31 companies cultivating an area of about 1500 hectares. Main cultivation is rice

Orange fiber

Italian start-up that developed and patented an industrial process to make fashion textiles from orange skin, after squeezing.

Facing resource scarcity and developing alternatives

'Nowadays 60% of textile products are produced from oil, while only 30% are obtained from cotton and cellulose. To satisfy the increasing demand for textiles, due to the constant growth of population and the future scarcity of oil, it is clear that cellulosic materials - as those obtained from organic waste - will be an essential resource. They would also help mitigating current impact of textile industry on the environment.'

The issue of scaling production with innovative products

'When you come up with a good idea, everyone is interested in it. However, nobody would invest in just an idea. We found two angel investors that allowed us to develop first prototypes and fill a patent. Going to scale and reduce costs of our products would require an higher investment with an industrial production line.'

Enrica Arena

Co-founder

http://www.orangefiber.it/

By transforming orange peel into cellulose fibres, the designers from italian startup Orange Fiber have developed an innovative fabricobtained from orange, lemon and grapefruit peel. This fabric could substitute wood and oil as raw material for fabrics production.

Marco Fabio Nannini
President & CEO

http://milan.impacthub.net/

Impact Hub Milano is part of international network of 'hubs' where entrepreneurs, creative professionals can access resources, be inspired by the work of others, to have innovative ideas, develop useful relationships and identify market opportunities. It as well has business incubator tailored to ramp up startups and accelerate your impact on local and global scales.

Impact Hub Milano

Italian national accelerator for start-ups.

Dealing with seasonality of natural materials

'One of the challenges that a start-up working with organic waste would have is the seasonality on which the supply chain depends. There has to be a business plan that allows maintaining and preserving the organic waste at good levels before being processed. This would be fundamental to support the opportunity of scaling up the production of products based on organic waste and to keep it up to speed throughout the year.'

Circular risk and investment opportunities

'Working in a circular supply chain would expose all stakeholders to risk. It is important that business models will properly address it and will put in practice mechanisms to mitigate it. Risk mitigation would make investing more attractive.'

Giulio Masotti
Architect, Designer

https://wood-skin.com/

Wood-Skin is a composite material created by the Milan design studio Mamma Fotogramma. Its plastic nature allows it to function as a stylish, organic-looking skin for projects that might otherwise be built with standard, flat materials.

Wood-Skin

Design studio based in Milan working with original wooden material.

Making customization sustainable

'At the present customization is still not competitive with standardization. Nevertheless it is booming since it intercepts our society's needs. The recipe to make customization affordable and more widespread is a mix of software development, digital fabrication technologies and expanding materials choices. Reusing waste to get a variety of materials might well serve this ambition and could become a strong enabler.'

Thinking in local loops applicable at global level

'Milan would be a great place to develop a Urban bio-loop since it combines on the territory high quality skills, materials and processes knowledge but also good taste for architecture and design. Key for such materials innovation to succeed is to stay local but serve on a global scale as a net.'

07 Conclusion

This document focuses on the application of a circular economy based approach to divert part of the organic waste stream - coming from both agriculture and green areas within our cities and from the countryside - towards use in construction. Applications would range from interior partition systems to acoustic ceilings and furniture. The analysis of the current amount of organic waste produced at both Europe level and specifically for the city of Milan, showcased that a significant feedstock would be available thus possibly triggering a significant production of construction products. Considering the case of thin cladding boards for interior it has been estimated that one kilogram of waste would generate a square meter of final product. Interestingly the commercial value of one kilogram of organic waste processed for construction purposes would be from five to six times higher respect to the value realized with current disposal processes - such as energy recovery. As a consequence of this increase in value there would be a number of cascade effects such as additional financial value for companies managing and processing organic waste streams. It will also allow the creation of new enterprises - both start-ups and SMEs - to develop new technologies to implement the use and increase the quality of bio-based products.

Use of organic waste would result in healthier products with a reduced environmental impact for the construction sector. In particular when considering that these components could be returned to the biosphere at the end of their service life, thus releasing the embedded nutrients to the soil. To make possible this transition it will be necessary a wide stakeholder engagement and the support of a regulatory framework that would allow an easier access to waste streams and make it a more attractive financial perspective.

Albeit this research did not address Solid Organic Waste alongside the other waste stream, relevant opportunities are seen for it to become a potential source of feedstock supply in particular when considering the creation of new base materials and polymers.

Resources

Built environment Circular economy. WRAP, 2013 [Online].

Construction and Demolition Waste. European Commission, 2016 [Online].

Urban Biocycles. Ellen MacArthur Foundation 2017

http://www.arup.com/projects/solarleaf

http://doggerel.arup.com/engineering-a-mushroom-tower

http://www.arup.com/projects/biobuild_facade_system

Eurostats Manual on Waste Statistics

Eurostat (Online statistics)

SimaPro software database

https://cereals.ahdb.org.uk/media/165158/3351-annual-project-report-2008.pdf

http://www.ahdb.org.uk/projects/straw.aspx

http://maxwellsci.com/print/crjbs/v4-673-675.pdf

http://ec.europa.eu/environment/waste/framework/

Electricity prices in Europe, Eurostat

http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics

Achieving Growth Within, published January 2017. The Ellen McArthur Foundation

Urban Biocycles. Ellen MacArthur Foundation, March 2017.

ISTAT, Censimento dell’agricoltura 2009, 2011

General Directorate for Energy European Commission Report on Maximising the yield of biomass from residues of agricultural crops and biomass from forestry, 2016

Authors

Guglielmo Carra

Silvia Ilardi

Clare Perkins

Devni Acharya

Contributors

Carol Lemmens

Jan Wurm

Francesca Baldessari

Serena Girani

Mariia Kapitonova

Martin Pauli

Chiara Fraticelli

Richard Boyd

Graphic Designers

Luca Orlandini

Mariia Kapitonova

Stella Viglianisi

Acknowledgements

We would like to thank all external companies and institutions providing their support and endorsement to this research and in particular: the Agricultural district of the City of Milan, the City of Amsterdam, Impact-Hub Milan, Intesa Sanpaolo, Orange-fibers, Wood-skin and the Polytechnic of Milan.

The “Materials as usual” scenario is not a viable option for the future of the construction sector that currently has the opportunity to develop novel materials to improve the quality of the built environment. In recent years we assisted to the growth of new technologies and an increasing number of solutions that support this need of change and could possibly trigger a transition to a different approach in construction.

The principles of Circular Economy provide a fundamental support for a shift from a linear – consumption based model, towards a circular supply chain. With this respect the use of bio-based products in construction – particularly those designed to exploit organic waste - might well allow a number of benefits respect to traditional solutions, having lower CO_2 content, providing reduced health risks and cost.

At the same time new business models could be identified and developed to support alternative use of organic waste streams as opposed to the current value chain. This could help enhancing local and rural economies with benefits for both existing and new potential stakeholders. This publication, *The Urban Bio-loop: growing, making and regenerating*, aims at demonstrating that a different paradigm in construction is possible.

ARUP

Corso Italia 1

20122 Milan, Italy

Emilan@arup.com