TFE 2021 [LBARC 2200] - LOCI Bruxelles

Titre :	From Farms to Construction: Association of agriculture and construction, via a valorization cycle of agro-sourced materials
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Date de présentation :	18 Juin 2020 à 16h00

RÉSUMÉ: Aujourd'hui, l'épuisement rapide des ressources et l'urbanisation entraînent une grave dégradation des écosystèmes naturels. Les sols fertiles sont remplacés par des environnements bâtis denses et de l'agriculture intensive. L'agriculture et la construction ont, sur l'environnement, un impact qu'une forte prise de conscience peut atténuer. Combiner agriculture et construction, sous le toit de matériaux agro-sourcés, pourrait aider à augmenter la biodiversité des terres agricoles ainsi qu'à réduire l'impact des bâtiments. Ce mémoire vise à illustrer, pour la Belgique, un cycle de valorisation des résidus agricoles associés à la construction, favorisant ainsi des méthodes écologiques sur les 2 disciplines. Des entretiens avec des experts dans des domaines connexes ont été réalisés pour identifier les conditions locales, les disponibilités et les défis pour développer un cycle local. Ensuite, les principes fondamentaux de viabilité du cycle ont été déterminés, également par des entretiens avec des experts. Enfin, différents enjeux, liés à l'intégration de chaque étape du cycle dans les zones rurales et urbaines, ont été identifiés pour estimer l'impact du cycle sur la durabilité.

MOTS-CLEFS: Construction en matériau végétal, Architecture écologique, Ressource naturelle, Écomatériau, Économie circulaire, Agriculture durable, Bilan carbone, Biodiversité, Environnement naturel

From farms to construction

Association of agriculture and construction,
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Acknowledgments

I would like to express my sincere gratitude for the support and assistance that I have received throughout the making of this thesis.

Firstly, I would like to thank Mr. Matthieu Delatte, whose expertise was invaluable, for his patient guidance, insightful comments and suggestions.

I am deeply grateful to my supervisors Mr. Geoffrey Van Moeseke, Mr. Benoit Thielemans, Mrs. Sandrine Meyer and Mr. Jean-Jacques Jungers, for their wonderful advice and support at every preparatory stage of the thesis.

I would like to express my sincere gratitude to Mrs. Géradon, Mr. Mossay, Mr. Durdu, Mr. Serteyn, Mr. Delcourt, Mr. Ernotte, Mr. Malfeyt, Mr. Laffineur, Mr. Vos and Mrs. Eckelmans for their precious time and for kindly sharing their wide experiences and expertise, which were critical for the completion of this thesis.

I would like to extend my sincere thanks to Mrs. Julie Denef, Mrs. De Lestrange, Mrs. De Bellefroid, Mr. Lefebvre, Mr. Bonnert, and Mr. Plateau for sparing their valuable time to answer my questions and for their advice.

My appreciation also goes out to my family for their unwavering support and encouragement.

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1. Consumer Societies

> *"We have entered the time and space of a new paradigm: the limitation of our planet's resources which we have used and have greatly benefited from. Today however, we need to manage them more carefully." (Correia, Dispasquale and Mecca, 2014).*

Today's rapid consumption of resources and urbanization cause serious degradation in natural ecosystems. In addition to high energy and resource consumption, increasing construction demands generate extremely dense built environments which are casting out nature instead of being hosted by it. The current situation of our society corrupts the peaceful relationship between humanity and nature that once existed.

> *"Without wanting to idealise this relationship, one could say it was based on respect and gratitude, recognizing the fact that the environment provided food, drink, materials for building and heating, and beautiful landscapes to contemplate. "(Correia, Dispasquale and Mecca, 2014).*

Protecting and increasing the presence of nature and respecting its natural rhythm while reducing the negative impact of built environments by turning towards less consuming ways to build our living environments could recreate the respectful bond that nature and humanity had once.

Reducing the energy and resource consumption of buildings, leaning towards renewable and local materials is essential to ensure great management of resources and to reduce the impact of built environments.

In the past, materials to build with were offered by territories and they bonded humans to their environments and encourage them to appreciate nature. Combining agro-sourced materials offered by the soil with nowadays technologies could be one of the solutions to minimize the impact of consumptive building materials that are currently in use. Crop types offered by soil and their availability to be used in construction highly depend on locations as climate conditions and soil types are quite different. Besides the local conditions, several factors need to be brought to light to ensure the sustainability and viability of the use of agro-sourced materials.

This thesis aims to analyze the current market situations and crop availabilities in Belgium to propose a cycle for agro-sourced materials, that highlights the interactions between different actors, the current flows, and main viability principles to follow to integrate the cycle in our societies. The outcomes of the integration of the cycle in living environments would be different for rural and urban areas as the conditions are quite different. This paper would finally illustrate the different impacts of the cycle on the sustainability of rural and urban areas.

2. Built Environments

2.1. Current Challenges

Today's settlements are highly constructed and built environments play an important role in the environmental crisis. 36% of global energy is used for construction activities or by buildings. Construction activities cover 39% of carbon dioxide emissions caused by energy use (UN Environment and International Energy Agency 2017). After the industrial revolution, the construction attitudes have been changed as for agricultural trends. Even if the new attitudes brought great efficiency, ease of application and mass-production opportunities, new materials as brick, concrete and steel are causing excessive energy consumptions during their extraction, production, and transportation. Relying on depleted raw materials with very low levels of recycling as concrete and steel is one of the problems that should be solved to create sustainable methods for future generations. (Lawrence, 2015).

Currently, used materials like concrete and steel are based on finite resources that require high energy consumptions. However, renewable materials which are regenerated sustainably within a short period, demand much less energy than current materials; they are mostly harvested from plants and or animals (Lawrence, 2015). Besides their sustainable renewability, the bio-sourced materials also contain the potential to be reused or turned back to the soil to provide nutrients for animals, plants or for the soil itself, at the end of their service life.

2.2. The Notion of "Sustainability" in Architecture

The recognition of natural resources not being unlimitedly available during the end of the 80s has forced humanity to create alternative development models taking their origins from the idea of sustainability. The appropriate use of resources by respecting natural laws became an inevitable challenge to provide to humanity and the next generations livable environments and resources. The intentions to discover effective ways to manage resources allow humanity to reveal the surprisingly high impact of buildings and construction on pollution and energy consumption. (Steemers 2010, Hegger M. 2008, Sanchez-Montanes Macias 2007; cited in Correia, Dispasquale and Mecca, 2014: 41). Following the research for alternative models based on sustainability, various concepts as "Green Architecture", "Low-tech Architecture", "Bio Architecture" and "Kilometer Zero Architecture" have appeared to ensure a balance between human needs and the well-being of the environment during the last decades. One of the main aims of these concepts is to reduce the impact of materials and construction techniques on human health and on the environment by reducing the embodied energy. Returning towards local economies provides local materials, techniques, and competencies intending to reduce the ecological impact via the reduction of transportation energy and increase the appropriation of materials to their territories. (Correia, Dispasquale and Mecca, 2014: 35).

2.3. Human vs. Territory

Traditionally the relationship between man and the soil was creating a respectful bond between man and its environment. The earth has always been in the center of human life as it offers directly or indirectly all the resources that shelter and feed humanity. (Fig.1) Observation of the territories allowed to deepen the connection while giving humanity the chance to obtain their primary needs. Before industrialization, the man was the builder while the materials were the products of territories picked from building sites (Correia, Dispasquale and Mecca, 2014: 143).

Today's rapid population growth and high demand for basic needs as housing and food would not allow turning back to traditional ways, as the financial efficiency of modern industry is undeniable. Yet, getting inspiration from traditional methods can bring alternative ways to build while responding to the main challenges of nowadays. Local materials sourced from nature and traditional knowledge can be combined with technological advancements to respond to high needs in construction and current economic, social, and environmental challenges. Natural materials could significantly reduce the cost of materials and the impact on human health while ensuring the well-being of the environment due to their low CO_2 content (Carra et al. 2017). Besides the use of natural and local materials can help man to use nature wisely while helping to create a peaceful and strong bond with the territory and overcome the rupture between man and nature. (Correia, Dispasquale and Mecca, 2014: 142). Rebuilding a connection with nature, soil and territory would contribute to the well-being of both nature and society.

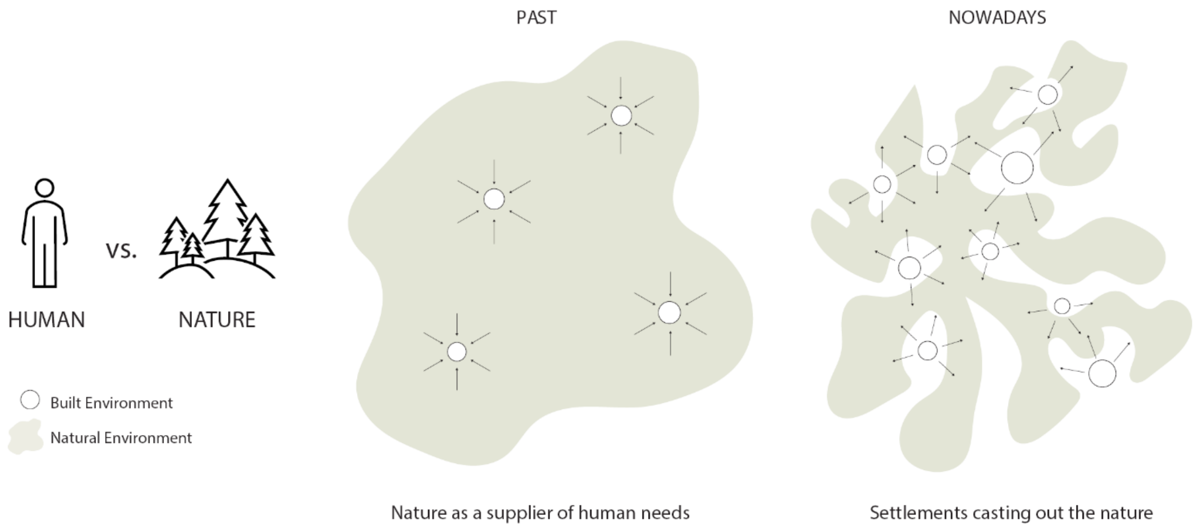

Figure 1. Changing relation between human and nature (Produced by the author)

2.4. Agriculture: an Alternative Resource for Construction

Agriculture has a huge potential to provide local bio-sourced materials for construction while restoring the connection between humans and the soil. Crops have been used very actively in construction in the past. Thatched roofs were mainly made with agricultural products and residues as grass found in ponds, reeds, and straw. (Correia, Dispasquale and Mecca, 2014). Crops have a great capacity of CO_2 sequester and they are specific to regions and climates. Moreover, valorization of green wastes and residues in construction could help reduce energy-consuming waste treatments such as incineration and landfilling and create an additional step in the biological cycle of natural materials before their return to the soil (Carra et al. 2017). Besides, the use of bio-sourced materials would bring an additional valorization domain complementary to nutrition and textile for agriculture that would create alternative opportunities for farmers.

3. Agriculture

Using agriculture, as a resource for environment-friendly construction materials, would not be consistent if agriculture itself would continue to harm the environment or if it is a sector under threat. It is very important to understand the current situation of agriculture in Belgium, to propose valorizing opportunities for agricultural residues and sustainable methods to reduce the environmental impact of both construction and agricultural production.

3.1. Agricultural Crisis

Agriculture, as the construction industry, has an important impact on the environment and the use of resources. Soil degradation and water and air pollution are some critical negative impacts due to excess nutrients pesticides and other pollutants. OECD (2019) states that 70% of worldwide water use is caused by farming activities. It is also pointed out that 10% of global greenhouse gas emission was caused by agriculture in 2019 (EPA, 2021). However, agriculture does not affect the environment only negatively, it can contribute to the well-being of it by reducing flood risks, sheltering insects, animals, and plants, and storing greenhouse gases within crops and soil (OECD, 2019).

OECD (2019) points out that, minimizing the impact on the environment and caring for natural resources for upcoming generations while responding to the increasing food demand of the global population is one of the main challenges for nowadays agriculture. Agriculture playing a critical role in environmental crises could also play an important role to resolve the problems. (OECD, 2019). The agroecological transition could be used to bring diversity to rural and urban landscapes, ensure biodiversity, reconnect people to the soil, and help to reduce energy use and waste generation in the construction industry by providing bio-sourced materials.

The crisis in agriculture is not only related to environmental factors but also economic and social factors. The sudden rise in human population, the immigration from rural areas to cities, and the high demand for urban areas have caused a necessity for a rapid change in agricultural production. Global farming models that have entered our lives during the second half of the 20th-century promote monocultural activities. This standardization results in intensive farming, the suppression of small-scale traditional farms, and forced migration to cities. Farmers are forced to deal with high financial loads for investments without an increase in their quality of life and only a few of them survive (Altieri, 2018; cited in Carpio Villarroel, 2018).

3.2. Agriculture in Belgium

Today 44% of the total area of Belgium is dedicated to agricultural activities. Even if there is not a significant change in the agricultural area, the numbers of farms and agricultural workers have decreased significantly during the past decades. Since 1980 the Belgian agriculture has lost 62% of its workforce and 68% of the farms have disappeared. The big infrastructures replacing the small-scaled traditional farms can explain the small loss of 2% in agricultural lands while the quantity of labor and farms went through a dramatic decline. The average surface of farms has been tripled since 1980 both in the Walloon and Flemish Region. (Statbel, 2020). This rise in the scale of agricultural infrastructure is both the reason and the consequence of increasing inequalities between farmers. The ones that could adapt to relentless technological advancements via heavy financial loads survive and evolve while the others are convicted to poverty (Van Hecke et al. 2000).

Lack of successors, high land prices, intensive farming, and monoculture are other threats to agriculture in Belgium. Interviews from 2016 point out that only 21% of the Walloon farmers above 50 have someone from the next generations to inherit their farms. The research also proves that the numbers are highly related to farm areas and small-scale farms are in greater danger to sustain (Service Public de Wallonie Agriculture, 2020). The transformation of small crop fields into huge fields of monoculture also impacts dramatically natural landscapes.

Gérard (2021) pointed out the critical changes in the patterns of crop fields between 1953 and 2004 in Neerpede which highlights the negative impact of intensive and mono-cultural farming on landscapes and biodiversity (Fig.2).

Figure 2. The pattern change in Neerpede between 1953 and 2004
(Bruciel 2021; as presented in Gèrard 2021)

Valorization of local agricultural products in construction could propose alternative economic models for small-scale farmers while bringing biodiversity to harvested areas to lodge more powerful ecosystems and propose diverse landscapes.

Another big threat to agriculture is rapid soil degradation. Erosion related to huge land parcels, industrial mass production, and monoculture; reducing organic matter amounts in soil due to the lack of biodiversity and implementation of inappropriate methods are the main reasons for soil degradation in Belgium (Gentile et al. 2009). The survival of small-scale traditional farms presents even bigger importance to ensure the conservation of soils as they are more likely to respond to the problems mentioned above.

It is crucial to consider social, economic, and environmental challenges in agriculture to propose an association model, based on the valorization of residues in construction. Encouraging traditional farms and effective management of resources are key factors to ensure sustainability in agricultural production.

3.3. The Notion of "Sustainability" in Agriculture

Deploying environment-friendly agricultural methods is one of the main principles of sustainability in agriculture to provide rural resilience but also due to environmental crisis becoming undeniable. Increasing care for the environment, leaving the current consumptive ways, and using more responsible methods that would ensure sustainability and the well-being of nature could bring solutions to the environmental crisis of the 21st century. Agroecology is one of the main approaches that is trying to ensure the continuity and resilience of agricultural production by joining environmental, social, and economic dimensions. The approach aims to increase the interactions between flora, fauna, humanity, and the environment (Gérard 2021). Today, the adoption of agroecology principles, enriching biodiversity, and conserving the fertile soils and resources are essential to ensure the sustainability of agricultural lands and fertile soils.

3.4. Strength in the Unity

The use of crops and residues in construction could favor agroecology principles and create alternative incomes for farmers, while agriculture could be one of the solutions to build with local and renewable materials. In addition to material choices, the collaboration between the two sectors could also be used to create public awareness, both for sustainable agriculture and construction. This thesis aims to propose a valorization cycle that illustrates the main principles of the association of agriculture and construction, under the roof of bio-sourced materials, to bring more sustainable solutions for both disciplines. Possible social, environmental and economic sustainability outcomes of this association are studied in this paper, by analyzing the current market situation, plant availabilities and resources to ensure viability for the association of agriculture and construction.

4. Methodology

Firstly, the main domains connected to the subject of the thesis are identified: agro-ecology, eco-construction, bio-sourced and circular economy. Then, organizations working on related domains as material producers or non-profit organizations are selected to reach out to the experts. The list of experts has evolved as the study progressed with new information gathered from interviews (Fig.4). Data obtained from interviews are presented in the following chapters throughout the thesis.

The combination of theoretical and practical data allows examining the feasibility for an association model of agriculture and construction, via agro-sourced materials. Adjusting and completing the information gathered through a literature review with the in-situ experiences of experts and their knowledge about current market situations, availabilities and potentials is the core of the study.

According to interview results and literature review, the main principles of the economic viability of agro-sourced materials, plants availability in Belgium and technical properties of agro-sourced materials are determined. Moreover, the risks, weaknesses, possible development axes, drawbacks, current flows, and main needs are pointed out.

Following the determination of plants availability and economic viability principles, the model describing an alternative use for organic waste streams, proposed by ARUP (Carra et al. 2017) in the report "The Urban Bioloop", is analyzed. The analysis allowed highlighting important principles and development points for the use of agricultural residues in construction. The model of ARUP emphasizes the main actions that should be added to current flows, to valorize agricultural residues treated as waste. A valorization cycle, inspired from the ARUP model, developed and modified according to the interview results and local needs, is proposed to encourage the use of agro-sourced materials in construction while raising a sensibility for the importance of sustainable agriculture.

Finally, different outcomes of sustainability for integration of the valorization cycle steps, in urban and rural areas, are highlighted to point out the potential benefits and impacts. The sustainability principles, featured by Correia, Dispasquale and Mecca (2014: 29-31) are used as inspiration to compare the cycle's potential contribution to sustainability in rural and urban areas.

The main environmental, economic and social criteria, that are used to compare the outcomes of the cycle in rural and urban areas, are: enriching biodiversity, local production & soil conservation, proposing alternative incomes, extending building's lifetime, supporting self-building, increasing social cohesion, connection to nature and transmitting know-how (Fig.3).

Figure 3. Sustainability criteria used to compare the outcomes of the cycle in urban and rural areas (Produced by the author, inspired by Correia, Dispasquale and Mecca 2014)

The main goal of the cycle is to valorize agricultural residues and secondary products to improve both agricultural and construction practices. Yet, outcomes and goals vary from rural to urban areas, as the conditions are quite different. Cycle in rural areas may help support urban resilience, ensure the viability of small-scale farms, propose alternative income areas for the farmers, increase biodiversity and encourage efficient management of resources. In urban areas, it may help create public awareness networks for agriculture and construction as well as promoting collective activities, social cohesion, connection to nature and employment possibilities.

4.1. Interviews with Experts

Experts	Expertise	Role	Date	Medium	Organization
Lou Plateau	Agroecology	PhD Researcher	January 28, 2021	E-mail	ULB
Alexandre Lefebvre	Urban Agriculture	Founder Alaube Manager of Maximilien Farm	February 4, 2021	Telephone Conversation	Alaube
Emmanuel Mossay	Circular Economy	Executive Committee Member Visiting Professor -UC Louvain	February 25, 2021	Video Conference	Ecores
Pascal Durdu	Sustainable Eco-Systems	Co-founder Farming for Climate	March 9, 2021	Video Conference	Farming for Climate
Charlotte De Bellefroid	Hempcrete Blocks	Marketing & Communication	March 15, 2021	E-mail	Isohemp
Emmanuel Malfeyt	Eco-construction	Coordinator Architect	March 23, 2021	Video Conference	Eco-Build
Quentin Laffineur	Sustainable Constuction	Advisor Innovative Sector	March 23, 2021	Video Conference	Eco-Build
Antoine Bonnert	Strawbale Constructions	Co-founder Pailletech	March 29, 2021	E-mail	Pailletech
Hanne Eckelmans	Self Construction-Stawbale	Architect	April 7, 2021	Video Conference	Hé! Architectuur
Céline Géradon	Bio-sourced Economy	Project Manager	April 9, 2021	Video Conference	Valbiom
Laurent Serteyn	Conservation Agriculture	Mission Head	April 23, 2021	Video Conference	Greenotec
Sébastien Ernotte	Hemp-lime Constructions	Mission Head Founder of Chanvreco	April 29, 2021	Video Conference	Chanvreco & Cluster Eco-Construction
Hugues Delcourt	Strawbale Constructions Eco-Construction	Project Manager Civil Engineer	April 29, 2021	Video Conference	Cluster Eco-Construction
Peter Vos	Strawbale Constructions	Architect	May 3, 2021	Video Conference	Architectengroep Barchi

Figure 4. List of Experts

5. Agro-Sourced Materials

Agro-sourced materials are the tie between the construction and agriculture sectors. It is essential to study first the viability of agro-sourced materials to subsequently examine the sustainability of a model based on the association of the two sectors (Fig.5).

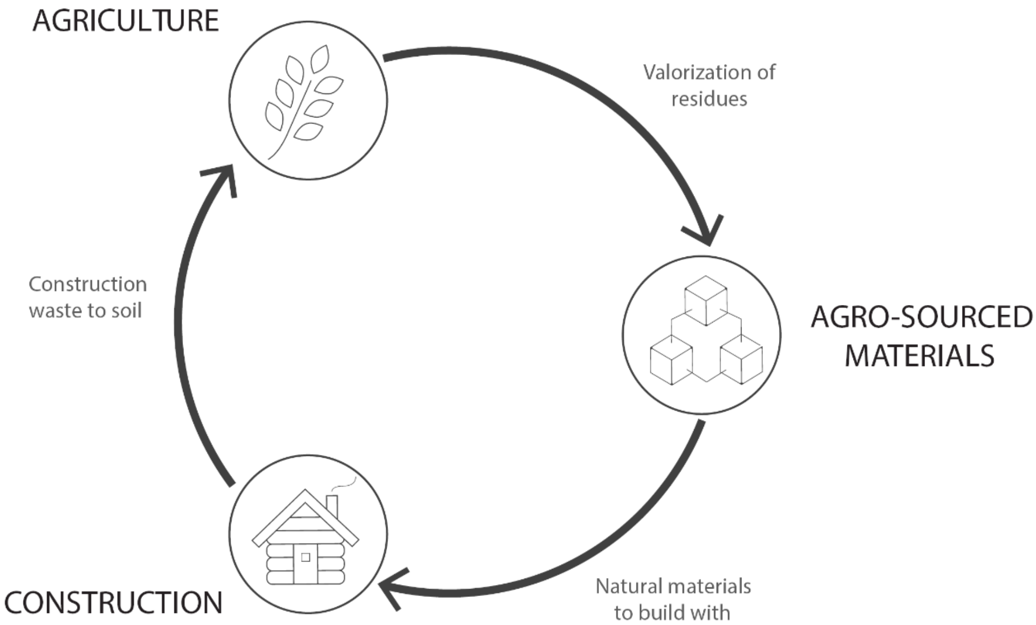

Figure 5. Association chart of agriculture and construction, under the roof of agro-sourced materials (Produced by the author)

5.1. Circularity and Economic Viability

The use of under-valued products as residues and waste in construction has several economic impacts. Increasing the service life of residues or secondary products by adding a valorizing step instead of producing new construction materials as steel and concrete would decrease the environmental impact while increasing the employment opportunities and reducing the need for investments (Emmanuel Mossay). Moreover, Emmanuel Mossay pointed out that currently most of the investments are placed at the bottom lines of the Lansink scale (Fig.6). Today, it is especially important to propose investment models that would consider the importance of reusability, recycling, and reduction of wastes. The valorization of bio-sourced materials, especially of the secondary and co-products and the residues in construction, could encourage investments that would be placed on the upper lines.

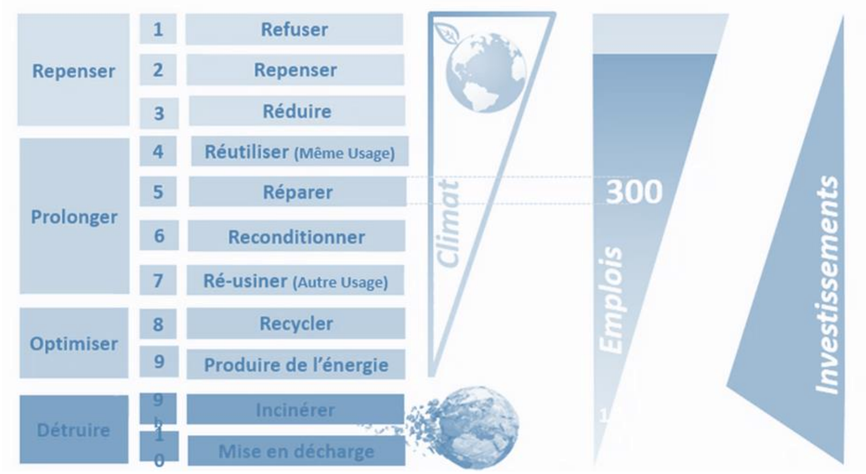

Figure 6. Impacts of Lansink Scale on Climat, Employment and Needed Investments (Mossay, 2021)

Sustainable supply, industrial and territorial ecology, eco-conception, reusing, and recycling are some main principles of the circular economy that were stated by Emmanuel Mossay. The use of bio-sourced materials offers a circular approach by being able to easily answer the main principles of the circular economy. Carra et al. (2017) state that:

> "The principles of Circular Economy would provide the rationale for a shift from a linear – disposal model - towards a circular value chain where natural waste is the main resource ".

Bio-sourced economies have started to take an important place to develop circular strategies. For instance, Céline Géradon mentioned a new strategy that has recently been introduced by the Walloon government "Circular Wallonia" to support the creation of circular economies and give a very important place to the development of bio-sourced economies. The creation and development of value chains based on agro-sourced materials would have an even more important role following these kinds of intentions.

Even if circularity is a positive notion to reinforce the viability of bio-sourced materials, many other critical points should be considered to ensure the economic viability of agro-sourced materials.

5.1.1. Cost- Efficiency and Competitive Price Range

Sébastien Ernotte declared that the most important points that would determine the economic viability are: good estimation of demand and determination of the volume of production, having a reasonable cost-efficiency, offering equal or better technical performances and reasonable prices compared to existing market materials. Furthermore, the business models should regularly be reviewed and actualized to readapt the current demands and volumes (Emmanuel Malfeyt).

5.1.2. Lifespan

During the interview, Hugues Delcourt mentioned the long lifespan offered by agro-sourced material. Yet, the long service life can only be ensured if materials are protected correctly from major risks like humidity. Wrong installations could cause serious problems which would dramatically reduce the service life of products (Hugues Delcourt). The materials should ensure resistance in time and necessary precautions related to fire and insect resistance should also be taken to prevent any premature failure (Carra et al. 2017: 25). It was also stated by Hugues Delcourt that any premature failure should be prevented during installation. As bio-sourced materials are still developing products and premature failures can easily provoke the already existing suspicions and the lack of confidence (Hugues Delcourt).

5.1.3. Recognition and Political Support

Another facilitating factor for the success of agro-sourced products in the market is the need to meet legislative expectations and product standards (Carra et al. 2017). Géradon et al. (2018) claim that the norms related to the commercialization of materials mostly do not consider the materials sourced from nature as they are recent. The lack of common norms that identify technical standards to be met for agro-sourced materials makes it harder to overcome the suspicions related to material performances. In Belgium, producers have the possibility to demand voluntarily technical approvals. The approvals facilitate the acceptance of the products yet it demands a financial investment and takes time. It remains practicable only for highly industrialized products (Géradon et al. 2018).

Even if there is a lack of standardization, the Walloon region proposes some premiums for the use of bio-sourced insulation in renovation projects (Hugues Delcourt). In addition to that, there is a new law proposition, imposing a minimum percentage of bio-sourced materials use for public housing projects, that have entered recently in Belgian Parliament. (Céline Géradon). Even if the law is still under discussion the attempt shows the positioning of regional actors on behalf of the use of bio-sourced materials. Political voluntary and supports could significantly increase the demand for agro-sourced materials and offer more certitude to the market which would facilitate the viability of the products by encouraging investment initiatives (Antoine Bonnert). It was confirmed by Emmanuel Malfeyt and Quentin Laffineur that the presence of legislation orienting enterprises towards more ecological methods and materials could create a real difference because it significantly encourages the attempt of investments and it enhances awareness.

5.1.4. Responding to Market Needs

Numbers declared by Statbel (2020) show that approximately 70% of building permits obtained in 2020 in Brussels are for renovation projects. Emmanuel Mossay confirmed that one of the key factors to ensure the viability of agro-sourced materials is their adaptability to be used for renovation projects and insulation needs.

5.1.5. Local Conditions

Finally, local, and regional conditions have a huge impact on economic viability and valorization possibilities for residues or wastes. The sustainability of potential markets and the scale of products are highly dependent on climate conditions, crop amounts, and yields (Carra et al. 2017). Shortage risks related to climate issues or seasonality of agricultural products are important factors that need to be considered to ensure the viability of supply chains (Carra et al. 2017). Types of local crops, their availability, crop yields, potentials plants that can be used to create alternative value chains following the local conditions need to be identified to propose durable value chains for Belgium.

5.2. Available Plants and Materials for Belgium

The construction sector is quite adapted for the valorization of biomass compared to other sectors as materials are locally used (Céline Géradon). The availabilities and potentials differ for each plant.

For construction-related uses value chains of wood products are considered well-structured. Valorization options for hemp, grass, and straw remain structured but there is a need for development. Value chains related to rapeseed and miscanthus need to be studied further to evolve (Géradon and Debatty, 2018). Sunflower could also propose a value chain that can be developed as its production has the potential to be integrated in Belgium due to climate changes related to global warming.

5.2.1. Straw

23% of agricultural lands were dedicated to cereal production in Belgium in 2019 (Statbel, 2020).[1] The country produces approximately 1 000 kilotons of straw each year. The straw is mainly used for soil restitution and animal needs (Delcour et al. 2014). The study realized by Apropaille (Arnaud et al. 2016) examines the availability of straw to be used in construction and the possible impacts of a new value chain. According to the study, only 33% of straw could be exported from crop fields to be used in diverse value chains as the animal needs, energy production and construction use.[2] 15% of exportable straw is equal to 5% of the total production and it allows the construction of 3400-7800 housing of 110 m² depending on the poisoning of bales and insulated zones (Arnaud et al. 2016). According to Cluster Eco-Construction (2020), 2.5 ha of cereal field is needed to construct 1 housing unit.

Miscanthus is another source of straw. Unlike cereals, it is not a widely used plant in Belgium (Statbel, 2020).[3] As miscanthus is not an annual plant, it could not be used in rotation rows which could create convergence with food production (Céline Géradon). Keeping its plantation in water or crop field borders would remove any convergence risks while providing biodiversity for crop fields. Moreover, miscanthus offers very interesting crop yields as it produces 4-5 times more straw annually than cereals (Promisc 2021). Besides, high crop

[1] Total area of 313.107 ha

[2] 5-50% of exported straw can be used in construction according to the best- and worst-case scenarios presented by Apropaille.

[3] Only a surface of 284 ha was covered with miscanthus in 2019.

yields and biomass percentage, miscanthus is also a very appealing plant for the rehabilitation of polluted soils, protection of the aquifer layer, and carbon sequestration (Promisc 2021).

Straw in Construction:

Strawbale has been used in construction since the end of the 19th century (Baldinelli et al 2017: 56). Despite its early use in construction, the idea of building with strawbale has been abandoned between the beginning and the middle of the 20th century because of World War II and the increasing use of Portland cement (Atkinson 2011: np; as cited in Baldinelli et al 2017: 56). Ashour et al confirm that strawbale constructions are very attractive; they provide energy efficiency, fire-resistance, and sustainability (Ashour, Georg and Wu 2011: 1960). Moreover, straw is gathered from various species which can be found all over the world as wheat, barley, oats, rice, and miscanthus (Beck et al. 2004: 228).

Beyond its qualities, straw has some weaknesses that should be overcome to obtain an optimal result. For instance, because of its organic nature, straw has a great sensibility to humidity (Evrard et al 2015: 1). The lifetime of strawbale insulation can be dramatically reduced if precautions are not provided. Additionally, the main properties of straw depend on a large amount of variant as the crops type, the density, and size of bales, the orientation of fibers which makes it difficult to obtain the same results in each construction (Chaussinand, Nik and Scartezzini 2015: 299). Furthermore, Baldinelli and others (2017: 57) explain that:

> “Straw is harvested using balers, i.e. farm machinery able to cut, compress and tie the stems of plants with steel wire (fallen into disuse) or polypropylene twine. Two-strings (size 35×45×100 cm) or three strings (size 70×100×200 cm) bales are commonly used in building applications. Bales are assembled at a density varying from 90 to 180 kg/m3.”

This variation in density may generate unexpected results if it is not taken into consideration from the right beginning. Despite the various densities of strawbales, the available dimensions are limited enough. The blocks with 80 cm of length, 46 cm of width, and 36 cm of height are mostly obtained after the pressure process in Belgium.

The thermal conductivity of strawbales could vary depending on several factors like the density of bales, the water content, the used plant type, and the orientation of fibers. The disposition of bales, the distance between them, and the presence of plaster can also play an important role to correctly estimate the conductivity values. (Baldinelli et al. 2017: 58).

Furthermore, humidity can provoke the generation of moisture on strawbales which would provoke dramatic damages in straw nature due to the microbial activity. Plastering can play a crucial role to provide moisture protection and durability for strawbales (Ashour, Georg and Wu 2011: 1961). Peter Vos stated that the junction between the foundation and strawbales is the most fragile part that needs to be protected from any source of water.

Fire resistance makes part of the main suspicions related to strawbale use in construction. Strawbale proposes a great fire resistance due to compression and even if the surfaces may be affected, the core remains unharmed for a very long time. A simple choice of density can make a difference in the attitude of straw against fire. King (2006) explains that:

> "… whereas loose straw is highly flammable, compressed strawbales walls show high resistance to flame spread and temperature increase [7], since oxygen, the combustive agent, is mostly removed during compression" (as cited in Baldinelli et al 2017: 58).

The coating is one of the most effective solutions to treat the bales and to improve their qualities. Brojan and Clouston (2014: 25) claim that strawbale walls combined with a natural coating that lets the straw breathe, offer a wonderfully comfortable interior environment due to a great level of sound insulation and fire resistance that they provide. Covering straw with earth coating enables combining low heating load with high thermal inertia which offers a comfortable inside environment during summer as well as in winter (Evrard 2013: 11-12). Both Peter Vos and Hanne Eckelmans pointed out that earth plaster reduces significantly overheating risks during the summer. They also reported that strawbale allows constructing in a very simple and low-tech manner, in contrast with nowadays' architecture becoming very complex due to the high variety of materials and equipment needed for different functions.

Straw can be used in form of bales in construction to build load-bearing walls or it can be stuck between structural elements (Cluster Eco-Construction,2020). Prefabricated systems composed of timber frame modules filled with strawbales and covered with earth plaster are developed by Pailletech to reduce the time spent on construction sites and offer ease of installation (Antoine Bonnert). [4] Thatch is another form of straw that can also be used in construction as cladding (Fig.7).

Figure 7. Use of straw on building façade and as interior finishing (Architype 2021, "University of East Anglia")

[4] Pailletech provides their entire needs of straw within Belgium (Bonnert, 2021)

Miscanthus in Construction:

Besides the use in form of bales in construction, the straw of miscanthus is also used in bulk form to fill between timber frames. Céline Géradon, stated that miscanthus was used in self-construction by personal initiatives in the Walloon region for insulation purposes. Moreover, a product prototype for insulation of blocks made by miscanthus and lime was developed, yet the product was never commercialized (Céline Géradon). [5]

5.2.2. Hemp and Flax: same structure as straw

Currently, hemp fields are rather limited in Belgium due to the lack of valorization opportunities for the products.[6] Hemp is a plant that does not have any sickness and proposes high amounts of biomasses (Pascal Durdu; Céline Géradon). The use of hemp shives and fibers in construction would propose a valorization area for hemp products which would encourage the farmers to bring diversity to their fields (Céline Géradon). Sébastien Ernotte pointed out that 1 ha of hemp provides approximately the insulation needed for a housing unit and the Walloon region can easily create 8.000 ha for hemp production by replacing the beetroot fields to build efficient rotation rows.

Flax production is more common than hemp production in Belgium. However, it is mostly produced to be used in textile, and valorization in construction could cause an increase in prices (Celine Géradon).[7] Nevertheless, as flax is more affected by drought is interesting to propose a combination of hemp and flax production to balance the possible negative impacts (Céline Géradon).

Hemp and Flax in Construction:

Hempcrete use in construction has been spread all over the world following its first use in France at the end of the 80s. Hemp and lime propose great thermal and sound protection while offering breathing and permeable exterior walls. The vapor permeability offers very simplified construction layers likewise strawbale. Hemp shives are protected from insects, fire, and moisture and the mixture offers very convenient hygrothermal properties (Hirst 2013). Even if there are ongoing development efforts hempcrete does not provide a load-bearing capacity. Hemp and lime can be used within a framework or as a finishing layer (Poelmans 2016).

In Belgium, there are several brands proposing insulation materials made with hempcrete, a mixture of water, lime, and hemp. Different methods are used by those producers to apply hempcrete. Molded blocks, prefabricated timber frames filled with the mixture, and the sprayed version, prepared in-situ are some different products that are currently used.[8] The hemp shives used by Belgian manufacturers are procured mainly from the north of France as a defibrillator factory is missing in Belgium to separate the shives and fibers (Sébastien

[5] The prototype was developed by Alkern. https://www.alkern-blog.fr/bloc-bio-source-a-partir-de-miscanthus/

[6] A total surface of 95 ha only was used to plant hemp in 2019 while the production goal determined by Chanvre Walloon for 2020 was 1000 ha for Walloon region (Chanvrewallon, 2021; Statbel ,2020)

[7] 14 887 ha was used to plant flax in 2019. Yet only 60 ha of the total surface was dedicated to produce oilseed flax. The fiber and shives from oilseed flax are more likely to be used in construction as fiber flax is mainly used for textile (STATBEL, 2020).

[8] Isohemp (https://www.isohemp.com/en) produces hempcrete blocks, while Chanvreco (https://www.chanvreco.be/) proposes an in-situ application with sprayed mixture. Hempinabox (https://hempinabox.be/nl/) offers prefabricated solution with timber frames filled with the mixture.

Ernotte; Charlotte De Bellefoid). Céline Géradon, stated that material producers in Belgium are not leaning towards integrating defibrillator units in their structures to share the risks through a two-phased transformation model.[9] It is especially important to create first the industrial demand before encouraging the farmers to plant hemp and projecting the installation of a defibrillator factory (Céline Géradon).

In addition to the shives, fibers of hemp and oilseed flax fibers also can be used to create thermal and acoustic insulation wools or biochemical rubber. (Céline Géradon).[10] Besides its use with hemp, flax offers different products that can be used in construction. The flax shives can be used either in bulk forms for insulation or mixed with earth to be used as acoustic panels.[11]

5.2.3. Grass

Estonian University of Life Sciences, studied in the past years the opportunities to make bio-sourced insulations from grasses and herbs obtained from unused lands (Teppand 2017).

> "The concept developed in Estonia was to use the biomass of specific herbs directly as loose-fill insulation material as done historically or to mix with other agents to get create new composite materials" (Teppand 2017).

The study proves that compressed mats do not require a vapor barrier as they have great resistance to moisture and offer thermal conductivity values between 0.034 - 0.09 W/mK (Teppand 2017).

Gramitherm is a unique insulation material based on grass/herb fiber produced in Belgium.[12] The grass insulation has a great capacity of carbon sequestration as 1 kg of insulation stores 1,5 kg of CO_2. Only the unvalued grass waste, generated during the maintenance of the airport zones, road and canal sides, is used to produce the panels. A grass surface of 1 ha offers needed insulation panels to construct 3 to 4 individual houses. The semi-rigid panels are composed of 72% of grass fibers, 20% of recycled jute fibers and 8% of polyester fibers mixed and thermoformed together. The insulation has several application areas as roofs, exterior walls and floors (Blomme 2020).

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[9] A defibrillator factory was installed in 2013 in Walloon region but due to an inefficient business model it could not survive (Céline Géradon).

[10] Biofib,(https://www.biofib.com/) a French brand, proposes different product made with hemp or with a mixture of flax and hemp fiber and recycled coton.
Home-Eos (https://www.home-eos.eu/), a producer from Walloon region, offers rubber made with hemp and flax fibers with the use biochemistry to be used for acoustical purposes.

[11] The brand Panterre (https://www.acoustix.be/fr/isolation-acoustique/acoustix-panterre) offers acoustic panels made with flax shrives and earth and Linex Pro-Grass (https://linex.nl/en/products/flaxboard/) offers flaxboards for insulation and interior finishing purposes.

[12] Gramitherm insulation as for the bio-chemical rubbers of Home-Eos and Isohemp blocks is labeled by solar impulse. Solar impulse evaluates the impact environmental and social, technical feasibility and the economic profits.
https://solarimpulse.com/efficient-solutions/gramitherm

5.2.4. Potentials: Colza and Sunflower

There are some crop fields covered with rapeseed in Belgium contrary to sunflower.[13] However, Walloon region recently launched a research project to create a local production chain based on sunflower growing.[14] The main aim of the project is to ensure local oil production, yet the initiative can present a potential for residues to be valorized as construction materials. Both sunflower residues and rapeseed straw could offer potential materials to be used in construction.

There are many studies, that have been realized on the properties of sunflower stalks and rapeseed straw that point out the promising potential of both products (Stefan de Carvalho et al. 2020; Eschenhagen et al. 2019). Thomas Vailly[15], a designer from Netherlands, proposes furniture, interior finishing and acoustic panels made with sunflower particles. (Fig.8) Moreover, there are already some product initiatives using rapeseed oil in waterproofing membranes for roofs and particles in bio-sourced concrete boards. The production chains and product properties based on rapeseed needs to be developed (CODEM 2021).

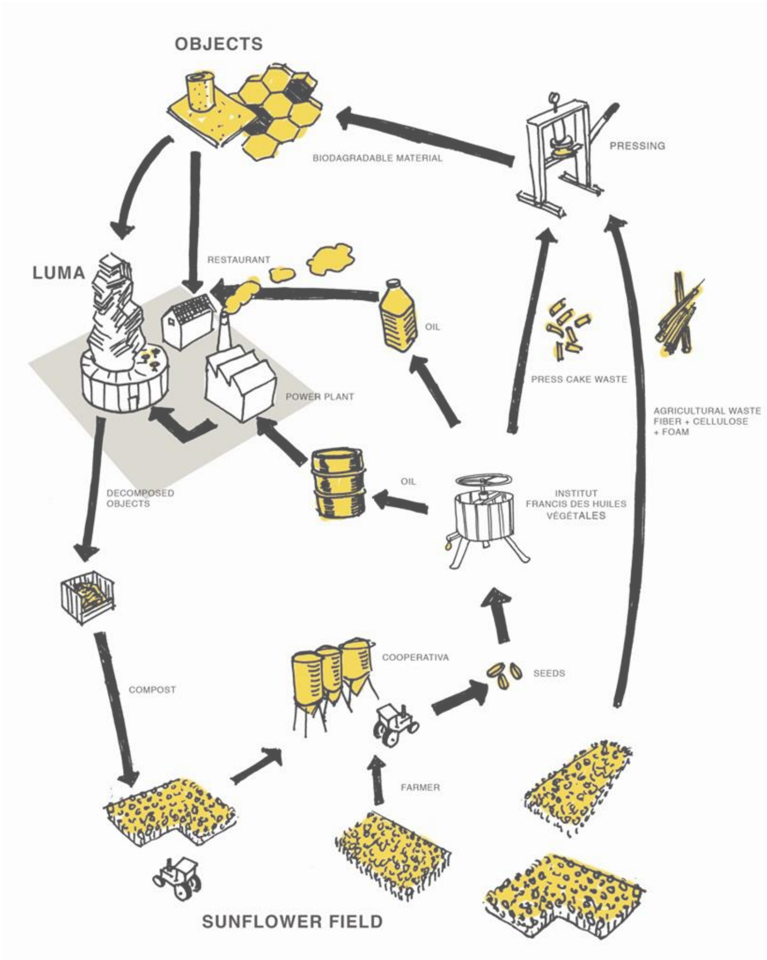

Figure 8. Transformation of sunflower waste into materials (Studio Thomas Vailly 2021)

[13] Rapeseed planted on a surface of 92624 ha in Belgium in 2019.
[14] Sunwall is a research project initiated with the partnership of farmers, CRA-W, SCAM and Alvenat to find appropriate species of sunflower that can be planted in Belgium and to share knowledge between farmers and to produce local oil.
[15] http://studiothomasvailly.com/project/sunflower-entreprise-i/

6. A Valorizing Life Cycle for Agro-sourced Materials

6.1. A case study: The Urban Bioloop by ARUP

The report prepared by ARUP, "The Urban Bioloop" proposes an alternative model for the exploitation of organic waste[16] based on circular economy principles that are inspiring for the creation of local value chains. The model proposed by ARUP aims to bring alternative ways to valorize organic waste streams that could help to improve the situation of both rural and local economies by adding new stakeholders into current business models (Carre et al. 2017). New valorizing steps as making, using, disassemble, and repurposing are added to the current cycle in which residues and wastes are directly sent to incineration, landfill or composting. (Fig.9) The model enables the return of residues to soil at the end of their service life by creating a circular approach.

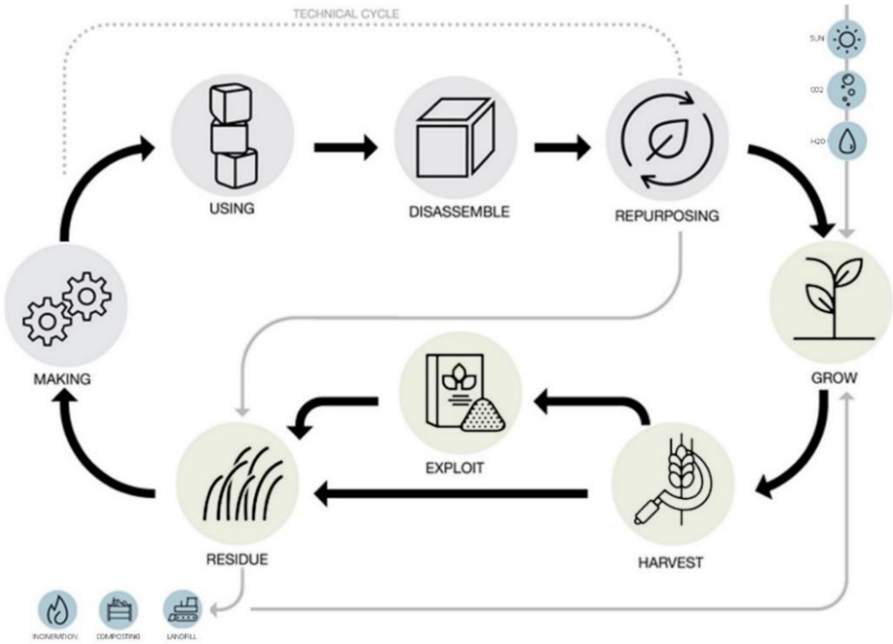

Figure 9. Alternative Model for Organic Waste (Carre et al. 2017 "Alternative Model")

The ARUP model describes the main actions and steps for the valorization of organic wastes. However, it does neither reflect local conditions nor illustrate the actual flows, needed structures, the role of actors and the relations between them. Local and regional conditions and structures have a huge impact on valorization possibilities for residues or wastes. Moreover, the ARUP model does not put forward the mutual relationship between agriculture and construction that should be created. A complementary valorization cycle, aiming to improve both construction and agriculture attitudes needs to be developed in order to highlight the main principles of viability and sustainability of "agro-sourced" materials. The cycle should be based on the current situations and structures in Belgium.

Instead of organic waste, the term "agro-sourced" is used in this paper to include materials made from secondary products, residues, and wastes obtained during the agricultural process and/or their processing.

[16] 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". (Carra et al. 2017: 15)

6.2. A Valorization Cycle for Agro-sourced Materials in Belgium

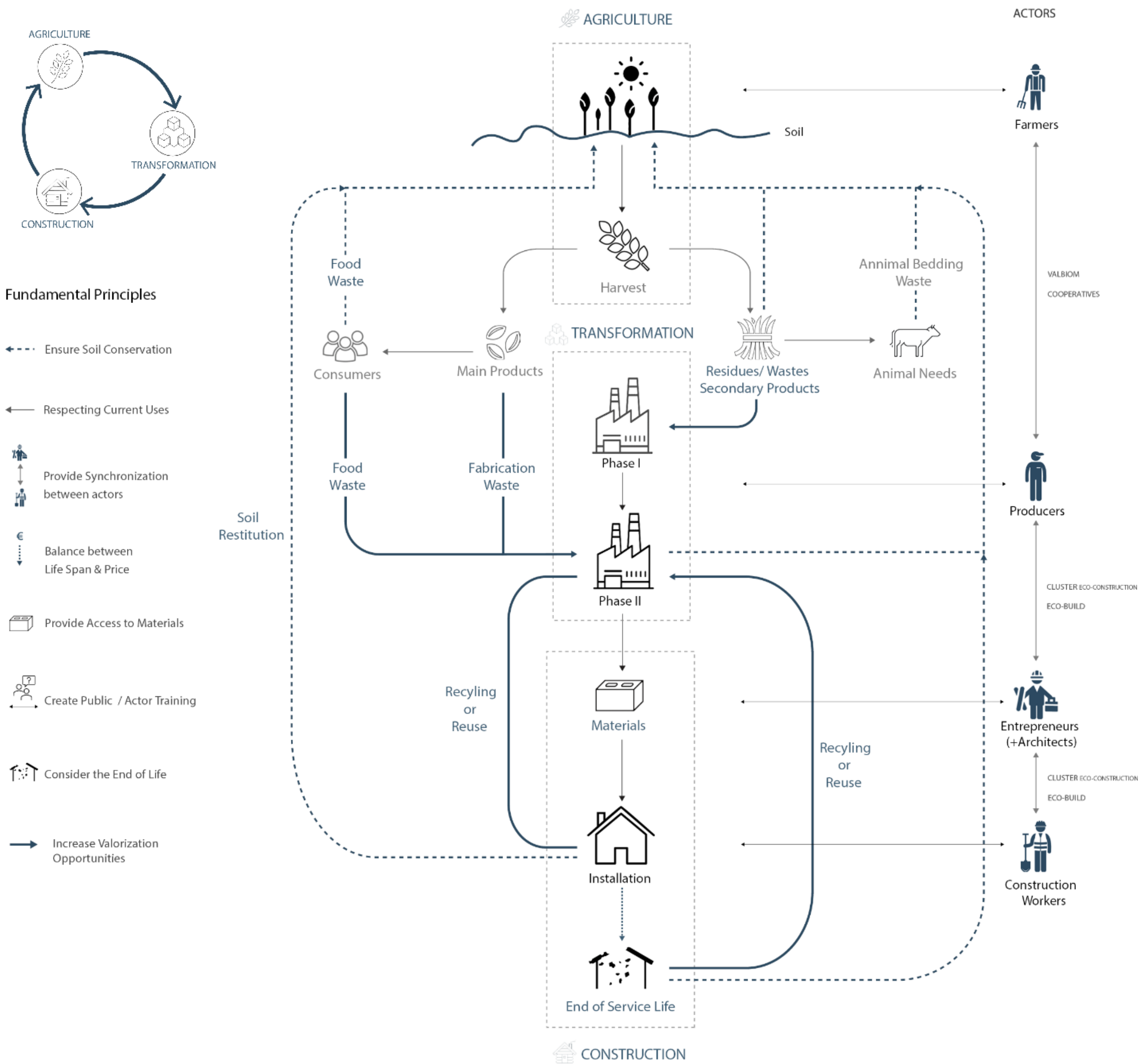

Figure 10. The Valorization Cycle (Produced by the author)

The valorization cycle demonstrates the mutual benefit relation that should be developed between agriculture and construction via agro-sourced materials. (Fig. 10) The interactions between the main actors, actual flows, valorization opportunities and the key principles to ensure the viability of the association in Belgium are presented via the cycle. The key principles are detailed in the next section. The cycle summarizes the fundamental operational principles and stages of the use of agro-sourced materials in construction via a mutual relation built between agriculture and construction in Belgium.

6.3. Fundamental Principles of the Valorization Cycle

Some key points should not be ignored to propose the integration of the valorization cycle that combines agriculture and construction in current flows and supply chains. The association between agriculture and construction via agro-sourced materials should contribute to reducing the environmental impact of both agriculture and construction while ensuring cost-efficiency for farmers and material producers.

According to expert interviews, some fundamental principles were identified: consideration of the importance of residues to ensure soil health, not being in convergence with current flows, ensuring synchronization between stakeholders, providing easy access to products, create public awareness and consider the end of life of agro-sourced materials.

6.3.1. Soil Conservation Agriculture

The sustainability of natural environments and agriculture highly depends on soil health. Three main steps of soil conservation agriculture are crop rotations, a permanent cover of soil with plants or organic matters, reducing the labor to ensure minimum soil disturbance; they should be applied altogether to obtain efficient results (Laurent Serteyn). Those practices help significantly reduce the use of pesticides and machinery in fields. Having a permanent soil cover on fields provides missing elements for the soil after each harvesting period (Pascal Durdu; Laurent Serteyn).

During the interview, Pascal Durdu and Laurent Serteyn emphasized that the amount of organic matter that is exported from fields should be imported each time, to ensure soil restitution. Adoption of plants with high biomass ratios as hemp and older species like ancient wheat are alternative practices to balance the exported carbon (Pascal Durdu). The use of residues in construction does not create any convergence with soil conservation principles if the exported amounts are well-thought.

According to Laurent Serteyn, bringing organic matters as municipal organic solid wastes and/or compost to fields is essential if important quantities of residues are exported from lands. The soil type, carbon amount in soil, frequency of exports, plants used in rotation rows, plant successions, and imported organic matter are main parameters that play an important role to determine the ratio of residues that can be exported annually (Duparque et al. 2011, mentioned by Laurent Serteyn). Calculation of the exact amounts that could be exported and the frequency of exportations can be calculated using some tools (Pascal Durdu and Laurent Serteyn).[17] The recommendations made on exportable quantities by Duparque et al. (2011) prove that the small quantities of residues needed for construction would not cause any negative impact on soils and the imports of organic wastes in fields could completely remove any kind of potential impact on soil health. Yet, during the exports of residues, it is important to correctly calculate appropriate quantities and balance the exported volume of carbon with imported organic matter if needed.

[17] For instance, Agro-transfert (2021) proposes a tool named "Simeos-Amg" that allows calculating the right amounts of residues that can be exported from the fields.

Crop rotation is also a very related principle of soil conservation to agro-sourced material production. The use of plants like hemp, flax, and colza has mutual benefits both for construction and agriculture. (Laurent Serteyn). Their use in construction creates valorization opportunities and encourages farmers to integrate those plants in their rotation rows. Permanently planting the same species creates huge weaknesses in the soil while planting different species consecutively on the same field helps to completely restore missing ingredients (Laurent Serteyn). The use of crop rotation principles also helps to put an end to mono-cultural practices and enriches plant biodiversity.[18] The use of plants like hemp, rapeseed, and flax as construction materials are fully in line with rotation principles as they bring biodiversity for crop rows mainly based on cereals. Their integration in crop fields subserves both agriculture and construction sectors (Laurent Serteyn).

6.3.2. Respecting the current uses

The compatibility of agro-sourced materials with the actual flows is one of the most questioned subjects. Avoiding generating any convergence with other sectors that use agricultural products and residues is a key factor to convince the main actors of agriculture and construction. Yet, the current use of residues or secondary products should not be seen as an obstacle to propose alternative uses. Emmanuel Mossay emphasized the importance to correctly evaluate the potential of each product and being able to reconsider if they are being used in the most efficient ways compared to their real value. Mobilizing partially the residues to be used as construction materials would not have a huge impact on the initial use while offering a higher environmental value (Antoine Bonnert). The return of residues and wastes after their use in construction to their previous cycle could be a very appropriate solution to reduce the impact on existing flows. At the end of their service life in construction, residues can be reused for animal needs or as organic matter for soil conservation (Emmanuel Mossay). The quantities of needed residues for construction with agro-sourced materials are usually very low and their use in construction does not provoke any opposition with the food industry (Hugues Delcourt). Yet, Sébastien Ernotte, emphasized that agricultural fields and production rows need to be well-organized to prevent any negative impact on existing flows.

6.3.3. Synchronization between actors

Communication between different actors from construction, agriculture, and manufacturing plays a critical role to ensure the functioning of the model. The expected qualities of harvest, technical specifications as well as needed quantities should be communicated to farmers before production. Otherwise, it is highly possible to end with wrong investment models and put extra financial loans on farmers (Céline Gérodan).

As one of the most important outcomes of the use of agro-sourced material in construction is to offer farmers alternative income areas, putting extra loans on them would be deeply contradictory. It was cited by Céline Géradon that the used vocabulary by actors from construction and agriculture is quite different which creates communication difficulties. Finding a common language via intermediate structures as Valbiom, Eco-Cluster, Eco-Build and organizations favoring cohesion between farmers is one of the most important factors to

[18] During the interview, it was mentioned by Géradon (2021) that the main goals to be attained by Walloon Region are having the same crops turning back to the same field every 6 years or even more, and never having the same plants two consecutive years on the same field.

ensure an efficient relation between various actors from different sectors and competencies. Materials producers could also contribute to the creation of common values, goals, and languages between farmers and constructors.

6.3.4 Life Span vs. Price

Buildings constructed with agro-sourced materials mostly cost 10-15% more than conventional constructions (Hugues Decourt). However, prices of crop residues, strawbales and hemp shives are significantly lower than other conventional market materials (Hugues Delcourt) Even if there is a price rise after their transformation the final market prices are very comparable with conventional materials. The higher costs of bio-sourced constructions could be explained with longer installation processes. (Hugues Decourt ; Emmanuel Malfeyt). Ernotte and Delcourt (2021) stated that both the installation of strawbale and sprayed hempcrete demands more workforce than the installation of conventional materials and their installation takes more time. Prefabricated systems can be alternatives to decrease the time spent on construction sites. However, the need for more workforce during the installation of agro-sourced materials could be considered as an advantage more than a weakness. Sébastien Ernotte confirmed that agro-sourced materials could propose very interesting employment opportunities. According to Peter Vos and Hanne Eckelmans, the installation of strawbales does not require any expertise and remains a simple but time-consuming process. The simplicity of the installation and the low prices of strawbales also presents a real opportunity for self-construction attempts.[19]

Even if prices are a little costlier for bio-sourced constructions the lifespan of materials is much higher and except for premature failures they do not demand any maintenance or replacement unlike conventional insulations (Antoine Bonnert). For instance, Gramitherm (2021), offers a life span of up to 50 years. Both Hugues Delcourt and Peter Vos confirmed that bio-sourced buildings offer exceptional interior comforts for users. Hugues Delcourt claimed that strawbale constructions allow obtaining ecologic and passive buildings which propose excellent acoustic performances and high air quality which could not be obtained with the reference prices of conventional buildings. While the building prices are compared with the lifespan of materials and interior comfort, they remain very reasonable. It is quite important to explain the reasons for price differences to the actors of construction.

6.3.5. Access to materials

Agro-sourced materials are not as easily accessible as frequently used insulation products. Hugues Delcourt cited that it is harder to consider constructing with agro-sourced materials as it requires determining in advance the supply opportunities. Enhancing the procurement opportunities and providing easier access to bio-sourced materials for builders could facilitate their use in construction. It is essential to assure the main actors of construction about the efficiency and accessibility of bio-sourced materials.

[19] Vos (2021) stated that some of his clients were willing to construct their buildings with their efforts after he realizes the technical drawings. He pointed out that a brief demonstration on-site was enough to explain the main principles of installation and then the installation was easily done by owners on their own.

6.3.6. Create Public Sensibility and Actor Training

It is observed that many entrepreneurs chose the conventional ways and materials at first sight; they consider conventional methods as more secure ways (Hugues Delcourt). Creating public awareness and connecting the main actors could contribute to increasing the trust for the use of bio-sourced materials. It is crucial to overcome the prejudgments and drawbacks related to the use of bio-sourced materials in construction projects. Having pools to physically connect producers and constructors and build strong relationships between them could remove the drawbacks and encourage constructors to employ bio-sourced materials. Social pools and associations to create public awareness for agro-sourced material could also be used to reach larger target groups to spread agroecology principles and create awareness to employ the right methods.

6.3.7. End of Life

The bio-sourced materials based on under-valued products could push even further the notion of circularity if they can be recycled, reused, or turned back to soils for restitution at the end of the building life. As many of the industrialized products have been developed recently, the information about their use at the end of the building life remains very theoretical. It is known that strawbales after their use in buildings can easily return to their current flows and/or be used for soil conservation. Moreover, Sébastien Ernotte, stated that for hempcrete, laying the crushed hempcrete on soil for restitution at the end of the building life is theoretically possible. The insulation panels proposed by Gramitherm are partially recyclable, it is prospected to be able to recollect and recycle 50% of the unused panels (Gramitherm 2021). However, the panels cannot be laid on soils or 100% recycled (Blomme 2021). As a further development step, it could be interesting to ensure the reuse, complete recycling, or/and soil restitution opportunities for agro-sourced materials which would remove any possible impact on existing flows and reduce energy needs of transformation and waste management.

6.4. In a nutshell

The development of a valorization cycle allows illustrating the main steps, the actual flows, actors and valorization opportunities, as well as the mutual relation between agriculture and construction that should be created in Belgium via agro-sourced materials, while respecting current situations and dynamics. The fundamental principles of the cycle need to be followed to ensure the viability and sustainability of agro-sourced materials. Each step of the cycle from agricultural production to transformation, construction and soil restitution, needs to be integrated in Belgium by following the main principles of the valorization cycle. Yet, the aims and outcomes vary from rural to urban areas as the conditions are quite different.

7. Same Cycle, Different Outcomes

The integration of the cycle steps, from agriculture to transformation and construction, highly depends on the location to find appropriate business models and scales. The convenient production scale and business model vary from rural to urban areas. Integration of the cycle in urban and rural areas follows the same fundamental cycle principles and mainly aims to create valorization opportunities for agricultural residues. Yet, secondary goals and outcomes are different according to various contexts.

In Belgium, agricultural production is highly dependent on rural areas and the main needs of cities are provided from their rural peripheries. Considering the soil pollution levels, excessive land prices, low availability, and high density in cities, urban areas would not be able to respond to all needs alone.[20] Moreover, materials producers prefer to settle in rural areas as costs are much higher in cities and they have broad space needs (Malfeyt; Laffineur). Sébastien Ernotte and Céline Géradon confirmed that the economic viability of producers highly depends on their production capacity and scale. As the needed investments for industrialized materials are quite high due to machinery and equipment costs their viability highly depends on their production capacity and urban areas are very inconvenient to provide space requirements. Even if the main fields of agricultural production and industrial transformation should remain in rural areas to obtain cost-efficiency, bringing the cycle steps to cities could answer several challenges related to economic, environmental and social sustainability. For instance, urban agriculture could provide contact with nature and soil, enrich biodiversity, remove monotonous landscapes, increase social cohesion and create fertile terrains for the transmission of know-how.

Furthermore, De Lestrange (2021), claims that having a new network based on different types of fertile soil productions as wildlands, gardens, and agricultural lands would support agroecological transitions and enhance green and blue networks (Fig.11). Having small-scaled local production fields in urban areas could generate several social, economic, and environmental benefits and support the creation of a “Yellow Network” developed by De Lestrange (2021). Moreover, urban areas could have a more important role to play to create public awareness for both agroecology and eco-construction.

[20] Fievet (2019) states that to provide 30% of the vegetable need of Brussels 1600ha of field is needed while Brussels possesses potentially 250 ha.

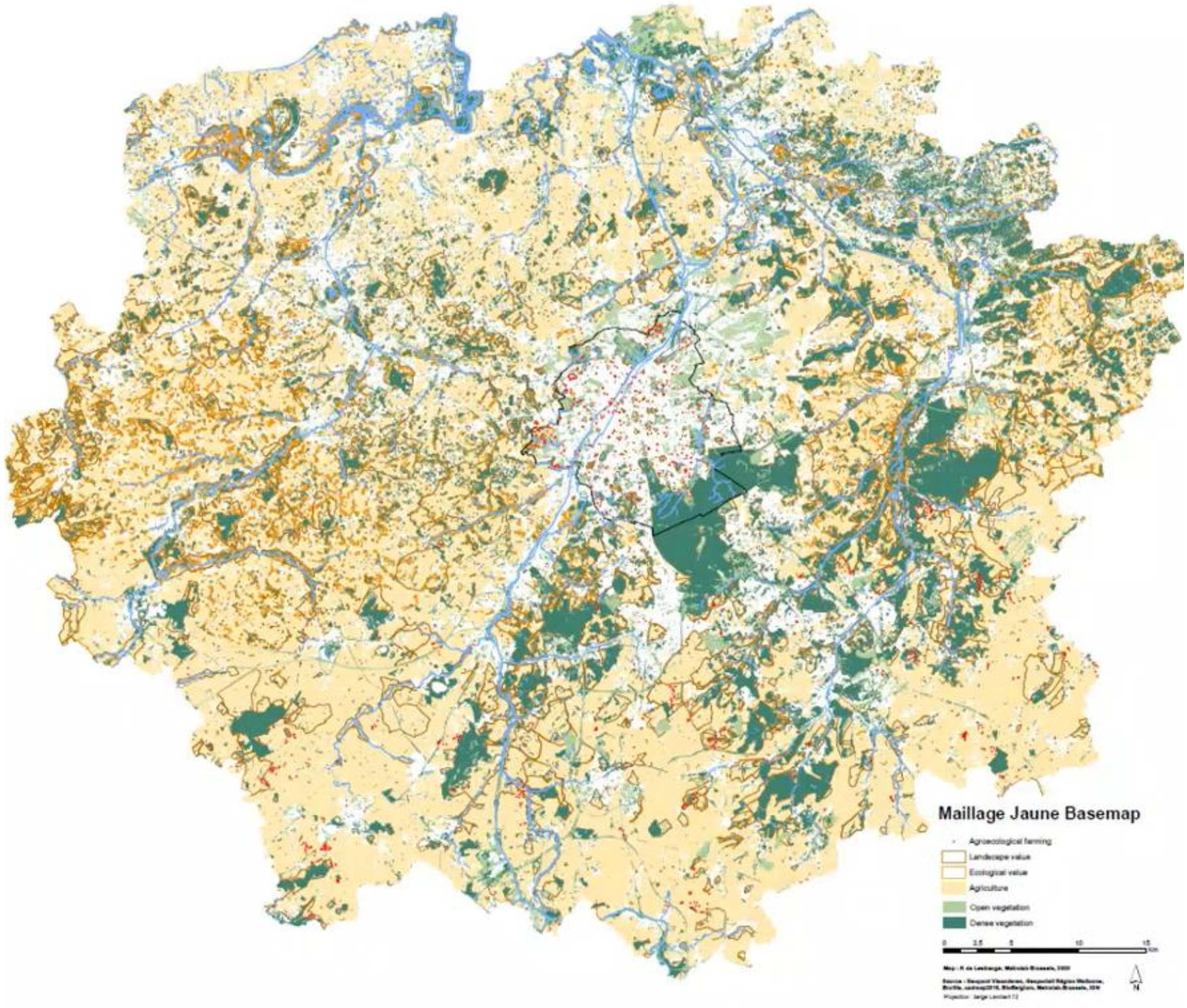

Figure 11. The Yellow Network developed by De Lestrange (De Lestrange 2021 "Maillage Jaune Basemap")[21]

[21] The map points out all the agricultural lands with ecologic and landscape value around Brussels and agroecological farming areas within Brussels that can be connected to develop a "Yellow Network".

7.1. Cycle in Rural Areas to Enhance Rural Resilience

Integration of the cycle of agro-sourced materials should be used to offer opportunities both for construction and agriculture sectors by reinforcing environmental awareness and proposing viable economic models to the farmer in rural areas. Even if the main goal would be to have efficient production and transformation units to ensure cost-efficiency, the model could support agroecological transition and help to increase rural resilience. Reducing pesticide and machinery use, increasing human presence in agricultural lands, and increasing soil fertility while offering agro-sourced materials for construction would be the main outcomes of the rural model.

The volume of production and space needs should be carefully determined by producers before their installation. Intermediate organizations like Valbiom and Eco-Cluster would play an even more important role to facilitate the communication between farmers, manufacturers, and constructors. Besides, the cost-efficiency of manufacturers, the viability of small farms and farmers should be also at the center of the rural model. Farmers need to be informed and follow soil conservation techniques to ensure the cost-efficiency of their products and the health of the soils and nature. That is why it is important to have social organizations train and support farmers about rotation principles, crop yields, and soil conservation techniques.

The main assembling factor, between agriculture and construction in the rural model, would ensure the well-being of the environment, offer alternative incomes and encourage local production, to safeguard rural resilience (Fig.12). Environmental care should be reinforced in each step of the production flow from agriculture to construction.

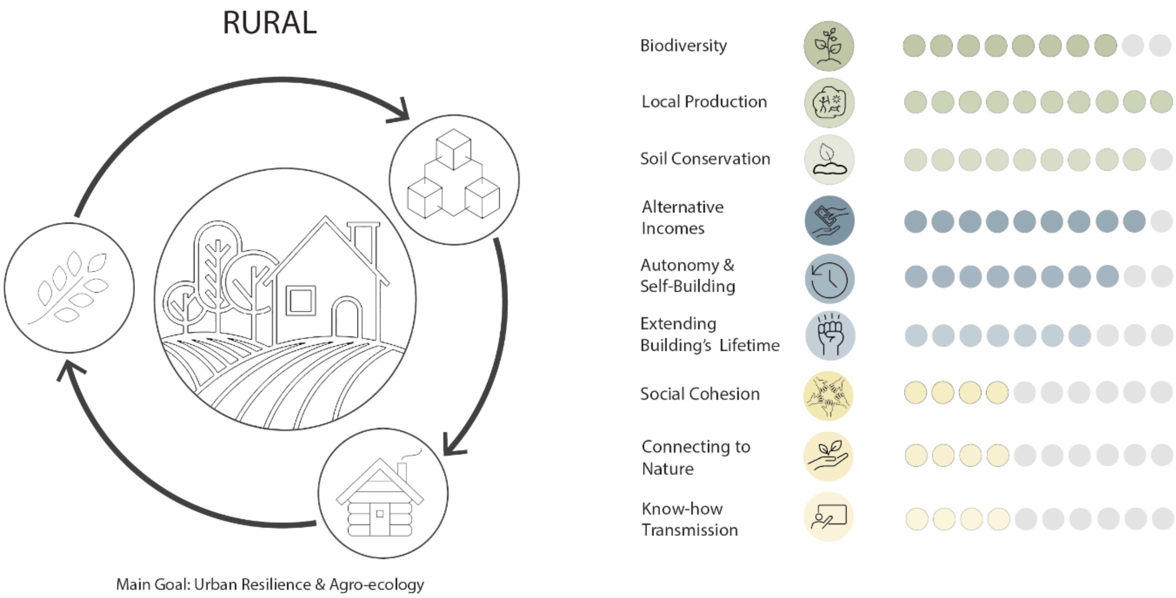

Figure 12. Expected outcome and goals of the cycle in rural areas, according to sustainability criteria (Produced by the author)

7.2. Cycle in Urban Areas for Public Awareness

The integration of the model in cities should aim at the creation of display areas for sustainable agricultural methods and agro-sourced materials. The model should offer training, employment opportunities and encourage self-construction efforts for inhabitants while providing connection pools for farmers, material producers and constructors.

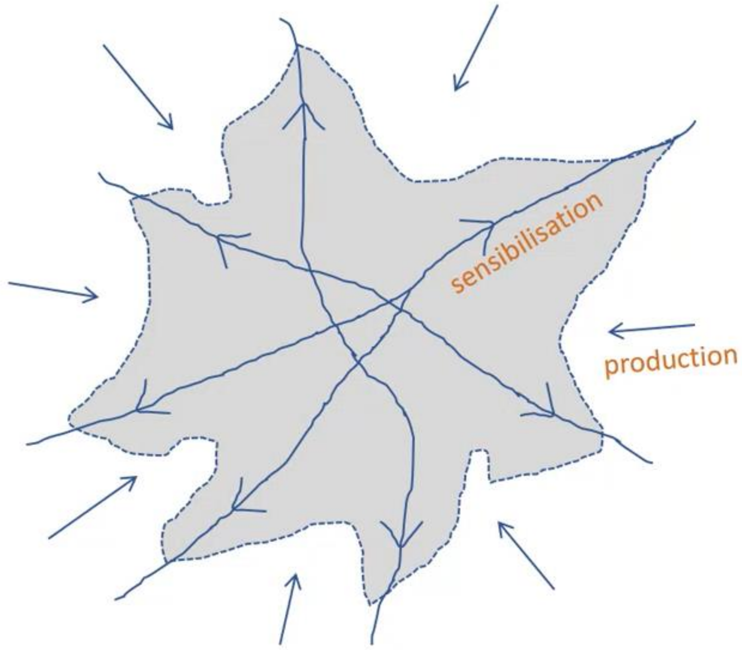

Figure 13. Relation between urban and rural (De Lestrange 2021, "D'après Patrick Geddes, 1915")

Cities would become mini-satellites of rural production to create awareness which would also bring biodiversity and reinforce the relationship with nature (Fig.13). The concept of a pedagogical urban farm could be used as a spatial model to host the cycle in cities. Besides the pedagogical urban farm model, the integration of the cycle in urban areas via partial use of public parks to lower the impacts of high land cost could be a possible solution. Yet, the proportion of agricultural production that can be integrated into public parks remains to be determined.

The insufficiency to provide all needs, the soil quality and pollution[22], high land costs and proximity to main agricultural lands of cities like Brussels should not be ignored while proposing the integration of the operational eco-system in urban areas (Pascal Durdu). Durdu, emphasized that the main supply chains and production should remain in rural areas and the urban model should be used to create public awareness, support social cohesion, and reinforce the connection with the soil (Fig. 14). Moreover, the integration of agricultural production areas in cities would contribute to the development of a yellow network[23] that would cooperate with green and blue networks.

[22] Durdu stated (2021) hyperaccumulator plants can be used for soil rehabilitation, yet the rehabilitation process can take years depending on pollution rates of soils.

[23] The term Yellow Network is introduced by Roselyne de Lestrange.

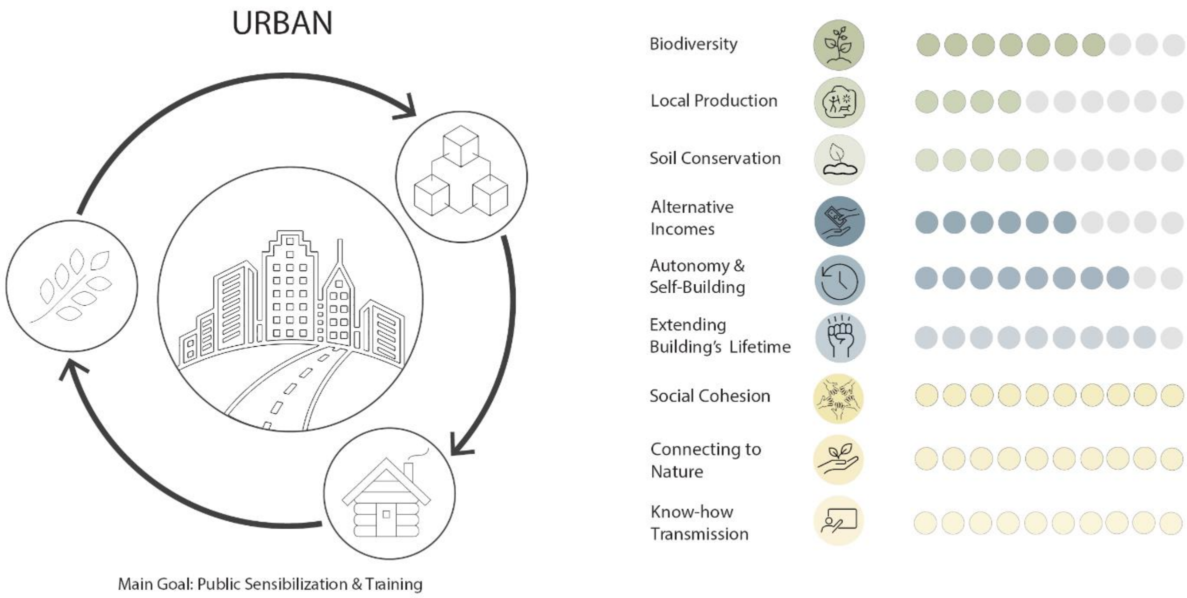

Figure 14. Expected outcome and goals of the cycle in urban areas, according to sustainability criteria (Produced by the author)

However, it is important to find economically viable models to integrate agricultural production and low-tech transformation in cities (Emmanuel Mossay). The high cost of land in urban areas causes serious difficulties for urban farms to maintain their existence in cities (Alexandre Lefebvre). It is also revealed that the key point to viability for an urban farm is being able to impact both the neighborhood, the community and the city via all means of created eco-systems. (Emmanuel Mossay). The more an urban farm contributes to biodiversity and creates complex eco-systems that serve common well-being the higher value it would gain. Food supply, carbon storage, reducing air pollution, proposing recreational areas, valorizing green wastes, creating economic exchanges with locals, offering workshops and training, ensuring security, and providing partial self-sufficiency are several impacts of urban farms that would determine their viability (Emmanuel Mossay).

Furthermore, integration of the cycle steps in cities via pedagogical urban farms would help to connect with main construction actors and assure the constructors about the efficiency of agro-sourced materials. Quentin Laffineur (2021) stated that the main construction actors in Brussels were more tightly integrating urban farming and circular economy principles in their projects, than using bio-sourced materials as they need to be assured first. Having pools for connection and awareness in urban areas plays a very particularly important role to increase the use of agro-sourced materials in urban areas where are the center of construction activities. Emmanuel Malfeyt pointed out that the relationship between material producers and entrepreneurs plays a critical role in the use of agro-sourced materials. According to Emmanuel Malfeyt, in the Walloon and Flanders regions relations between producers and entrepreneurs create strong networks which significantly encourages the use of bio-sourced materials. As in Brussels, there is a lack of producers due to high prices, connection between materials producers and constructors from Brussels should be provided to convince them about agro-sourced material efficiency. Emmanuel Malfeyt highlighted that human relations and trust-building are very essential and even more important than all kinds of technical documentation to ensure the penetration of agro-sourced materials in the Brussels market.

7.2.1. Pedagogical Aspect

The pedagogical aspect of the model can be enriched by reaching out to several actors. The model can propose training for the population, on self-construction with agro-sourced materials. Habitants and urban farmers can also be trained to learn soil conservation agriculture via the urban model. Professionals and small-scaled investors can learn about low-tech transformation techniques, construction principles and development axes for industrialized and self-made agro-sourced materials. Moreover, research and development centers could be integrated into a pedagogical urban farm model, to improve the performances of existing materials, while searching for alternative species and products that would bring biodiversity to agricultural lands as well as additional income for farmers.

7.2.2. Encouraging self-building with local materials in cities

An important part of society is more fragile and has difficulties affording renovation costs in cities (Emmanuel Malfeyt). Having training hubs in urban areas for self-construction techniques with self-made agro-sourced materials can significantly decrease the renovation costs. Strawbale, miscanthus and hemp shives could also be used for low-tech constructions.

Peter Vos and Hanne Eckelmans emphasized that strawbale highly favors self-construction as its installation is quite easy and does not require any expertise.

7.2.3. Composting with urban municipal waste for soil conservation

The urban areas are great resources for organic matters as they produce high amounts of municipal organic wastes. Those wastes can be valorized to support soil restitution in the urban model as the soils in cities are more fragile and exposed to more pollution.

> “Aujourd’hui, le compostage est un acte citoyen qui fait du bien ! Composter c’est se reconnecter à la terre et s’inscrire dans un cycle naturel. “ (Worms, 2021)

Alexandre Lefevbre and Pascal Durdu confirmed that the cities produce much more municipal organic waste than the needed amount to restore the organic matter in the soil after agricultural activities. Composting contributes to the well-being of soils while proposing great management of waste. The process also allows reconnecting inhabitants to the soil.

8.Conclusion

Before industrialization, the obligation to carefully manage resources offered by nature, respecting the cycle of local resources, and exploiting them in a very efficient way to respond to basic needs, were some of the principles followed to create a sustainable settlement in a respectful relationship with nature. The man was the builder, and the materials were offered by its natural environment. (Correia, Dispasquale and Mecca, 2014). The use and collective management of renewable resources as well as the ability to provide basic needs with land-based resources and agriculture bonded humans to territories and nature.

Today the relationship between humans and their environment is damaged. The use of traditional skills and know-how has become a marginal aspect. Cities are suffering more and more from the lack of green areas where to appreciate nature. Reinforcing the link by integrating agriculture in our daily lives by respecting the natural pace of nature could help create an alternative way to respond to today's environmental, social, and even economic challenges. Besides being a source for food and well-being, agriculture could propose materials for construction with several benefits for human health and the environment.

Small-scale pedagogical production and manufacturing areas based on bio-sourced materials could be used to reintroduce the traditional know-how in our daily lives. Moreover, it could help to learn to produce only the quantities provided by the natural rhythms and cycles. Having green areas in cities by putting its natural pace at the center without a mass-production rush and a desire to respond to all needs would help people to appreciate nature, gain an awareness against squandering, and create a peaceful connection with nature. Nevertheless, the presence of small-scale local production areas could ensure urban resilience by providing citizens with the fundamental knowledge and resources to adapt themselves in case of unexpected events and then rebound.

This paper aims to create an alternative model based on the association of agriculture and construction to enhance the use of renewable, bio-sourced materials while promoting agroecological transition. A complementary valorization cycle for agro-sourced materials is created to conduct this research based on the cycle proposed by ARUP. Following the development of a valorization cycle, fundamental viability principles are identified according to the literature review and expert interview. Furthermore, different impacts of the integration of the cycle in rural and urban areas, on sustainability are pointed out. Biodiversity, local production & manufacturing, soil conservation & organic waste management, employment opportunities, extending the lifespan of buildings, self-building & autonomy, the transmission of know-how, collectivity, and connection to nature are some of the main sustainability principles and goals of the integration of the cycle in rural and urban areas.

Being able to use agriculture to provide construction materials besides food, changes the current way to build, answers the problems related to finite resources in the construction industry and adds a valorizing step to the life cycle of agricultural products. This alternative usage of agricultural products needs to be integrated into current flows to be developed more and to change our ways to live and construct.

The research confirms that only a relatively small part of the basic needs can be provided by agriculture in urban areas as main productions should remain in rural. Yet, the integration of the urban model has various benefits to gather people around, teach them basic production skills, create public awareness for innovative methods, and transfer the know-how. Likewise, the rural model contributes to agroecological transition, the cost-efficiency of farmers, the viability of material producers, and rural resilience.

Current studies on organic residues and their performances prove that they can be valorized in a much better and efficient way than being considered as waste or being used for functions below their potential. Several products made with organic residues are already present in the market but to increase their effective use in the construction industry, there is a need for public awareness and transmission of construction techniques.

Creating social and educative production units has several benefits for the social, environmental, and economic well-being of societies. The integration of the model in urban areas could help citizens regain their basic survival skills while giving birth to collective activities to create social cohesion. It would increase the awareness of the natural environment and local resources while encouraging the transmission of traditional and cultural values and know-how. Furthermore, it would promote a fertile terrain for the transferring of knowledge of innovative methods. Other benefits derived from the integration of the model in cities are the increasing local employment opportunities as well as social reinsertion.

Even if the local production of agricultural products would only meet a tiny part of food supply and construction needs, local production networks would introduce the association model and increase public awareness, transfer the traditional and innovative technical knowledge for manufacturing and production while connecting people to nature. Similarly, the model would promote sustainable agricultural and building methods in rural areas.

The ways to integrate research and development centers in rural and urban areas, alternatives to reduce bio-sourced building costs and appropriate business models for urban integration of the cycle are some notions that deserve further thought. Moreover, the list of the available plants can be developed, as the climate changes related to global warming would allow the introduction of new species to crop fields. The use of the urban model to favor the development of the yellow network proposed by De Lestrange (2021) and integration of value chains based on earth and timber products in the alternative model could be further research areas and potential development axes.

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