MAKING BIODEGRADABLE BUILDING MATERIAL FROM AGRICULTURE RESIDUE

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ABSTRACT

The contemporary products used in the building industry result in a significant environmental impact due to high energy demand production and low regenerative potential. Biodegradable materials can be an opportunity towards this current concern. This study aims to develop a potential scenario of transforming the local agricultural residue into biodegradable building materials in Amsterdam.

The Brettenscheg and Scheg van West areas of Amsterdam are investigated to identify and quantify the possible residue flow in order to realize the desired scenario. These residues, featuring wheat and barley straw, husk, corn stalk, and reed, are further studied for their making process, properties, and application method in structure, façade, and interior.

The result suggests the biggest potential comes from cereal straw material, including bale, panel, and thatch. Corn stalk, cereal husk, and reed also show various opportunities in making boards and thatches. With the specific design, these materials can be applied in traditional and modern architecture for a fair life span and re-introduced to nature by composting. On this basis, low-impact and regenerative material can be provided alongside food, which enables a sustainable relationship between the city and the local hinterland.

KEYWORDS: *biodegradable building material, cereal straw, cereal husk, corn stalk, reed, thatch, interior board.*

I. INTRODUCTION

The conventional scenario of the building industry, including the production, construction, and demolition phase, has a great impact on the natural environment, as modern building products require a lot of energy to produce, yet they are neither renewable nor degradable. (Blackburn, R.S. 2005) Nowadays, the building industry has witnessed a positive shift towards the awareness of environmental problems and motivation for a more sustainable way of development. (Arup. 2013) This gives rise to the re-popularization of natural biodegradable building materials, as they can be easily reused, recycled, or decomposed. Moreover, these natural biodegradable materials have extra potential to be sustainable with a minimum of processing and transportation, which in other words, when they are sourced and manufactured locally. (Ganotopoulou, E. 2014)

The principles of the circular economy provide an alternative scope that considers waste as the main resource of new materials. (Arup. 2013) In this context, a new range of natural waste can be viewed as the potential feedstock of biodegradable building material. Focusing on the situation of the Netherlands, a huge proportion of the land is used as agricultural land, which generates significant waste streams. (Yuan, Z. 2019) This characteristic situation reveals an opportunity to shift the locally available organic waste stream from the agricultural system towards the feedstock of natural building materials. The natural waste usually includes the on-site residue from crops and plants, as well as vegetal wastes from food preparation. (Arup, 2013) Certain types of natural residue have already been used as building materials, such as straw bale and thatched roofs. Correspondingly, there are also many explorations and practices of transforming natural residues into modern building products, in particular, interior board and finishing. (Mahieu, A. 2019) Given the above, in this paper, I will explore the potential of making degradable building material from agricultural waste in the context of Amsterdam. A specific agricultural area is selected in the neighborhood of Amsterdam for a case study. In the case study, the available natural resource and potential building materials will be analyzed.

II. METHODOLOGY

This study aims to develop an overview of the bio-degradable building material which could be made from the agricultural residue of the Brettenscheg and the Scheg van West area of the Amsterdam region, acknowledging the reader with their properties, fabrication technique, and applications on structure, façade and interior level. The thesis report is divided in two main sections. The first part focuses on analyzing the type and amount of residue resource from the context. The second part focuses on the architectural applications.

The research starts with identifying the available agricultural residue through mapping the crops and plants in the selected area. These crops and plants are further studied on their on-site residues through case study respectively. Secondly, in order to show the amount of each residue and their relationship with food production, material flow analysis is used to quantify and illustrate the flow of residue. The size of the residue flow further determines the amount and the type of building material that can be made. Furthermore, literature study on commercial building products and architecture cases through books, scientific articles and publications is conducted to analyze the potential building products from residues, focusing on the making process, the physical characteristics and the application in different building layers.

III. STUDY ON ORGANIC RESIDUES FLOW

3.1. General information about the Brettenscheg and Scheg van West area

Amsterdam has a great tradition of integrating green areas during major urban expansions. (2019, ARCAM) There are seven green areas around the urban area, which have been introduced since the General Expansion Plan (AUP) of Cornelis van Eesteren. The Brettenscheg and Scheg van West are two adjacent green areas on the west part of the city.

Nowadays, the two green areas are used as agricultural land. The Scheg van west includes part of the Haarlemmermeer and the polders between Geuzenweld-Slotermeer and Osdorp. The land is mainly used for growing arable crops. The Brettenscheg is located between Haarlem and Amsterdam, with the harbor area on the north side. Besides sports parks and traditional allotment gardens, most of the land is used as grassland for livestock. (2019, ARCAM)

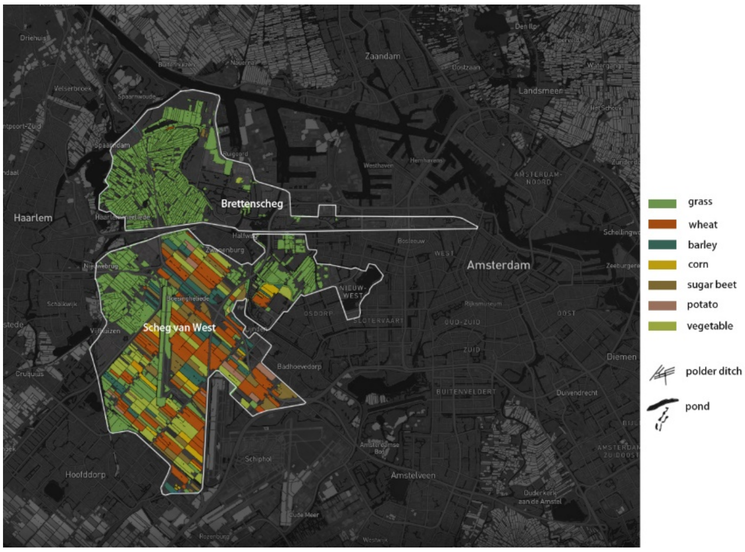


Figure 1. Brettenscheg and Scheg van West area (base image from https://map.onesoil.ai/)

3.2. Classification of on-site residue from crops and plants

The arable cropland of Scheg van West produces wheat, barley, corn, potato, sugar beet, and vegetables; whereas the meadow landscape of Brettenscheg grows forage grass. In addition, the reed is a common plant that grows along the ditches around the cropland and grassland.

When harvested or consumed by animals, each of the crops and plants produces its own residue. In this paper, I will only focus on the on-site residue which can be collected directly on the harvested land or during the harvesting procedure. The residue produced during the further food processing process will not be included as there is insufficient data to trace their whereabouts. Table 1 below shows the identified on-site residue of different crops and plants.

Table 1. catalogue of on-site residue

Type of land	**Crop/Plant**	**Residue**
Crop land (Scheg van west)	Wheat	Straw, husk
	Barley	Straw, husk
	Corn	Stalk
	Potato	Above-ground plant
	Sugar beet	Above-ground leaves
	Vegetable	Various vegetal particles
		Reed plant
Grass land (Brettenscheg)	Grass	Root
		Reed plant

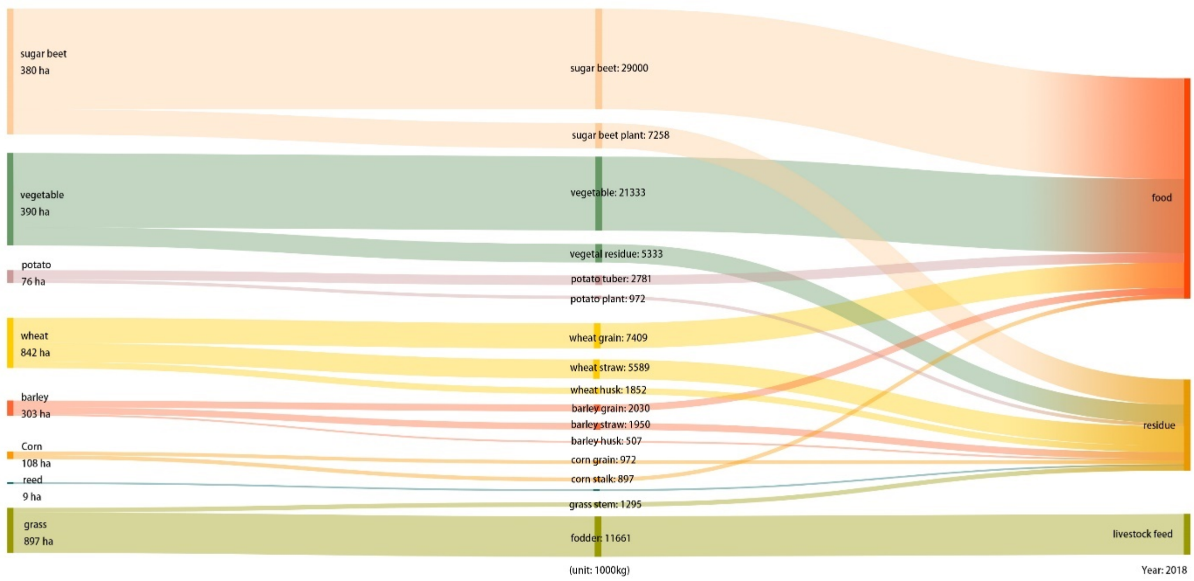


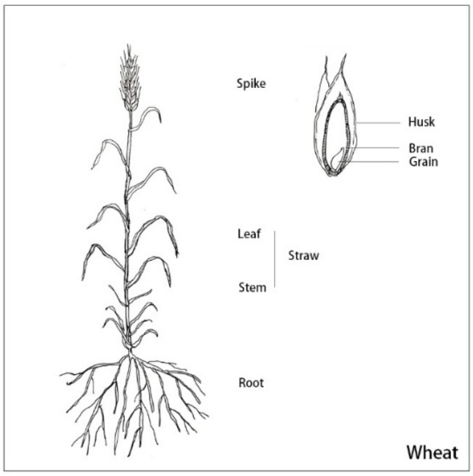
Figure 2. An overview of the agricultural material flow of the Brettenscheg and Scheg van West area

(image by author)

3.3 Selection of on-site residue for building material making

① Wheat straw and husk

Wheat occupies the largest proportion of land in the Scheg van west area. It is also the most-produced cereal crop in the Netherlands. (CBS, 2021) Therefore, it leads to the biggest potential for residue. Wheat is usually planted from September to November, and harvested by the end of summer or early autumn of the next year (Wiki, 2021). When harvesting, the leaves and a large part of the stem are considered as 'wheat straw' residue. Wheat husk, a thin, dry layer of skin around the grain, is another residue that is separated when threshing and winnowing. To be added, the husk should not be confused with bran, which is part of the grain itself.



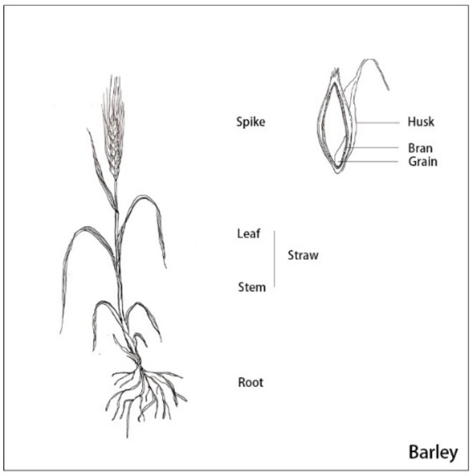


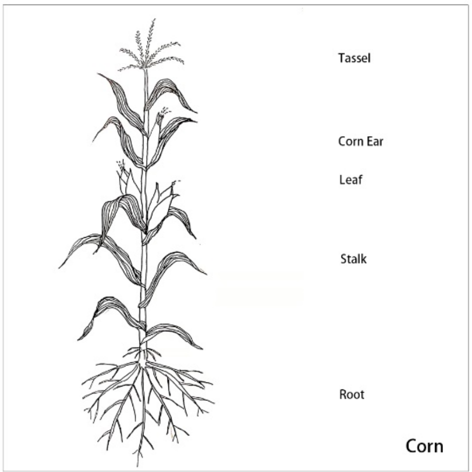
Figure 3, 4. Diagram of wheat and barley plant, image by author

② Barley straw and husk

Spring barley is typically harvested at the end of summer while winter barley is harvested between spring and summer. (Wiki, 2021) Similar to wheat, a large portion of stem and leaf is harvested as barley straw. The husk of barley grain can also be collected when threshing the grain.

③ Corn stalk

Corn is the third-largest cereal crop on the site. It is usually harvested during September and October in the Netherlands. The primary residue of corn is corn stalk, which is composed mainly of leaves and stems. Leaf accounts for 40% of corn stalk by weight. Its morphological fiber structure is similar to bagasse and cotton stalk, which reveals its potential for building material. (Chen, H. 2015)



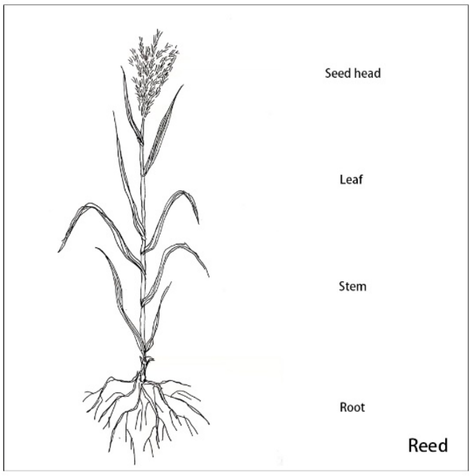


Figure 5, 6. Diagram of corn plant and reed plant, image by author

④ **Reed**

Reed is not a crop but a common plant that grows along the ditches around the grassland and also some parts of the cropland. Although it is not a direct residue from food production, it is a by-product of the typical polder agricultural water system. In addition, the reed has a special water purification characteristic which protect the polder from salinization. The dry stem part of the reed has been used as a traditional building material in the Netherlands for a long time. Dry reed is usually cut during winter and early spring.

⑤ **Vegetable, potato, sugar beet and grass**

The residues from vegetable, potato and sugar beet are vegetal particles such as leaves, stems and root. These perishable materials are difficult to be made into building material unless they are carefully collected and dried, which increases considerable labor and energy costs, thus might jeopardize the sustainable goal of bio-based materials. Moreover, comparing with the straw and stem residues, there is also less cellulose content which means less sufficient strength in the final product unless additional ingredients are added.

In addition, the plant part of potatoes contains natural toxins (Wiki, 2021), which might bring health risks for people when used as a building material. The grass root left after the grazing season is difficult to collect, thus it is not considered as available residue. (Cornelissen, J.M.R. 2015)

These characteristics shows less potential when transforming the residue from vegetable, potato and sugar beet into building materials.

3.4. The amount of available residue for building material making

This section will demonstrate the calculation and final amount of different organic residues. These data indicate the sizes of the residue flows which could be diverted into the building material sector.

Among all identified residues, some have the potential to be applied in the building material making, such as the straw from cereal crops, and also dry reed plants. These residues contain high cellulose content and low moisture rate. (Zhao, L. 2013) The residue from vegetables, potato and sugar beet are less suitable for building material in current situation, thus they are not discussed in this section.

3.2.1 Wheat, barley and corn

In the year 2018, the agricultural land of the Brettenscheg and Scheg van West area contains 842 hectares of wheat, 303 hectares of barley, and 108 hectares of corn respectively. The amount of straw residue is calculated based on the harvest index of each crop and the size of the land area. Likewise, the amount of husk residue is calculated regarding the gross yield of grain and the husk content rate. The result shows there are 5589 tons of wheat straw, 1950 tons of barley straw, and 897 tons of corn stalk produced. Theoretically, there are also 1852 tons of wheat husk and 507 tons of barley husk that could be collected from the selected area.

Table 2. Straw and husk residue from wheat, barley and corn

Crop	Wheat	Barley	Corn
Area (ha)	842	303	108
Gross yield (1000kg/ha)	8.8	6.7	9.0
Actual crop (1000kg)	7409	2030	972
Harvest index	0.57	0.51	0.52
Straw residue yield (1000kg/ha)	6.63	6.43	8.3
Straw residue	5589	1950	897

(1000kg)			
Husk content rate	0.2	0.2	-
Husk residue (1000kg)	1852	507	-

3.2.2 Reed

As reed is not an arable crop, the calculation of reed waste is different from the crops which have been demonstrated above. There is currently no available data on the amount of the reed grown in the selected area. Therefore, an assumption is made to look for the theoretical amount which could be produced from the area. The calculation is based on the estimated size of the reed fringe and the yield of reed land. The result shows 107 tons of reed could be produced from the 8.95 hectares of reed fringes alone the ditches and pond in the Brettenscheg and Scheg van West area.

Table 3. residue from reed plant

Plant	**Length of reed fringe/m**	**Width of reed fringe/m**	**Area/ha**	**Residue yield, 1000kg/ha**	**Residue/1000kg**
Reed	89500	1	8.95	12	**107**

3.5. Current organic material flow of wheat, barley, corn and reed

The grain part of wheat, barley and corn is processed as 10411 ton of cereal and flour product. Certain amount of the wheat and barley straw is used as frost protector for the flower industry, or animal bedding material for the livestock. (Ecofys, 2013) The leftover part of the straw, as well as corn stalks is treated as compost or plowed back to the soil after the harvest season. (Ecofys, 2013) The husk from wheat and barley, as well as reed is usually disposed as organic wastes as it cannot serve as animal feed or bedding material. (Ecofys, 2016)

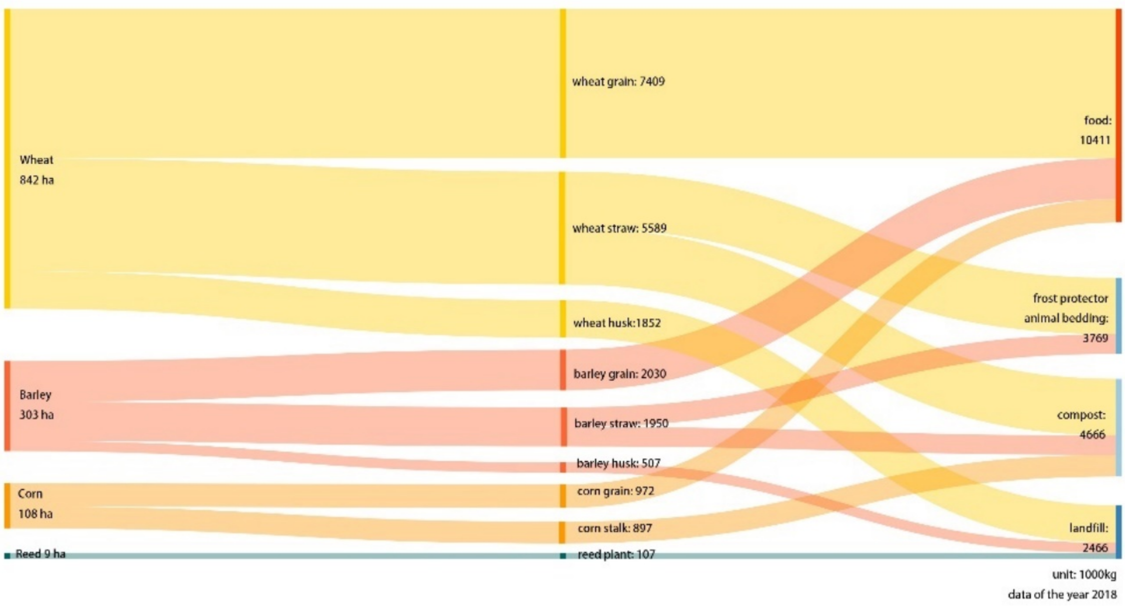


Figure 7. Organic material flow of the Brettenscheg and Scheg van West area (image by author)

IV. STUDY ON POTENTIAL BIODEGRADABLE BUILDING MATERIAL

4.1 Cereal straw

① Straw bale

Straw is a natural insulation material. Straw bales can be applied mainly as wall infill in architecture, provided there is sufficient distance from the ground level to prevent ground moisture from entering the compact straw fiber. The typical straw bale wall is around 400 mm thick and at least 110kg/m3 in order to gain a sufficient insulation rate and fire resistance. (Sutton, A. 2011)

In the Netherlands, the traditional supporting structure of a straw bale building is a normal timber skeleton. The straw bales are later installed as wall insulation between the timber frame. In additionally, modern application of straw bales features pre-fabric straw building blocks with wooden frame, which could be customizable designed and assembled on-site easily. (ecococoon, 2021)

A straw wall is a breathable wall system. The most suitable interior finishing for a straw wall is clay plaster as clay absorbs indoor moisture. Lime plaster or well-ventilated cladding is suitable for the exterior of the straw wall. The finish must be resistant to rain but at the same time vapor-permeable. If well-maintained, a straw bale construction could last for over 100 years. (Owens, T. 2016)

② Self-bind straw panel

Wheat and Barley straw contains 35-45% cellulose, 20-30% hemicelluloses, and around 15% lignin. (del Rio, J, C. 2012) The presence of lignin allows the straw to be made into a self-bind panel without adhesive or resin. The cereal straw is pre-selected, dried, and then compressed through a dry extrusion process with extreme heat and pressure which release the lignin. After cooling, the straw panel could be sealed with recycled kraft paper on both sides in order to create a smooth surface.

One ton of cereal straw could produce approximately 50 m2 of the panel with a thickness of 50mm. (Durra, 2021) The straw panel has good insulation performance, high strength, and fire resistance. It could be applied as an interior partition wall and ceiling. According to real cases, the interior straw panel could last for more than 50 years.

③ Straw thatch

The straw for thatching has to be harvested manually in order to keep the original shape and length. After collection, the leaves and grain have to be removed carefully through a 'comb' technique, which is different from threshing. Dried, combed straw can be made into thatch. Traditionally straw thatch can be applied on timber frame roof by attaching or weaving the straw bundle on to the rafters. A straw thatch roof could last for 30-40 years is well-maintained. Furthermore, straw thatch bundle in various shape can be used in specific ways on façade to create unique aesthetics in modern architecture.

4.2 Cereal husk and corn stalk

① Mycelium composite brick/panel

Mycelium is a root fungus which can be grown on a substrate of organic fibers, such as corn stalks and grain husks. The mycelium functions as a binding structure between the loose organic fibers, which will become stiff after a drying process. (de Bruin, 2019) As an entirely biodegradable material, the growing process of the mycelium bricks takes from one to three weeks, depending on the scale of the mold, and they decompose when expose to external ground within six weeks. Furthermore, the mycelium can be grown in -between structural panels which naturally forms a bond to the surface, meaning structurally insulating panels can be produced without any thermal bridging.

A mycelium brick has high insulation rate and sufficient fire resistance properties; however, it is vulnerable to moisture and bacteria as it might decompose easily.

② Corn particle panel

Corn stalk is difficult to be applied as a building material in its original shape. However, as corn straw composites of 35% cellulose, 35% hemicellulose, and 7% lignin, it is possible to make use of the natural fiber to make interior board material. (Wu, T. 2012) Dry corn stalk is cut into 2mm size and then soaked in water in order to soften the natural fiber. The corn fiber is then ground into a pulp and hot-pressed in a mold. During this forming process, the separated micro fiber recombines each other which contributes to the strength of the particle panel. However, the natural bonding strength is not comparable with normal particle boards with chemical adhesives. Therefore, the corn panel is only suitable for interior finishing and decorations.

4.3 Reed plant

① Reed thatch

Reed has been considered as a common roof-thatching material in the Netherlands. Reed thatch is a lightweight, natural insulative, and weather-resisted material. If well-maintained, a thatched roof could last for more than 30 years. For thatching, only the long, straight, and flexible stem of the reed is suitable.

The roof framework is usually a wood rafter structure with a minimal 45°of pitch. The distance between two battens is between 10 and 20 cm. Before being applied on the roof, the reed plant is bound into bundles. The bundles are then fixed to the roof battens with the help of steel wire. Traditionally, the roof covering should have an overhang of at least 50 cm all-round and the visible front end of the eaves should be more than 30 cm thick. Typically, a 30 cm thick roof thatch requires 10 reed bundles per square meter. (Köbbing, JF, 2013)

② Bound reed panel

The bond reed panel is made of natural shape reed spears. The reed spears are pressed together tightly under pressure and bound with galvanized wire in various thicknesses. The panels are applicable as an exterior fence, interior partitions, and also roof insulation. The air-filled hollow spaces within each reed spear provide the material with a high level of thermal protection and noise reduction properties. When used in the interior, the reed panel could be covered with lime or clay to form a smooth finish, it could also be used in its original appearance. Wood poles are added to the two sides to connect multiple panels together.

③ Reed particle board

The low-quality reed plant and also the leftover part of the thatched roof and bond panel could be transformed into particle panel. The making process includes cutting reed, soaking in water, grinding into pulp and hot pressing in mold. It is similar to the making process of corn particle panel which has been written above. The reed particle panel can be applied as interior finishing and decorations.

V. RESULTS AS FUTURE SCENARIO

Considering 50% of wheat and barley straw can be diverted to the building material sector, this would result in approximately 30000 m^2 straw bale for building structure or 190000 m^2 of the straw panel, as well as 5000m^2 of straw thatch. The available husk residue and corn stalk can be made into 15900 m3 of mycelium product for interior partition or wall insulation products. Besides, with 100% of reed residue, it is also possible to make 800m^2 of thatched product for exterior, 6600m^2 of bound reed panel, 4000 m^2 reed particle board for the interior.

The result indicates that there is a fair potential to transform the organic residue from the agricultural land in Amsterdam into biodegradable building materials. The greatest potential comes from straw products and mycelium products from corn and husk which are suitable material for both traditional and modern construction methods. Besides, these products are versatile for different construction and has the potential to add aesthetic value to the design.

More importantly, considering these building materials can be composted and returned to the local land after their service life, this will activate a local value chain that includes many stakeholders to benefit from the practice. In particular the suppliers of agricultural residue, the producer and service manager of the building materials, and the corporative designers.

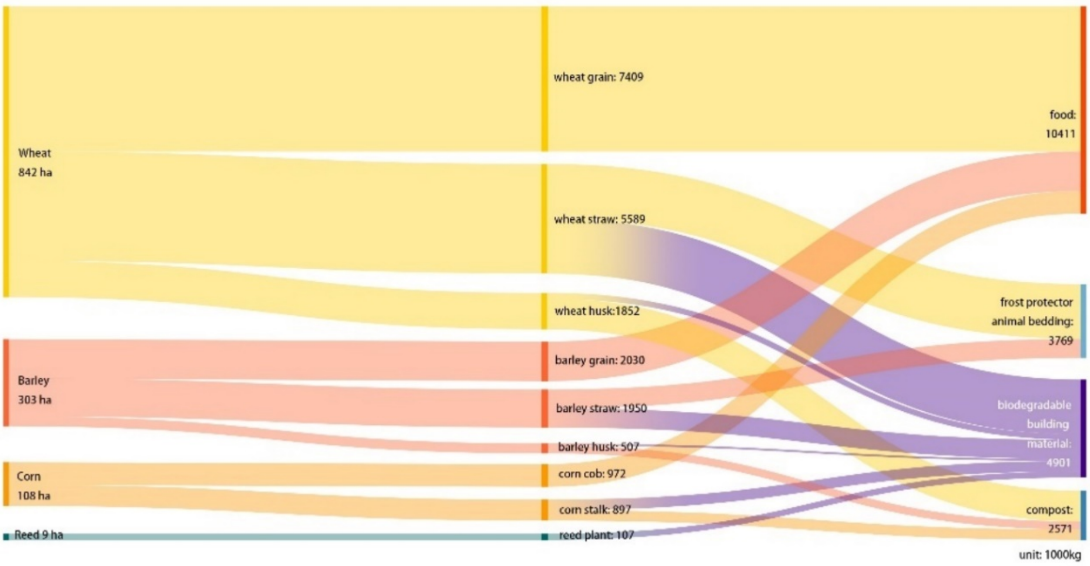


Figure 8. Designed organic material flow of the Brettenscheg and Scheg van West area (image by author)

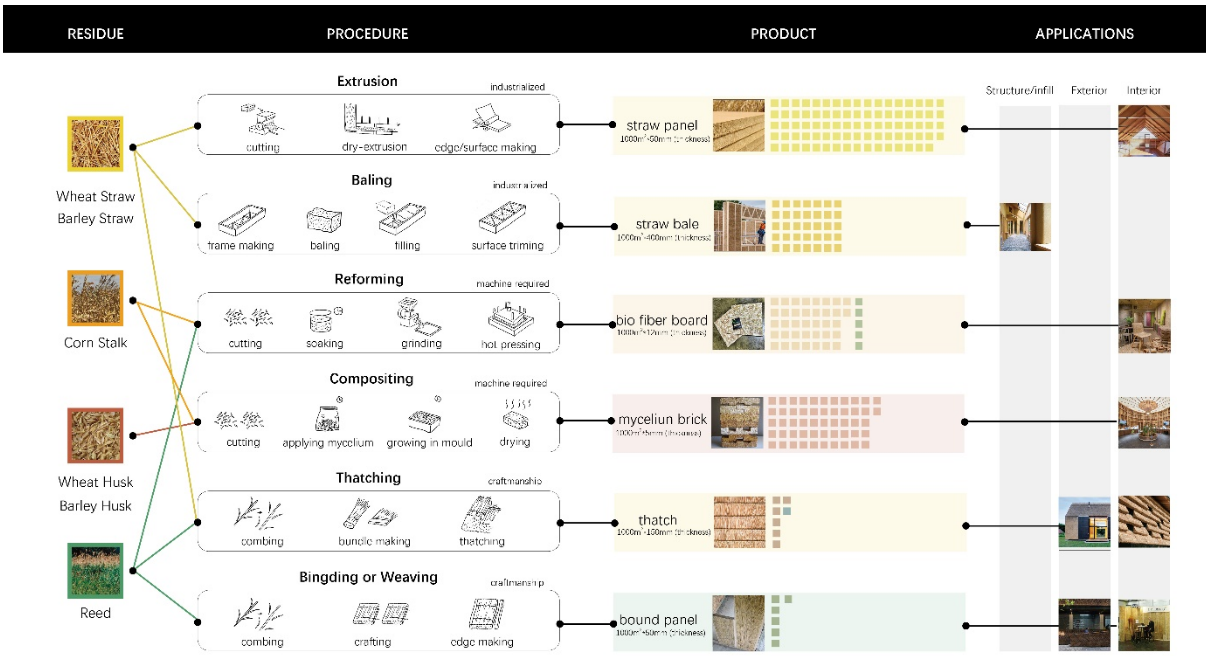


Figure 9. A map of specific flow between agricultural residue and building material (image by author)

VI. LIMITATION AND REFLECTION

There are certain limitations to the research methodologies. First, the data of the crop production and land size been used for the flow calculation is specifically from the year 2018, as that is the latest data available online. As the Netherlands agriculture system uses the crop rotation method, the data of crop production and land use might differ each year. Secondly, several assumption data have been used in the flow calculation, regarding the reed production, as it is difficult to account for the reed fringe in reality. Last but not the least, the real potential amount of residue will differ from the theoretical calculation. There is the current usage of cereal straw residue in the Netherlands, which makes it hard to define the real potential to apply it in the building sector.

However, this research still reveals a scheme of an alternative method to utilize agriculture waste in the building sector, which is meaningful for the green future of the construction industry and also the local stakeholders.

VII. CONCLUSION

As the construction industry is under urgent need to shift towards a more sustainable practice, the use of natural renewable building material indicates its potential. In the context of Amsterdam, the organic waste stream from the neighborhood agriculture system reveals a considerable feedstock for making biodegradable building material, which benefits both the city and the hinterland. Several identified residues have various application potentials in the building material factor, such as wheat barley straw, husk, corn stalk, and reed. They can be used as wall infill, roof, interior wall, finishing, and decorations.

There are many benefits from using these local biodegradable materials from agriculture residue, as they are renewable resources with low embodied energy, and some show a high level of thermal and acoustic properties. The natural essence of these materials also leads to a healthier indoor environment compared with synthetic-chemical products. Furthermore, biodegradable materials are able to close the material loops through an organic recycling process. This is a great benefit for reducing the amount of construction waste. On the other hand, it also enables a new value chain that benefits multiple local stakeholders. However, there are also drawbacks of biodegradable materials because they require particular design and construction methods to avoid any possible significant degradation during its service life, as they are sensitive to moisture, bacteria and fire. At the same time, many biodegradable materials have not entered the market as their production is not standardized and qualified enough for the current regulations. (Ganotopoulou, E, 2014) Therefore, it is clear that a collective effort should be made from the building and scientific community to classify the properties and acknowledgments of biodegradable material with scientific reference. Positively, the last decade reveals increase attention to biodegradable materials (especially straw construction) by both the scientific community and commercial practice. Moreover, with the development of the circular economy, more attention will be paid to enable the alternative use of organic materials. These opportunities will both contribute to a sustainable future of the construction industry.

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APPENDIX 1: CROP MAPPING OF BRETTENSCHEG AND SCHEG VAN WEST AREA

Image 9. An overview of Amsterdam Scheggen (image by author)

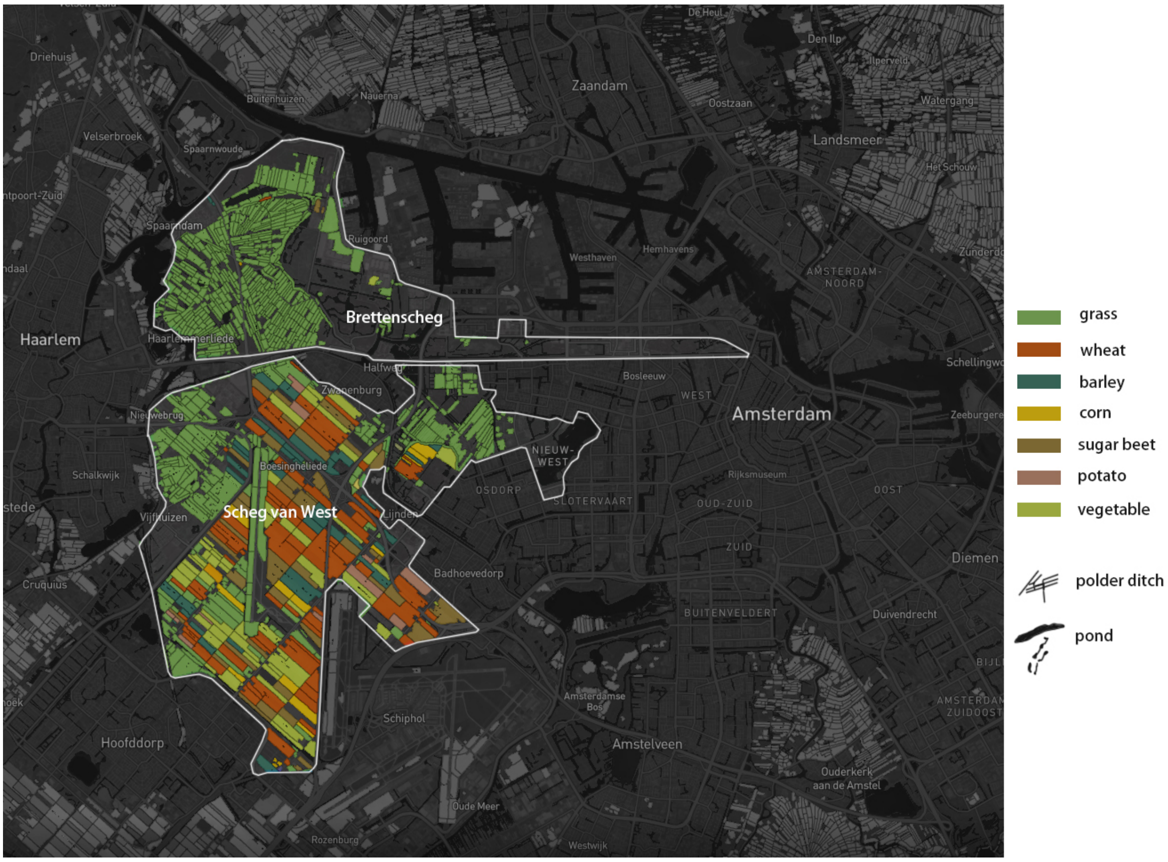


Image 10. Crop map of Brettenscheg and Scheg van West area

(image by author, base map from https://map.onesoil.ai/)

APPENDIX 2: CALCULATION OF AVAILABLE RESIDUE AND POTENTIAL PRODUCTS

Regions: Nederland

Periods **Topic**

Arable crops	2000 Area under cultivation	2000 Harvested area	2000 Gross yield per ha	2000 Gross yield, total	2018 Area under cultivation	2018 Harvested area	2018 Gross yield per ha	2018 Gross yield, total	2019 Area under cultivation	2019 Harvested area	2019 Gross yield per ha	2019 Gross yield, total	2020 Area under cultivation	2020 Harvested area	2020 Gross yield per ha	2020 Gro yiel tot
	ha		1 000 kg		ha		1 000 kg		ha		1 000 kg		ha		1 000 kg	
Wheat (total)	136,686	136,072	8.4	1,142,695	112,044	111,660	8.8	984,874	121,064	120,546	9.6	1,157,429	109,628	108,908	8.8	953,86
Wheat, winter	120,510	119,929	8.6	1,032,342	96,273	95,971	9.1	874,353	112,203	111,756	9.8	1,095,086	92,844	92,462	9.2	848,71
Wheat, spring	16,176	16,143	6.8	110,354	15,771	15,689	7.0	110,522	8,861	8,790	7.1	62,343	16,784	16,447	6.4	105,14
Barley, winter	3,635	3,630	5.8	20,876	8,244	8,199	8.1	66,043	11,134	11,092	9.1	100,389	9,724	9,618	7.6	73,17
Barley, spring	43,537	43,391	6.2	266,967	27,911	27,775	6.7	187,361	22,570	22,297	6.6	147,797	28,968	28,763	6.2	178,83
Grain maize	20,298	20,298	16.9	343,505	9,735	9,415	9.0	84,788	12,668	12,424	10.3	127,395	12,819	12,732	11.6	147,20
Maize, corn cob mix	7,219	7,219	18.5	133,274	4,511	4,345	7.7	33,501	6,632	6,585	10.3	67,773	6,707	6,690	10.7	71,76
Potatoes (total)	180,200	174,929	46.5	8,126,799	164,973	164,597	36.6	6,025,365	167,523	165,733	42.0	6,961,230	165,621	164,504	42.7	7,020,06
Sugar beet	110,998	109,714	61.3	6,727,494	85,196	85,196	76.4	6,506,309	79,176	79,176	83.9	6,644,707	81,459	81,459	82.1	6,691,36

Source: CBS

Table 4. Data of arable crops production in the Netherlands, 2018 (data from CBS)

crop	area/ha	gross yield (1000kg/ha)	crop (1000kg)	harvest index	residue yield (1000kg/ha)	straw residue	husk content	husk residue yield	husk residue
wheat	842	8.8	7409.6	0.57	6.638596491	5589.698246	0.2	2.2	**1852.4**
barley	303	6.7	2030.1	0.51	6.437254902	1950.488235	0.2	1.675	507.525
corn	108	9	972	0.52	8.307692308	897.2307692			
sugar beet	380	76.4	29032	0.8	19.1	7258			
potato	76	36.6	2781.6	0.75	12.2	927.2			
vegetable	390	54.7	21333	0.8	13.675	5333.25			
grass	897	13	11661	0.9	1.444444444	1295.666667			
reed	8.95				12	107.4			

Table 5. Data of the production of crop and residue from Brettenscheg and Scheg van West

Residue	amount per year/1000kg	used for building material/1000kg		building material	amount of residue used/1000kg	weight		production	
wheat straw	5589.698246	2794.849123	3770.09324	straw panel	1885.04662	20	kg/m2*50mm	94252.33101	m^2
				straw thatch	188.504662	34	kg/m2*150mm	5544.254765	m^2
barley straw	1950.488235	975.2441176		straw bale	1696.541958	110	kg/m3*400mm	15423.10871	m^2
wheat husk	1852.4	185.24	235.9925	husk surface	117.99625	2	kg/m2*5mm	58998.125	m^2
barley husk	507.525	50.7525							
corn stalk	897.2307692	448.6153846	448.6153846	corn board	448.6153846	10	kg/m2*12mm	44861.53846	m^2
reed	107	107	107	reed thatch	21.4	25	kg/m2*150mm	856	m^2
				reed panel	53.5	8	kg/m2*50mm	6687.5	m^2
	*data of 2018			reed board	32.1	8	kg/m2*12mm	4012.5	m^2

Table 6. The production of different building materials

production method	productivity	machine required	worker	source
Industrialize straw panel	5000-10000 cbm per year	drum shredder	3—5	https://linyiruifeng.en.alibaba.com/product/60802799637-807441237/Small_capacity_chipboard_rice_husk_parti
		Drying machine		
		Mixing machine		
		Dry extrusion machine		
		Edge trimming machine		
Pre-fab construction straw bale	unknow	computer	designer 2-5	EcoCocon
		Large lasar cut machine	operator 3	
			assembler 3-5	
		Pressing machine	operator 3	
		Surface trimming machine	operator 2	
Reed and corn particle board	1000 cmb per year	Drum shredder	operator 2	https://www.alibaba.com/product-detail/Wood-machine-hot-press_60417062552.html?s
		Mixer	operator 2	
		Hot-press machine	operator 2	
		Edge trimming machine	oprator 2	
Husk surface panel	12-20 m2 per day	Mixer	operator 2	Organoid
		Hot-press machine	operator 2	
Thatch	6 weeks a normal house		thatcher 2-3	Hiss Reet

Table 7. Production method and requirements of different product

APPENDIX 3: FLOW CHARTS AND DIAGRAMS

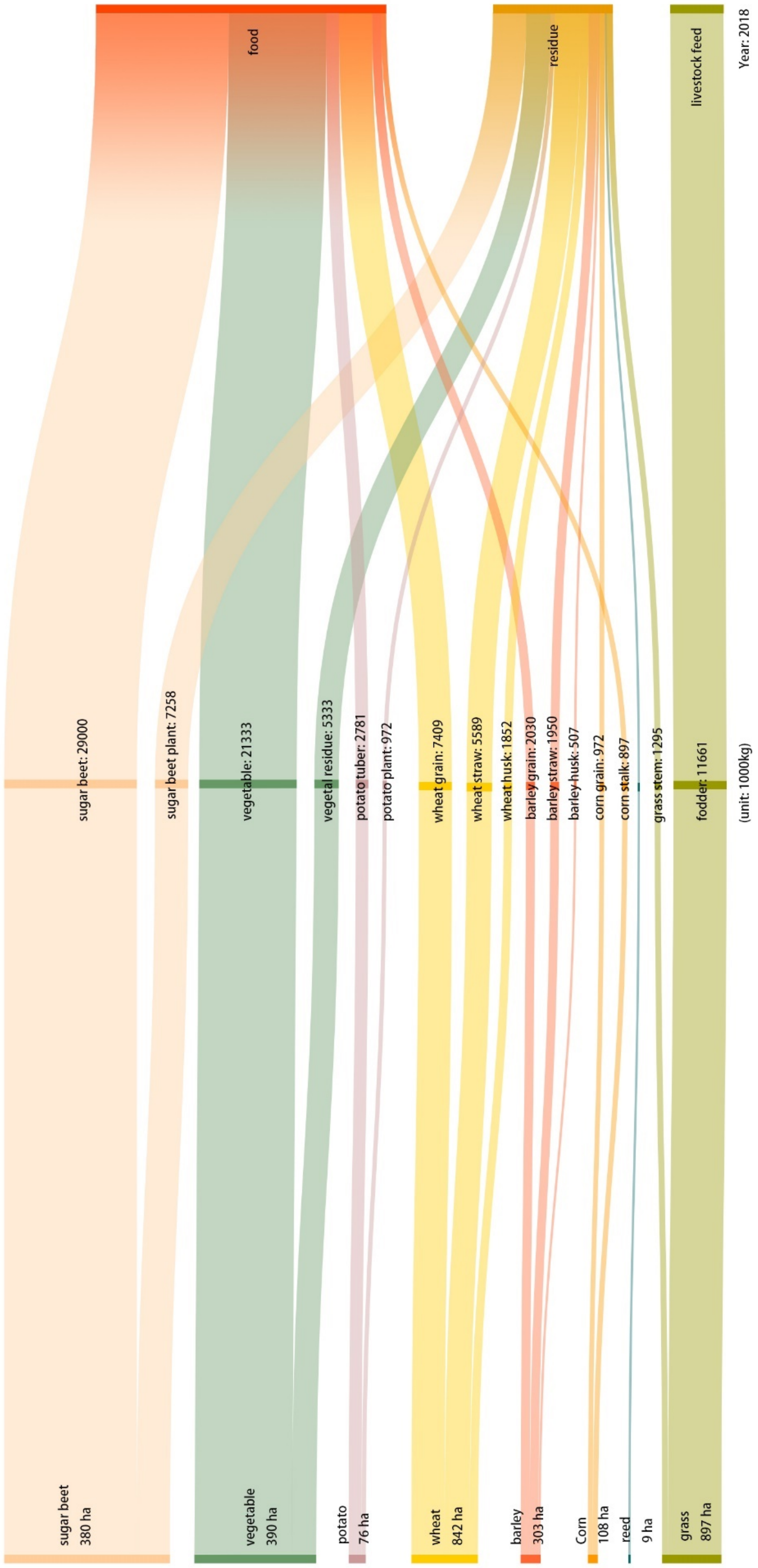


Figure 12. An overview of the agricultural material flow of the Brettenscheg and Scheg van West area

(image by author)

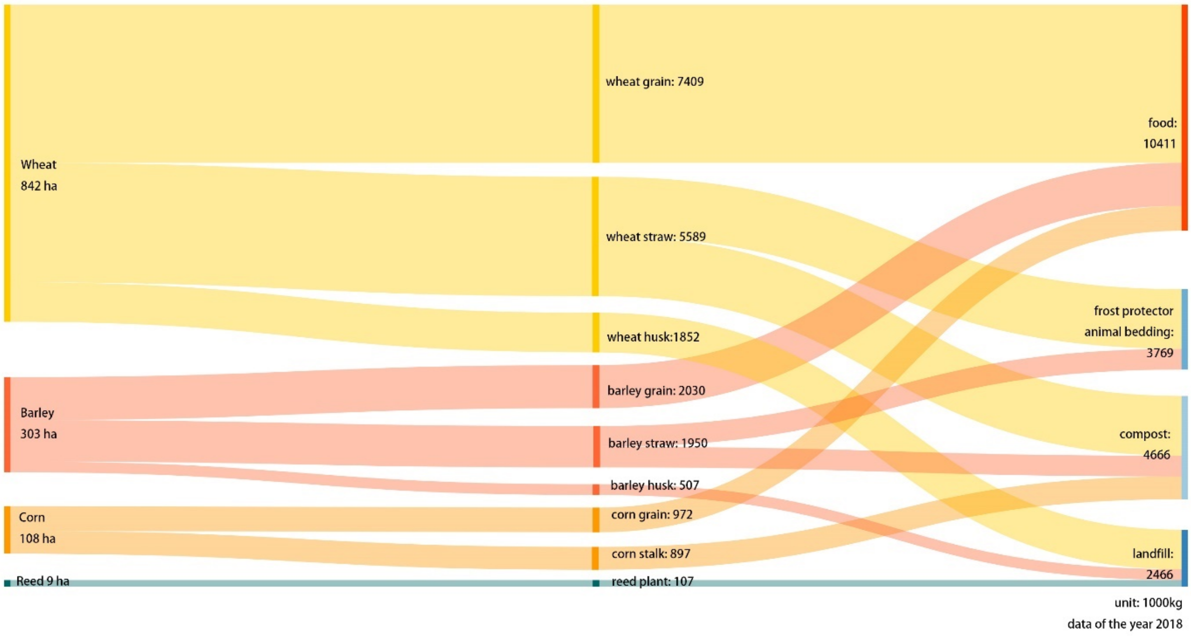


Figure 13. Organic material flow of the Brettenscheg and Scheg van West area (image by author)

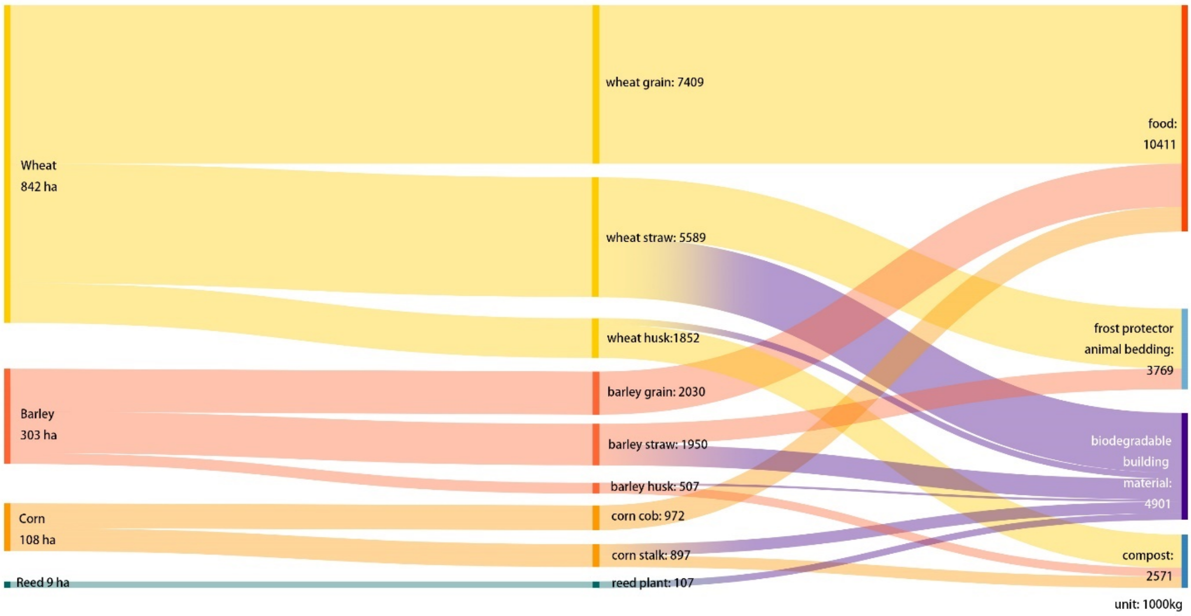


Figure 14. Designed organic material flow of the Brettenscheg and Scheg van West area (image by author)

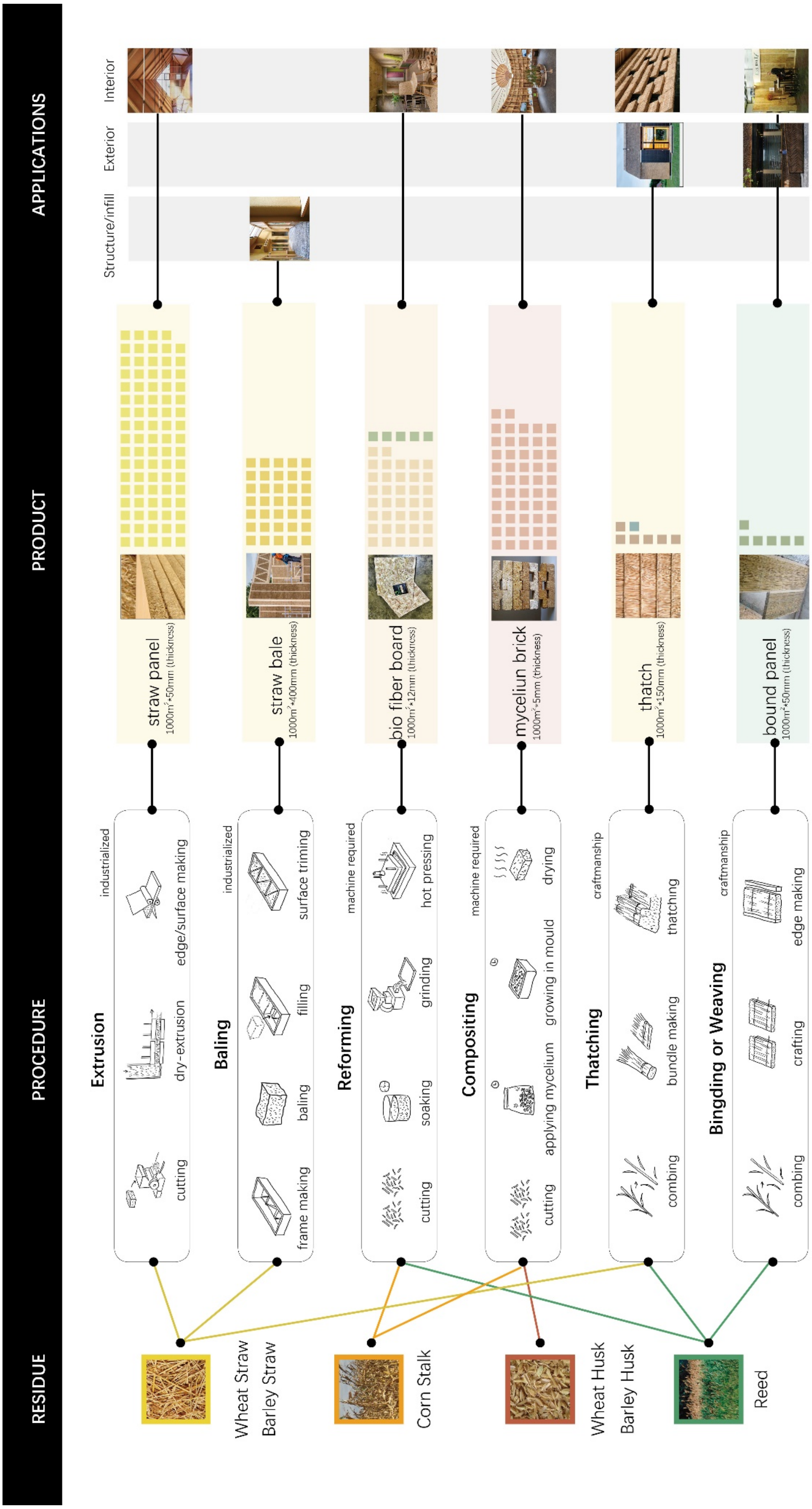


Figure 15. A map of specific flow between agricultural residue and building material (image by author)

APPENDIX 4. ARCHITECTURE CASES

Material/product	Building layer	Architecture case	source
Straw bale	Wall infill (structure)	De Groene Griffioen	

Picture	Specifc/detail

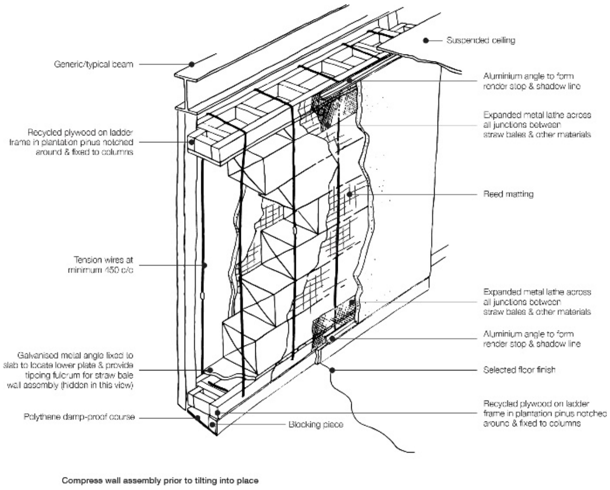
Picture

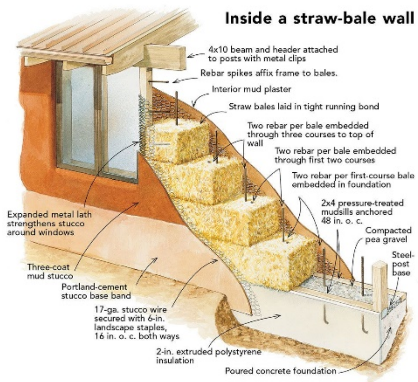
Specifc/detail

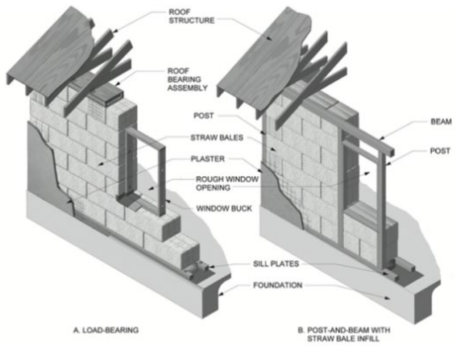
Structure: timber frame

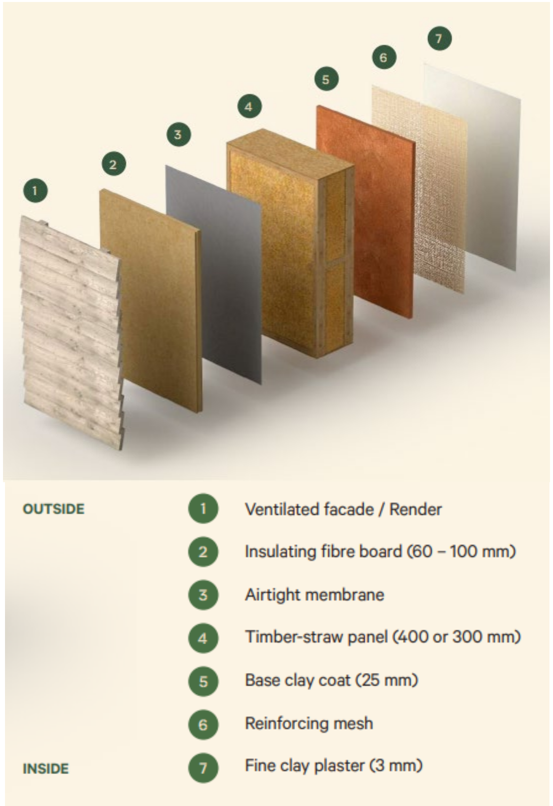
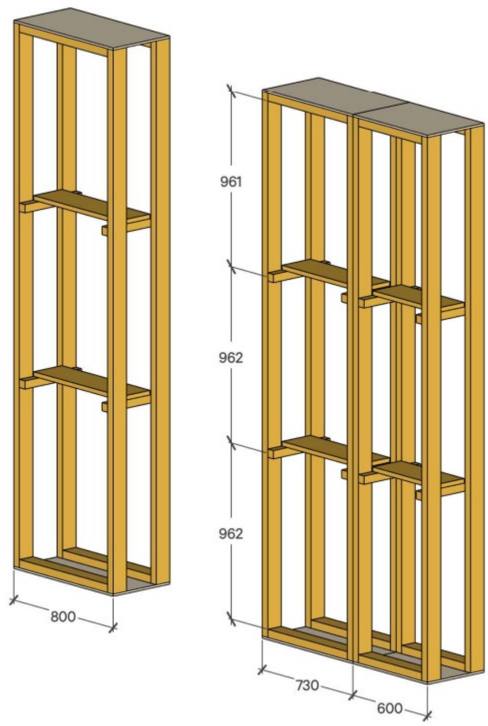
Exterior: wood cladding

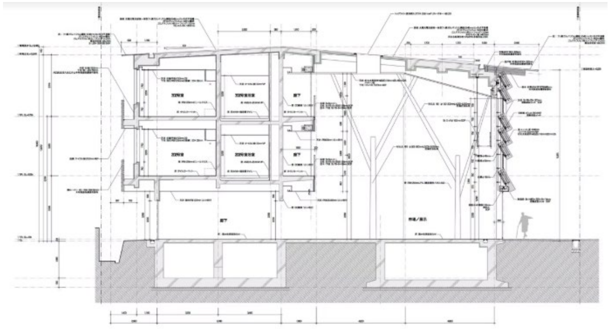
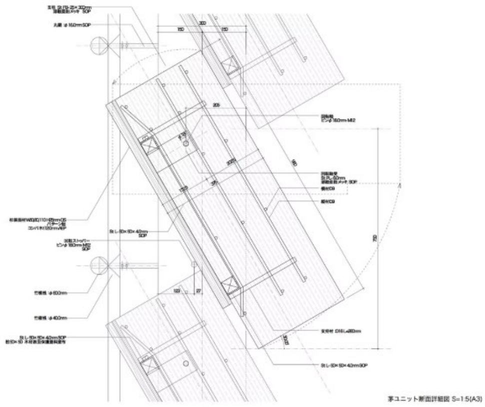
Interior: loam



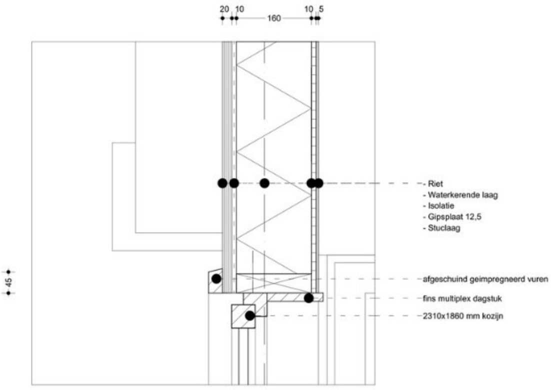




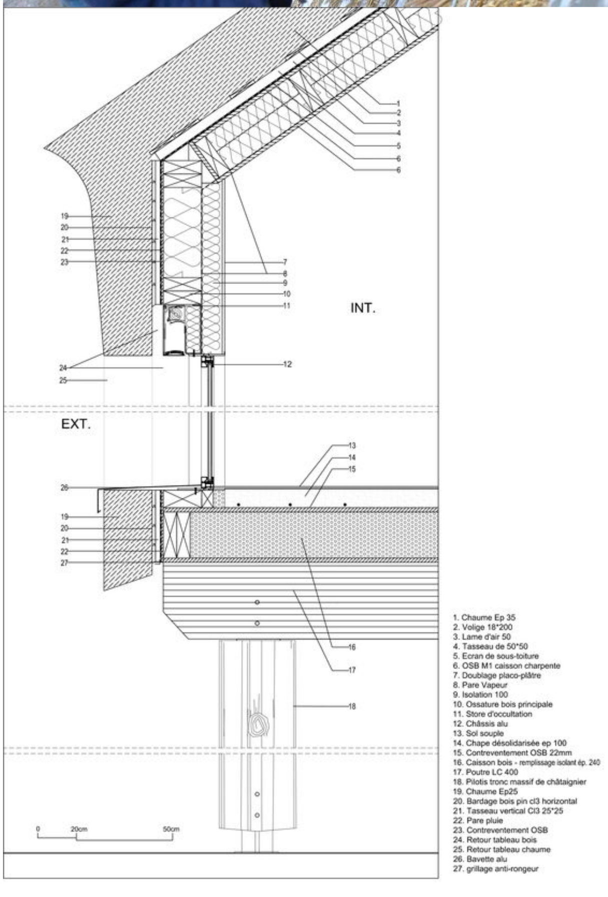
Material/product	Building layer	Architecture case	source
Pre-fab straw block	Structure	Tegelen Gym	EcoCocon
Picture		**Specifc/detail**	
  		 Panel construction 	

Material/product	Building layer	Architecture case	source
Straw thatch	Facade	Yusuhara Marche	Kengo Kuma
Picture		**Specifc/detail**	
  		 	

Material/product	Building layer	Architecture case	source
Bound reed panel	Facade	Photostudio	Thomas Hagemeijer

Picture	Specifc/detail
  	Structure: timber frame  the reed is used for the front and back façade. When approaching the building, the reed forms a friendly greeting and tangible projection of the landscape behind it. The reed that is applied in the facade is available in any home-improvement store and generally functions as a fence. An air cavity is applied to allow the reed to dry naturally. A grid of timber planks serves to attach the reed units, according to a local building technique called 'potdekselen'.

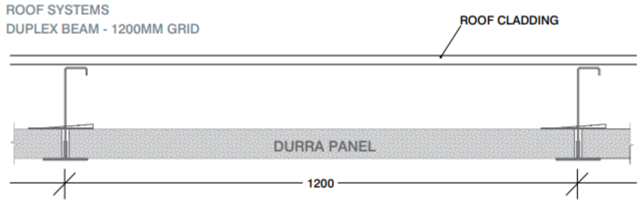
Material/product	Building layer	Architecture case	source
Reed thatch	Façade, interior	Daycare Centre Felsoord	Möhn + Bouman Architects

Picture	Specifc/detail
  the thatch-facade as well as the pine-wood facades are extended into the interior, ending in the form of a huge sky-light hovering over the reception desk. 	 

Material/product	Building layer	Architecture case	source
Straw panel	Interior ceiling	Cornish College	Durra

Picture

Specifc/detail



Durra Panel S50

Product Name	Durra Panel S50 Plain
Nominal Thickness	50mm
Weight	18.5 kg/m² (nominal)
Width (Standard)	1187mm
Maximum Length	3600mm
Face Colour	Brown (Kraft paper)
* Strength	Point load 5.8kN
Impact Resistance	High
Thermal Conductivity	0.081 W/mK
Thermal Resistance	0.62 m²W/k
Specific Heat Capacity	1050 J/kgK
Embodied Energy	12.6 MJ/m²
VOC Emission rate (ASTM D5116)	<0.05 mg/m²/hr (7 days)
Biscuit Slots	Available

Material/product	Building layer	Architecture case	source
Husk, reed, corn panel	Interior, product		Organoid, Van Hier

Picture

Specifc/detail

Hot press machine, possible for crafting